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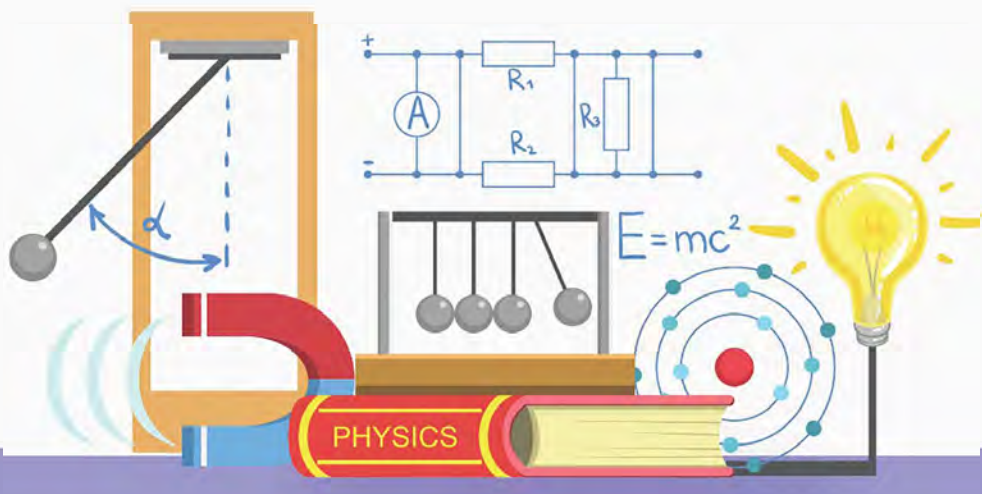
PHYSICS

As Per the Latest Syllabus of NTA

- Concise Theory
- Solved Examples and Illustrations
- Previous Year Questions with Solutions
- Trick Cards for Quick Revision

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Contents

ELECTROSTATICS

THEORY ..... 1 – 69
TIPS & FORMULAS ..... 70 – 74
SOLVED EXAMPLES ..... 75 – 78
EXERCISE - I ..... 79 – 82
EXERCISE - II ..... 83 – 89
EXERCISE - III ..... 90 – 94
EXERCISE - IV ..... 95 – 102
MOCK TEST ..... 103 – 108
ANSWER KEY ..... 109 – 109
HINTS & SOLUTIONS ..... 110 – 130

CAPACITANCE

THEORY ..... 131 – 157
TIPS & FORMULAS ..... 158 – 160
SOLVED EXAMPLES ..... 161 – 164
EXERCISE - I ..... 165 – 169
EXERCISE - II ..... 170 – 175
EXERCISE - III ..... 176 – 177
EXERCISE - IV ..... 178 – 183
MOCK TEST ..... 184 – 190
ANSWER KEY ..... 191 – 191
HINTS & SOLUTIONS ..... 192 – 208

NEET & AIIMS SYLLABUS

ELECTROSTATICS

Electric charges and their conservation. Coulomb's law-force between two point chages, forces between multiple chages; superposition principle and continuous charge distibution.
Electric field, electric field due to a point charge, electric field lines; electric dipole, electric field due to a dipole; torque on a dipole in a uniform electric field.
Electric flux, statement of Gauss's theorem and its applications to find field due to infinitely long straight wire, uniformly charged infinite plane sheet and uniformly charged thin spherical shell (field inside and outside)
Electric potential, potential difference, electric potential due to a point charge, a dipole and system of charges; equipotential surfaces, electrical potential energy of a system of two point charges and of electric dipoles in an electrostatic field.

CAPACITANCE

Conductors and insulators, free charges and bound charges inside a conductor. Dielectrics and electric polarization, capacitors and capacitance, combination of capacitors in series and in parallel, capacitance of a parallel plate capacitor with and without dielectric medium between the plates, energy stored in a capacitor, Van de Graaff generator.

Contents

CURRENT ELECTRICITY

THEORY ..... 1 – 46
TIPS & FORMULAS ..... 47 – 53
SOLVED EXAMPLES ..... 54 – 61
EXERCISE - I ..... 62 – 68
EXERCISE - II ..... 69 – 72
EXERCISE - III ..... 73 – 74
EXERCISE - IV ..... 75 – 86
MOCK TEST ..... 87 – 92
ANSWER KEY ..... 93 – 93
HINTS & SOLUTIONS ..... 94 – 122

MAGNETIC EFFECT OF CURRENT AND MAGNETISM

THEORY ..... 123 – 175
TIPS & FORMULAS ..... 176 – 181
SOLVED EXAMPLES ..... 182 – 187
EXERCISE - I ..... 188 – 193
EXERCISE - II ..... 194 – 205
EXERCISE - III ..... 206 – 209
EXERCISE - IV ..... 210 – 221
MOCK TEST ..... 222 – 228
ANSWER KEY ..... 229 – 229
HINTS & SOLUTIONS ..... 230 – 255

NEET & AIIMS SYLLABUS

CURRENT ELECTRICITY

Electric current, flow of electric charges in a metallic conductor, drift velocity and mobility, and their relation with electric current; Ohm's law, electrical resistance, V - I characteristics (liner and non-linear), electrical energy and power, electrical resistivity and conductivity.

Carbon resistors, colour code for carbon resistors; series and parallel combinations of resistors; temperature dependence of resistance.

Internal resistance of a cell, potential difference and emf of a cell, combination of cells in series and in parallel.

Kirchhoff's laws and simple applications. Wheatstone bridge, metre bridge.

Potentiometer-principle and applications to measure potential difference, and for comparing emf of two cells; measurement of internal resistance of a cell.

MAGNETIC EFFECT OF CURRENT AND MAGNETISM

Concept of magnetic field, Oersted's experiment. Biot-Savart law and its application to current carrying circular loop.

Ampere's law and its applications to infinitely long straight wire, straight and toroidal solenoids. Force on a moving charge in uniform magnetic and electric fields, Cyclotron.

Force on a current-carrying conductor in a uniform magnetic field. Force between two parallel current conductors-definition of ampere. Torque experienced by a current loop in a magnetic field; moving coil galvanometer-its current sensitivity and conversion to ammeter and voltmeter.

Current loop as a magnetic dipole and its magnetic dipole moment. Magnetic dipole moment of a revolving electron. Magnetic field intensity due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis. Torque on a magnetic dipole (bar magnet) in a uniform magnetic field; bar magnet as an equivalent solenoid, magnetic field lines; Earth's magnetic field and magnetic elements.

Para-, dia-and ferro-magnetic substances, with examples.

Electromagnetic and factors affecting their strengths. Permanent magnets.

Contents

ELECTROMAGNETIC INDUCTION

THEORY ..... 1 – 47
TIPS & FORMULAS ..... 48 – 51
SOLVED EXAMPLES ..... 52 – 54
EXERCISE - I ..... 55 – 59
EXERCISE - II ..... 60 – 63
EXERCISE - III ..... 64 – 66
EXERCISE - IV ..... 67 – 72
MOCK TEST ..... 73 – 78
ANSWER KEY ..... 79 – 79
HINTS & SOLUTIONS ..... 80 – 92

ALTERNATING CURRENT

THEORY ..... 93 – 119
TIPS & FORMULAS ..... 120 – 122
SOLVED EXAMPLES ..... 123 – 125
EXERCISE - I ..... 126 – 129
EXERCISE - II ..... 130 – 133
EXERCISE - III ..... 134 – 136
EXERCISE - IV ..... 137 – 142
MOCK TEST ..... 143 – 148
ANSWER KEY ..... 149 – 149
HINTS & SOLUTIONS ..... 150 – 165

NEET & AIIMS SYLLABUS

ELECTROMAGNETIC INDUCTION

Electromagnetic induction; Faraday's law, induced emf and current; Lenz's Law, Eddy currents. Self and mutual inductance.

ALTERNATING CURRENT

Alternating currents, peak and rms value of alternating current/voltage; reactance and impedance; LC oscillations (qualitative treatment only), LCR series circuit, resonance; power in AC circuits, wattles current.

AC generator and transformer.

Contents

GEOMETRICAL OPTICS

THEORY ..... 1 – 57
TIPS & FORMULAS ..... 58 – 66
SOLVED EXAMPLES ..... 67 – 75
EXERCISE - I ..... 76 – 83
EXERCISE - II ..... 84 – 93
EXERCISE - III ..... 94 – 96
EXERCISE - IV ..... 97 – 106
MOCK TEST ..... 107 – 111
ANSWER KEY ..... 112 – 112
HINTS & SOLUTIONS ..... 113 – 142

WAVE OPTICS

THEORY ..... 143 – 172
TIPS & FORMULAS ..... 173 – 174
SOLVED EXAMPLES ..... 175 – 178
EXERCISE - I ..... 179 – 183
EXERCISE - II ..... 184 – 194
EXERCISE - III ..... 195 – 198
EXERCISE - IV ..... 199 – 204
MOCK TEST ..... 205 – 210
ANSWER KEY ..... 211 – 211
HINTS & SOLUTIONS ..... 212 – 231

NEET & AIIMS SYLLABUS

GEOMETRICAL OPTICS

Reflection of light, spherical mirrors, mirror formula. Refraction of light, total internal reflection and its applications optical fibres, refraction at spherical surfaces, lenses, thin lens formula, lens-maker's formula. Magnification, power of a lens, combination of thin lenses in contact combination of a lens and a mirror. Refraction and dispersion of light through a prism.

Scattering of light - blue colour of the sky and reddish appearance of the sun at sunrise and sunset.

Optical instruments : Human eye, image formation and accommodation, correction of eye defects (myopia and hypermetropia) using lenses.

Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers.

WAVE OPTICS

Wavefront and Huygens' principle, reflection and refraction of plane wave at a plane surface using wavefronts. Proof of laws of reflection and refraction using Huygens' principle.

Inteference, Young's double hole experiment and expression for fringe width, coherent sources and sustained interference of light.

Diffraction due to a single slit, width of central maximum.

Resolving power of microscopes and astronomical telescopes. Polarisation, plane polarized light; Brewster's law, uses of plane polarized light and Polaroids.

Contents

MODERN PHYSICS

THEORY ..... 1 – 63
TIPS & FORMULAS ..... 64 – 71
SOLVED EXAMPLES ..... 72 – 75
EXERCISE - I ..... 76 – 87
EXERCISE - II ..... 88 – 97
EXERCISE - III ..... 98 – 100
EXERCISE - IV ..... 101 – 119
MOCK TEST ..... 120 – 124
ANSWER KEY ..... 125 – 126
HINTS & SOLUTIONS ..... 127 – 166

SOLID & SEMICONDUCTORS

THEORY ..... 167 – 210
TIPS & FORMULAS ..... 211 – 213
SOLVED EXAMPLES ..... 214 – 218
EXERCISE - I ..... 219 – 222
EXERCISE - II ..... 223 – 228
EXERCISE - III ..... 229 – 230
EXERCISE - IV ..... 231 – 243
MOCK TEST ..... 244 – 248
ANSWER KEY ..... 249 – 249
HINTS & SOLUTIONS ..... 250 – 268

ELECTROMAGNETIC WAVES

THEORY ..... 269 – 284
TIPS & FORMULAS ..... 285 – 286
SOLVED EXAMPLES ..... 287 – 288
EXERCISE - I ..... 289 – 290
EXERCISE - II ..... 291 – 292
EXERCISE - III ..... 293 – 293
EXERCISE - IV ..... 294 – 297
ANSWER KEY ..... 298 – 298
HINTS & SOLUTIONS ..... 299 – 301

NEET & AIIMS SYLLABUS

MODERN PHYSICS

Alpha-particle scattering experiments; Rutherford's model of atoms; Bohr model, energy levels, hydrogen spectrum. Composition and size of nucleus, atomic masses, isotopes, isobars; isotones.

Radioactivity-alpha, beta and gamma particles/rays and their properties decay law. Mass-energy relation, mass defect; binding energy per nucleon and its variation with mass number, nuclear fission and fusion.

Photoelectric effect, Hertz and Lenard's observations; Einstein's photoelectric equation - particle nature of light.

Matter waves - wave nature of particles, de Broglie relation. Davisson-Germer experiment (experimental details should be omitted; only conclusion should be explained).

SOLID & SEMICONDUCTORS

Energy bands in solids (qualitative ideas only), conductors, insulators and semiconductors; semiconductor diode- I-V characteristics in forward and reverse bias, diode as a rectifier, I-V characteristics of LED, photodiode, solar cell, and Zener diode; Zener diode as a voltage regulator, Junction transistor, transistor action, characteristics of a transistor; transistor as an amplifier (common emitter configuration) and oscillator. Logic gates (OR, AND, NOT, NAND and NOR), Transistor as a switch.

ELECTROMAGNETIC WAVES

Electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, x-rays, gamma rays) including elementary facts about their uses.

CHAPTER 01

ELECTROSTATICS

There are many ways of knocking electrons out of atoms. The simplest is to rub two surfaces together.

"FRED HOYLE"

INTRODUCTION

Electromagnetism is, almost unarguably, the most important basic technology in the world today. Almost every modern device, from cars to kitchen appliances to computers, is dependent upon it. Life, for msot of us, would be almost unimaginable without electromagetism. In fact, electromagnetism cuts such a wide path through modern life that the teaching of electromagnetism has developed into several different specialities. Initially electricity and magnetism were classified as independent phenomena, but different specialities. Initially electricity and magnetism were classified as independent phenomena, but after some experiments (we will discuss later) it was found they are interrelated so we use the name **Electromagnetism.** In electromagnetism we have to study basic properties of electromagnetic force and field (the term field will be introduced in later section). The electromagnetic force between charged particles is one of the fundamental force of nature. WE being this chapter by describing some of the basic properties of one manifestation of the electromagnetic force, the electrostatic force between charges (the force between two charges when they are at rest) under the heading **electrostatics.**

Specific Properties of Charge

(i) Charge is a scalar quantity : It represents excess or deficiency of electrons.

(ii) Charge is transferable : If a charged body is put in contact with an another body, then charge can be transferred to another body.

(iii) Charge is always associated with mass

Charge cannot exist without mass though mass can exist without charge.

(a) So the presence of charge itself is a convincing proof of existence of mass.

(b) In charging, the mass of a body changes.

(c) When body is given positive charge, its mass decreases.

(d) When body is given negative charge, its mass increases.

(iv) Charge is quantised

The quantization of electric charge is the property by virtue of which all free charges are integral multiple of a basic unit of charge represented by e. Thus charge q of a body is always given by

$q = ne$ $\quad$ n = positive integer or negative integer

The quantum of charge is the charge that an electron or proton carries.

Note : Charge on a proton = (–) charge on an electron = 1.6×10^{-19} C

(v) Charge is conserved

In an isolated system, total charge does not change with time, though individual charge may change i.e. charge can neither be created nor destroyed. Conservation of charge is also found to hold good in all types of reactions either chemical (atomic) or nuclear. No exceptions to the rule have ever been found.

(vi) Charge is invariant

Charge is independent of frame of reference. i.e. charge on a body does not change whatever be its speed.

(vii) Accelerated charge radiates energy

v = 0 (i.e. at rest)	v = constant	v ≠ constant (i.e. time varying)
⊕ Q	⊕→ Q	⊕→ Q
produces only $\vec{E}$ (electric field)	produces both $\vec{E}$ and $\vec{B}$ (magnetic field) but no radiation	produces $\vec{E}$, $\vec{B}$ and radiates energy

(viii) Attraction – Repulsion

Similar charges repel each other while dissimilar attract

Methods of Charging

(i) Friction

If we rub one body with other body, electrons are transferred from one body to the other.

Transfer of electrons takes places from lower work function body to higher work function body.

Positive charge	Negative charge
Glass rod	Silk cloth
Woollen cloth	Rubber shoes, Amber, Plastic objects
Dry hair	Comb
Flannel or cat skin	Ebonite rod

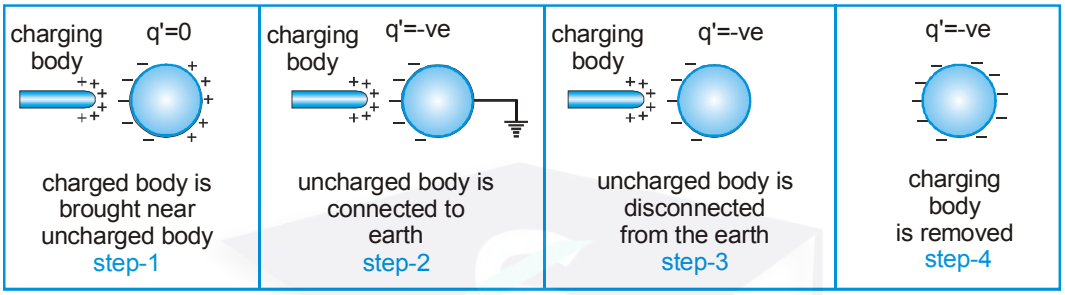
Note : Clouds become charged by friction

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(ii) Electrostatic Induction

If a charged body is brought near a metallic neutral body, the charged body will attract opposite charge and repel similar charge present in the neutral body. As a result of this one side of the neutral body becomes negative while the other positive, this process is called "Electrostatic Induction".

Charging a body by induction (in four successive steps)



Some important facts associated with induction-

(i) Inducing body neither gains nor loses charge

(ii) The nature of induced charge is always opposite to that of inducing charge

(iii) Induction takes place only in bodies (either conducting or non conducting) and not in particles.

(iii) Conduction

The process of transfer of charge by contact of two bodies is known as conduction. If a charged body is put in contact with uncharged body, the uncharged body becomes charged due to transfer of electrons from one body to the other.

(a) The charged body loses some of its charge (which is equal to the charge gained by the uncharged body)

(b) The charge gained by the uncharged body is always lesser than initial charge present on the charged body.

(c) Flow of charge depends upon the potential difference of both bodies. [No potential difference $\Rightarrow$ No conduction].

Positive charge flows from higher potential to lower potential, while negative charge flows from lower to higher potential.

(iv) Charge differs from mass in the following sense.

(a) In SI units, charge is a derived physical quantity while mass is fundamental quantity.

(b) Charge is always conserved but mass is not (Note : Mass can be converted into energy $E=mc^2$

(c) The quanta of charge is electronic charge while that of mass it is yet not clear.

(d) For a moving charged body mass increases while charge remains constant.

(v) True test of electrification is repulsion and not attraction as attraction may also take place between a charged and an uncharged body and also between two similarly charged bodies.

(vi) For a non relativistic (i.e. $v << c$) charged particle, specific charge $\frac{q}{m}$ = constant

(vii) For a relativistic charged particle $\frac{q}{m}$ decreases as v increases, where v is speed of charged body.

Ex. When a piece of polythene is rubbed with wool, a charge of -2×10^{-7} C is developed on polythene. What is the amount of mass, which is transferred to polythene.

Sol. From $Q = ne$, So, the number of electrons transferred $n = \frac{Q}{e} = \frac{2\times10^{-7}}{1.6\times10^{-19}} = 1.25 \times 10^{12}$

Now mass of transferred electrons = n × mass of one electron = $1.25 \times 10^{12} \times 9.1 \times 10^{-31} = 11.38 \times 10^{-19}$ kg

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Ex. 10^{12} α – particles (Nuclei of helium) per second falls on a neutral sphere, calculate time in which sphere gets charged by 2μC.

Sol. Number of α – particles falling in t second = 10^{12}t

Charge on α – particle = +2e , So charge incident in time t = $(10^{12}t).(2e)$

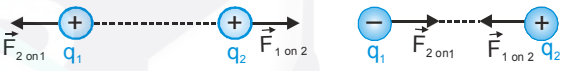
$\because$ Given charge is 2 μC $\therefore$ $2\times10^{-6}=(10^{12}t).(2e) \Rightarrow t=\dfrac{10^{-18}}{1.6\times10^{-19}}=6.25s$

Coulomb's Law

The electrostatic force of interaction between two static point electric charges is directly proportional to the product of the charges, inversely proportional to the square of the distance between them and acts along the straight line joining the two charges.

If two points charges q_1 and q_2 separated by a distance r. Let F be the electrostatic force between these two charges. According to Coulomb's law.

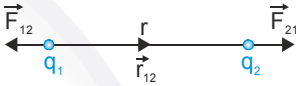
$F \propto q_1 q_2$ and $F \propto \dfrac{1}{r^2}$



$F_e=\dfrac{kq_1q_2}{r^2}$ where $\left[k=\dfrac{1}{4\pi\epsilon_0}=9\times10^9\dfrac{Nm^2}{C^2}\right]$ k = coulomb's constant or electrostatic force constant

Coulomb's Law in Vector Form

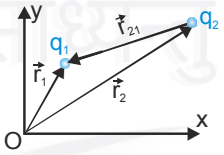
$\vec{F}_{12}$ = force on q_1 due to $q_2 = \dfrac{kq_1q_2}{r^2}\hat{r}_{21}$



$\vec{F}_{21} = \dfrac{kq_1q_2}{r^2}\hat{r}_{12}$ (here $\hat{r}_{12}$ is unit vector from q_1 to q_2)

Coulomb's law in terms of position vector

$\vec{F}_{12}=\dfrac{kq_1q_2}{|\vec{r}_1-\vec{r}_2|^3}(\vec{r}_1-\vec{r}_2)$



Principle of superposition

The force is a two body interaction, i.e., electrical force between two point charges is independent of presence or absence of other charges and so the principle of superposition is valid, i.e., force on a charged particle due to number of point charges is the resultant of forces due to individual point charges, i.e., $\vec{F}_1=\vec{F}_{12}+\vec{F}_{13}+...$

Note : Nuclear force is many body interaction, so principle of superposition is not valid in case of nuclear force.

When a number of charges are interacting, the total force on a given charge is vector sum of the forces exerted on it by all other charges individually

$F=\dfrac{kq_0q_1}{r_1^2}+\dfrac{kq_0q_2}{r_2^2}+\cdots+\dfrac{kq_0q_i}{r_i^2}+\ldots\dfrac{kq_0q_n}{r_n^2}$ in vector form $\vec{F}=kq_0\sum_{i=1}^{n}\dfrac{q_i}{r_i^2}\hat{r}_i$

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Some Important Points Regarding Coulomb's Law and Electric Force

(i) The law is based on physical observations and is not logically derivable from any other concept. Experiments till today reveal its universal nature.

The law is analogous to Newton's law of gravitation : $F = G\frac{m_1 m_2}{r^2}$ with the difference that :

(a) Electric force between charged particles is much stronger than gravitational force, i.e., $F_E >> F_G$. This is why when both F_E and F_G are present, we neglect F_G.

(b) Electric force can be attractive or repulsive while gravitational force is always attractive.

(c) Electric force depends on the nature of medium between the charges while gravitational force does not.

(d) The force is an action–reaction pair, i.e., the force which one charge exerts on the other is equal and opposite to the force which the other charge exerts on the first.

(ii) The force is conservative, i.e., work done in moving a point charge once round a closed path under the action of Coulomb's force is zero.

(iii) The net Coulomb's force on two charged particles in free space and in a medium filled upto infinity are

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} \text{ and } F' = \frac{1}{4\pi\varepsilon}\frac{q_1 q_2}{r^2}. \text{ So } \frac{F}{F'} = \frac{\varepsilon}{\varepsilon_0} = K,$$

(iv) Dielectric constant (K) of a medium is numerically equal to the ratio of the force on two point charges in free space to that in the medium filled upto infinity.

(v) The law expresses the force between two point charges at rest. In applying it to the case of extended bodies of finite size care should be taken in assuming the whole charge of a body to be concentrated at its 'centre' as this is true only for spherical charged body, that too for external point.

Although net electric force on both particles change in the presence of dielectric but force due to one charge particle on another charge particle does not depend on the medium between them.

(vi) Electric force between two charges does not depend on neighbouring charges.

Ex. If the distance between two equal point charges is doubled and their individual charges are also doubled, what would happen to the force between them?

Sol. $F = \frac{1}{4\pi\varepsilon_0}\frac{q \times q}{r^2}$ ....**(i)** Again, $F' = \frac{1}{4\pi\varepsilon_0}\frac{(2q)(2q)}{(2r)^2}$ or $F' = \frac{1}{4\pi\varepsilon_0}\frac{4q^2}{4r^2} = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2} = F$

So, the force will remain the same.

Ex. A particle of mass m carrying charge '$+q_1$' is revolving around a fixed charge '$-q_2$' in a circular path of radius r. Calculate the period of revolution.

Sol. $$\frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} = mr\omega^2 = \frac{4\pi^2 mr}{T^2}$$

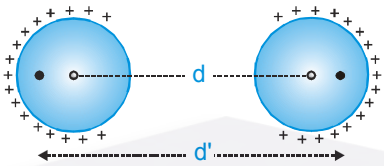
$$T^2 = \frac{(4\pi\varepsilon_0)r^2(4\pi^2 mr)}{q_1 q_2} \quad \text{or} \quad T = 4\pi r\sqrt{\frac{\pi\varepsilon_0 mr}{q_1 q_2}}$$

where $\vec{r}$ is the vector drawn from source charge is test charge.

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Ex. The force of repulsion between two point charges is F, when these are at a distance of 1 m. Now the point charges are replaced by spheres of radii 25 cm having the charge same as that of point charges. The distance between their centres is 1 m, then compare the force of repulsion in two cases.

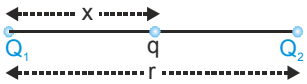
Sol. In 2nd case due to mutual repulsion, the effective distance between their centre of charges will be increased (d' > d) so force of repulsion decreases as $F \propto \frac{1}{d^2}$



Equilibrium of Charged Particles

In equilibrium net electric force on every charged particle is zero. The equilibrium of a charged particle, under the action of Colombian forces alone can never be stable.

(1) Equilibrium of Three Point Charges



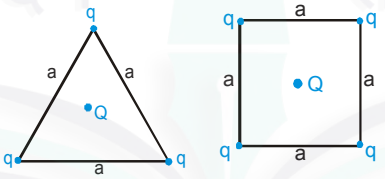
(a) Two charges must be of like nature as $F_q = \frac{KQ_1q}{x^2} + \frac{KQ_2q}{(r-x)^2} = 0$

(b) Third charge should be of unlike nature as $F_{Q_1} = \frac{KQ_1Q_2}{r^2} + \frac{KQ_1q}{x^2} = 0$

Therefore $x = \frac{\sqrt{Q_1}}{\sqrt{Q_1}+\sqrt{Q_2}}r$ and $q = \frac{-Q_1Q_2}{(\sqrt{Q_1}+\sqrt{Q_2})^2}$

(2) Equilibrium of Symmetric Geometrical Point Charged System

Value of Q at centre for which system to be in state of equilibrium

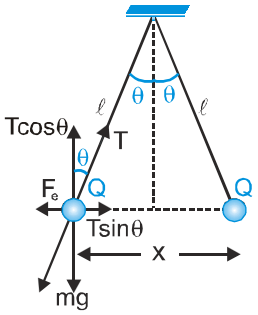


(i) For equilateral triangle $Q = \frac{-q}{\sqrt{3}}$ **(ii)** For square $Q = \frac{-q(2\sqrt{2}+1)}{4}$

(3) Equilibrium of Suspended Point Charge System

For equilibrium position

$T\cos\theta = mg$ and $T\sin\theta = F_e = \frac{kQ^2}{x^2} \Rightarrow \tan\theta = \frac{F_e}{mg} = \frac{kQ^2}{x^2mg}$



(a) If θ is small then tan

$$\theta \approx \sin\theta = \frac{x}{2\ell} \Rightarrow \frac{x}{2\ell} = \frac{kQ^2}{x^2mg} \Rightarrow x^3 = \frac{2kQ^2\ell}{mg} \Rightarrow x = \left[\frac{Q^2\ell}{2\pi\epsilon_0 mg}\right]^{\frac{1}{3}}$$

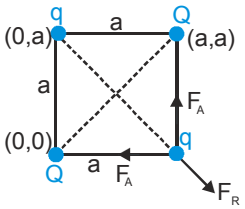
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(b) If whole set up is taken into an artificial satellite ($g_{eff} \simeq 0$) then $T = F_e = \frac{kq^2}{4\ell^2}$



Ex. For the system shown in figure find Q for which resultant force on q is zero.

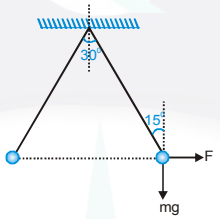
Sol. For force on q to be zero, charges q and Q must be of opposite of nature.



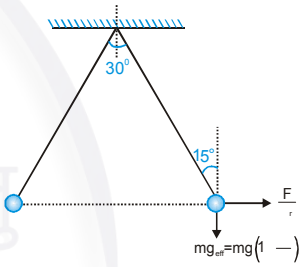
Net attraction force on q due to charges Q = Repulsion force on q due to q

$$\sqrt{2}\ F_A = F_R \Rightarrow \sqrt{2}\ \frac{kQq}{a^2} = \frac{kq^2}{(\sqrt{2}a)^2} \Rightarrow q = 2\sqrt{2}\ Q \text{ Hence } q = -2\sqrt{2}\ Q$$

Ex. Two identically charged spheres are suspended by strings of equal length. The strings make an angle of 30^0 with each other. When suspended in a liquid of density 0.8 g/cc the angle remains same. What is the dielectric constant of liquid. Density of sphere = 1.6 g/cc.



Sol. When set up shown in figure is in air, we have $\tan 15^0 = \frac{F}{mg}$ When set up is immersed in the medium as shown in figure, the electric force experienced by the ball will reduce and will be equal to $\frac{F}{\varepsilon_r}$ and the effective gravitational force will become $mg\left(1-\frac{\rho_\ell}{\rho_s}\right)$ Thus we have $\tan 15^0 = \frac{F}{mg\,\epsilon_r\left(1-\frac{\rho_\ell}{\rho_s}\right)} = \frac{F}{mg} \Rightarrow \epsilon_r = \frac{1}{1-\frac{\rho_\ell}{\rho_s}} = 2$



Ex. Given a cube with point charges q on each of its vertices. Calculate the force exerted on any of the charges due to rest of the 7 charges.

Sol. The net force on particle A can be given by vector sum of force experienced by this particle due to all the other charges on vertices of the cube. For this we use vector form of coulomb's law $\vec{F} = \frac{kq_1q_2}{|\vec{r}_1-\vec{r}_2|^3}(\vec{r}_1-\vec{r}_2)$

From the figure the different forces acting on A are given as $\vec{F}_{A_1} = \frac{kq^2(-a\tilde{k})}{a^3}$

$$\vec{F}_{A_2} = \frac{kq^2(-a\tilde{j}-a\tilde{k})}{(\sqrt{2}a)^3},\ \vec{F}_{A_3} = \frac{kq^2(-a\tilde{i}-a\tilde{j}-a\tilde{k})}{(\sqrt{3}a)^3};\ \vec{F}_{A_4} = \frac{kq^2(-a\tilde{i}-a\tilde{k})}{(\sqrt{2}a)^3}$$

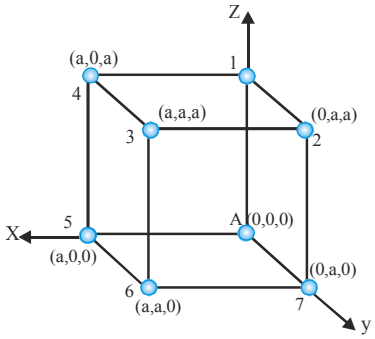
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$$\vec{F}_{A_5} = \frac{kq^2\left(-a\tilde{i}\right)}{a^3},\ \vec{F}_{A_6} = \frac{kq^2\left(-a\tilde{i}-a\tilde{j}\right)}{\left(\sqrt{2}a\right)^3},\ \vec{F}_{A_7} = \frac{kq^2\left(-a\tilde{j}\right)}{a^3}$$

The net force experienced by A can be given as

$$\vec{F}_{net} = \vec{F}_{A_1} + \vec{F}_{A_2} + \vec{F}_{A_3} + \vec{F}_{A_4} + \vec{F}_{A_5} + \vec{F}_{A_6} + \vec{F}_{A_7}$$

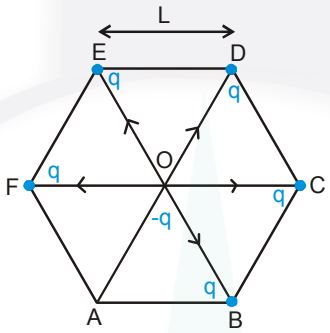
$$= \frac{-kq^2}{a^2}\left[\left(\frac{1}{3\sqrt{3}} + \frac{1}{\sqrt{2}} + 1\right)\left(\tilde{i}+\tilde{j}+\tilde{k}\right)\right]$$



Ex. Five point charges, each of value +q are placed on five vertices of a regular hexagon of side Lm. What is the magnitude of the force on a point charge of value –q coulomb placed at the centre of the hexagon?

Sol. If there had been a sixth charge +q at the remaining vertex of hexagon force due to all the six charges on –q at O will be zero (as the forces due to individual charges will balance each other).

Now if $\vec{f}$ is the force due to sixth charge and $\vec{F}$ due to remaining five charges.



$$\vec{F} + \vec{f} = 0 \Rightarrow \vec{F} = -\vec{f} \Rightarrow F = f = \frac{1}{4\pi\varepsilon_0}\frac{q \times q}{L^2} = \frac{q^2}{4\pi\varepsilon_0 L^2}$$

Electric Field

Electric field is the region around charged particle or charged body in which if another charge is placed, it experiences electrostatic force.

Electric Field Intensity $\vec{E}$: Electric field intensity at a point is equal to the electrostatic force experienced by a unit positive point charge both in magnitude and direction.

If a test charge q_0 is placed at a point in an electric field and experiences a force $\vec{F}$ due to some charges (called source charges), the electric field intensity at that point due to source charges is given by $\vec{E} = \frac{\vec{F}}{q_0}$

If the $\vec{E}$ is to be determined practically then the test charge q_0 should be small otherwise it will affect the charge distribution on the source which is producing the electric field and hence modify the quantity which is measured.

Ex. A positively charged ball hangs from a long silk thread. We wish to measure E at a point P in the same horizontal plane as that of the hanging charge. To do so, we put a positive test charge q_0 at the point and measure F/q_0. Will F/q_0 be less than, equal to, or greater than E at the point in question?

Sol. When we try to measure the electric field at point P then after placing the test charge at P, it repels the source charge (suspended charge) and the measured

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Properties of Electric Field Intensity $\vec{E}$:

(i) It is a vector quantity. Its direction is the same as the force experienced by positive charge.

(ii) Direction of electric field due to positive charge is always away from it while due to negative charge, always towards it.

(iii) Its S.I. unit is Newton/Coulomb.

(iv) Its dimensional formula is $[MLT^{-3}A^{-1}]$

(v) Electric force on a charge q placed in a region of electric field at a point where the electric field intensity is $\vec{E}$ is given by $\vec{F} = q\vec{E}$.

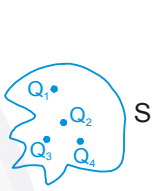
Electric force on point charge is in the same direction of electric field on positive charge and in opposite direction on a negative charge.

(vi) It obeys the superposition principle, that is, the field intensity at a point due to a system of charges is vector sum of the field intensities due to individual point charges.

i.e. $\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + ...$

(vii) It is produced by source charges. The electric field will be a fixed value at a point unless we change the distribution of source charges.

Ex. Electrostatic force experienced by $-3\mu C$ charge placed at point 'P' due to a system 'S' of fixed point charges as shown in figure is $\vec{F} = (21\hat{i} + 9\hat{j})\,\mu N$.



(i) Find out electric field intensity at point P due to S.

(ii) If now, $2\mu C$ charge is placed and $-3\ \mu C$ is removed at point P then force experienced by it will be.

Sol. **(i)** $\vec{F} = q\vec{E} \Rightarrow (21\hat{i} + 9\hat{j})\mu N = -3\mu C\,(\vec{E}) \Rightarrow \vec{E} = -7\,\hat{i} - 3\,\hat{j}\ \frac{N}{C}$

(ii) Since the source charges are not disturbed the electric field intensity at 'P' will remain same.

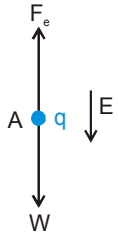
$\vec{F}_{2\mu C} = +2(\vec{E}) = 2(-7\,\hat{i} - 3\,\hat{j}) = (-14\,\hat{i} - 6\,\hat{j})\,\mu N$

Ex. Calculate the electric field intensity which would be just sufficient to balance the weight of a particle of charge $-10\ \mu c$ and mass 10 mg. (take g = 10 ms^2)

Sol. As force on a charge q in an electric field $\vec{E}$ is

$\vec{F}_q = q\,\vec{E}$

So, according to given problem:



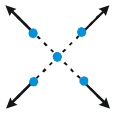
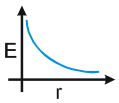
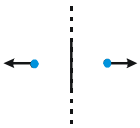
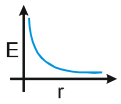
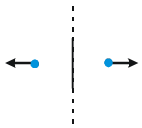
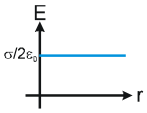
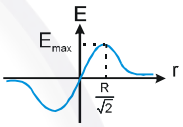
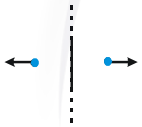
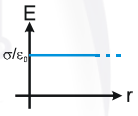
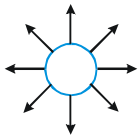
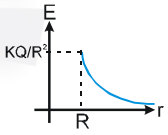
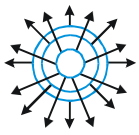
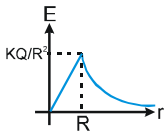
[W = weight of particle]

$|\vec{F}_q| = |\vec{W}|$ i.e., $|q|E = mg$

i.e., $E = \frac{mg}{|q|} = 10$ N/C., in downward direction.

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List of formula for Electric Field Intensity due to various types of charge distribution :

Name / Type	Formula	Note	Graph
Point charge 	$\vec{E}=\frac{Kq}{\lvert\vec{r}\rvert^2}\cdot\hat{r}$	* q is source charge. * $\vec{r}$ is vector drawn from source charge to the test point. outwards due to +charges & inwards due to –charges.	
Infinitely long line charge 	$\frac{\lambda}{2\pi\varepsilon_0 r}\hat{r}=\frac{2K\lambda\hat{r}}{r}$	* q is linear charge density (assumed uniform) * r is perpendicular distance of point from line charge. * r is radial unit vector drawn from the charge to test point.	
Infinite non-conducting thin sheet 	$\frac{\sigma}{2\varepsilon_0}\hat{n}$	* σ is surface charge density. (assumed uniform) * n is unit normal vector. * x = distance of point on the axis from centre of the ring. * electric field is always along the axis.	
Uniformly charged ring 	$E=\frac{KQx}{(R^2+x^2)^{3/2}}$ $E_{centre}=0$	* Q is total charge of the ring * x = distance of point on the axis from centre of the ring. * electric field is always along the axis.	
Infinitely large charged conducting sheet 	$\frac{\sigma}{\varepsilon_0}\hat{n}$	* σ is the surface charge . density (assumed uniform) * n̂ is the unit vector perpendicular to the surface.	
Uniformly charged hollow conducting/ nonconducting /solid conducting sphere 	(i) for r ≥ R $\vec{E}=\frac{kQ}{\lvert\vec{r}\rvert^2}\hat{r}$ (ii) for r < R E = 0	* R is radius of the sphere. * $\vec{r}$ is vector drawn from centre of sphere to the point. * Sphere acts like a point charge. placed at centre for points outside the sphere. * $\vec{E}$ is always along radial direction. * Q is total charge ($=\sigma 4\pi R^2$). (σ = surface charge density)	
Uniformly charged solid nonconducting sphere (insulating material) 	(i) for r ≥ R $\vec{E}=\frac{kQ}{\lvert\vec{r}\rvert^2}\hat{r}$ (ii) for r ≤ R $\vec{E}=\frac{kQ}{R^3}\vec{r}$	* $\vec{r}$ is vector drawn from centre of sphere to the point * Sphere acts like a point charge placed at the centre for points outside the sphere * $\vec{E}$ is always along radial dir^n * Q is total charge ($\rho,\frac{4}{3}\pi R^3$). (ρ = volume charge density) * Inside the sphere $E\propto r$. * Outside the sphere $E\propto 1/r^2$.	

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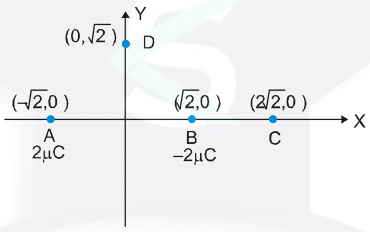
Ex. Find out electric field intensity at point A (0, 1m, 2m) due to a point charge –20μC situated at point B($\sqrt{2}$ m, 0, 1m).

Sol. $E = \frac{KQ}{|\vec{r}|^3}\vec{r} = \frac{KQ}{|\vec{r}|^2}\hat{r}$ $\Rightarrow$ $\vec{r}$ = P.V. of A – P.V. of B (P.V. = Position vector)

$= (-\sqrt{2}\ \hat{i} + \hat{j} + \hat{k})$ $|\vec{r}| = \sqrt{(\sqrt{2})^2 + (1)^2 + (1)^2} = 2$

$E = \frac{9\times10^9 \times (-20\times10^{-6})}{8}(-\sqrt{2}\,\hat{i} + \hat{j} + \hat{k}) = -22.5 \times 10^3 (-\sqrt{2}\ \hat{i} + \hat{j} + \hat{k})$ N/C.

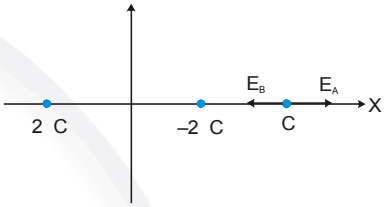
Ex. Two point charges 2μc and – 2μc are placed at points A and B as shown in figure. Find out electric field intensity at points C and D. [All the distances are measured in meter].



Sol. Electric field at point C :

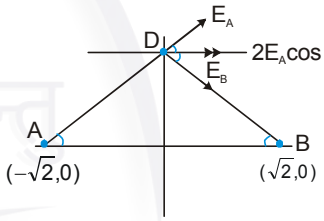
(E_A, E_B are magnitudes only and arrows represent directions)

Electric field due to positive charge is away from it while due to negative charge, it is towards the charge. It is clear that $E_B > E_A$.



$\therefore$ $E_{Net} = (E_B - E_A)$ towards negative X-axis

$= \frac{K(2\mu c)}{(\sqrt{2})^2} - \frac{K(2\mu c)}{(3\sqrt{2})^2}$ towards negative X-axis $= 8000\,(-\hat{i})$ N/C



Electric field at point D :

Since magnitude of charges are same and also AD = BD

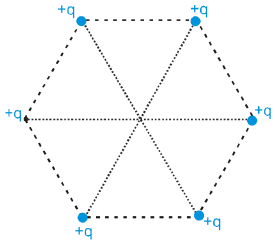
So, $E_A = E_B$

Vertical components of $\vec{E}_A$ and $\vec{E}_B$ cancel each other while horizontal components are in the same direction.

So, $E_{net} = 2E_A\cos\theta = \frac{2.K(2\mu c)}{2^2}\cos45^0$

$= \frac{K\times10^{-6}}{\sqrt{2}} = \frac{9000}{\sqrt{2}}\hat{i}$ N/C.

Ex. Six equal point charges are placed at the corners of a regular hexagon of side 'a'. Calculate electric field intensity at the centre of hexagon ?



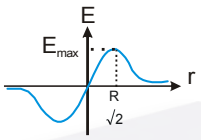
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Ans Zero (By symmetry)

The y-component of electric field due to all the elements will be cancelled out to each other. So net electric field intensity at the point will be only due to X-component of each element.

$$E_{net} = \int dE_x = \int dE \cos\theta = \int_0^Q \frac{K(dq)}{R^2+x^2} \times \frac{x}{\sqrt{R^2+X^2}} = \frac{k\,x}{(R^2+x^2)^{3/2}} \int_0^Q dq$$

$$E_{net} = \frac{KQx}{[R^2+x^2]^{3/2}}$$



Graph for variation of E with r.

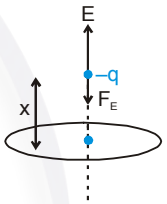
E will be max when $\frac{dE}{dx} = 0$, that is at $x = \frac{R}{\sqrt{2}}$ and $E_{max} = \frac{2KQ}{3\sqrt{3}\,R^2}$

Case (i) : if x>>R, $E = \frac{KQ}{x^2}$ Hence the ring will act like a point charge

Case (ii) : if x<<R, $E = \frac{KQ\,x}{R^3}$,

Ex. Positive charge Q is distributed uniformly over a circular ring of radius a. A point particle having a mass m and a negative charge –q, is placed on its axis at a distance y from the centre. Find the force on the particle. Assuming y << a, find the time period of oscillation of the particle if it is released from there. (Neglect gravity)

Sol. When the negative charge is shifted at a distance x from the centre of the ring along its axis then force acting on the point charge due to the ring:



$F_E = qE$ (towards centre)

$$= q\left[\frac{KQy}{(a^2+y^2)^{3/2}}\right]$$

If a >> y then

$a^2 + y^2 \simeq a^2$

$$\therefore \quad F_E = \frac{1}{4\pi\varepsilon_0}\frac{Qqy}{a^3} \qquad \text{(Towards centre)}$$

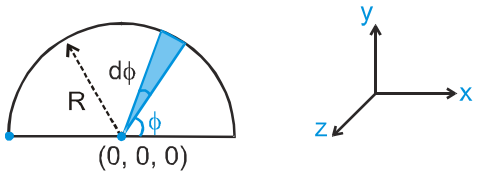
Since, restoring force $F_E \propto y$, therefore motion of charge the particle will be S.H.M.

Time period of SHM:

$$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{m}{\left(\frac{Qq}{4\pi\varepsilon_0 a^3}\right)}} = \left[\frac{16\pi^3\varepsilon_0 m a^3}{Qq}\right]^{1/2}$$

Ex. Calculate electric field intensity at a point on the axis which is at distance x from the centre of half ring, having total charge Q distributed uniformly on it. The radius of half ring is R.

Sol.



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Consider an element of small angle dϕ at an angle ϕ as shown.
Coordinates of element : (R cos ϕ, R sin ϕ, 0)
Coordinates of point : (0, 0, x)
Now electric field due to element :-

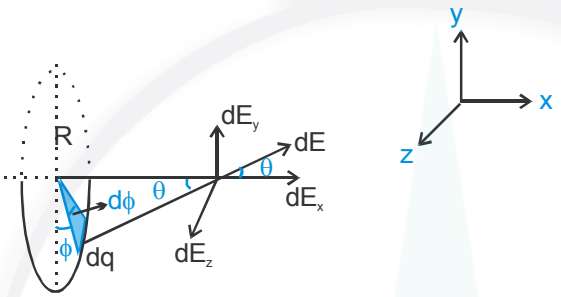
$$\overrightarrow{dE} = \frac{K(\lambda R d\varphi)\cdot[-R\cos\varphi\hat{i} - R\sin\varphi\hat{j} + x\hat{k}]}{(R^2\cos^2\varphi + R^2\sin^2\varphi + x^2)^{3/2}} \Rightarrow E_x = \Sigma dE_x = -\int_0^{\pi} \frac{K\lambda R^2\cos\varphi d\varphi}{(R^2+x^2)^{3/2}} = 0$$

$$E_y = \Sigma dE_y = -\int_0^{\pi} \frac{K\lambda R^2\sin\varphi d\varphi}{(R^2+x^2)^{3/2}} = \frac{2K\lambda R^2}{(R^2+x^2)^{3/2}} = \frac{2KQR}{\pi(R^2+x^2)^{3/2}}$$

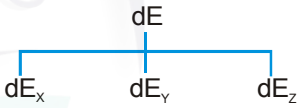
$$E_z = \Sigma dE_z = \int_0^{\pi} \frac{K\lambda R x d\varphi}{(R^2+x^2)^{3/2}} = \frac{KQx}{(R^2+x^2)^{3/2}}$$

$$E_{net} = \sqrt{E_x^2 + E_y^2 + E_z^2} \qquad = \frac{KQ}{(R^2+x^2)^{3/2}}\sqrt{\frac{4R^2}{\pi^2} + x^2}$$

Alternate Solution



Consider an element of charge dq at an angle ϕ on circumference of half ring. Due to this element electric field at the point on axis, which is at a distance x from the centre of half ring is dE.
This electric field can be resolved into three component



$$E_Z = \int_{-\pi/2}^{\pi/2} dE\sin\theta\sin\varphi = 0$$

$$E_X = \int_{-\pi/2}^{\pi/2} dE\cos\theta = \frac{KQx}{[R^2+x^2]^{3/2}} \qquad \text{.....(1)}$$

$$E_Y = \int_{-\pi/2}^{\pi/2} dE\sin\theta\cos\varphi = \int \frac{Kdq}{R^2+x^2}\ \sin\theta.\cos\phi = \frac{2K\lambda R\sin\theta}{R^2+x^2} \qquad \text{.....(2)}$$

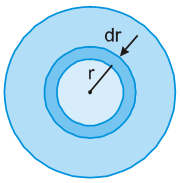
$\therefore$ $dq = \lambda R d\phi$, $\sin\theta = \dfrac{R}{\sqrt{R^2+x^2}}$ $\Rightarrow$ $E_{net} = \sqrt{E_X^2 + E_Y^2}$

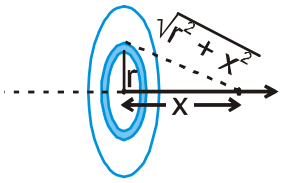
Ex. Derive the expression of electric field intensity at a point 'P' which is situated at a distance x on the axis of uniformly charged disc of radius R and surface charge density σ. Also, derive results for
(i) x >> R **(ii)** x << R

Sol. The disc can be considered to be a collection of large number of concentric rings.
Consider an element of the shape of rings of radius r and of width dr. Electric field due to this ring at P is

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$$dE = \frac{K.\sigma 2\pi r.dr.x}{(r^2 + x^2)^{3/2}}$$





Put, $r^2 + x^2 = y^2$

$2rdr = 2ydy$

$\therefore \quad dE = \frac{K.\sigma 2\pi y.dy.x}{y^3} = 2K\sigma\pi.x\,\frac{ydy}{y^3}$

Electric field at P due to all rings is along the axis :-

$$\therefore \quad E = \int dE \Rightarrow E = 2K\sigma\pi x \int_x^{\sqrt{R^2+x^2}} \frac{1}{y^2}dy = 2K\rho\pi x.\left[-\frac{1}{y}\right]_x^{\sqrt{R^2+x^2}}$$

$$= 2K\sigma\pi x\left[+\frac{1}{x} - \frac{1}{\sqrt{R^2+x^2}}\right] = 2K\sigma\pi\left[1 - \frac{x}{\sqrt{R^2+x^2}}\right]$$

$$= \frac{\sigma}{2\varepsilon_0}\left[1 - \frac{x}{\sqrt{R^2+x^2}}\right], \text{ along the axis}$$

Cases : (i) If $x >> R$

$$E = \frac{\sigma}{2\varepsilon_0}\left[1 - \frac{x}{x\sqrt{\frac{R^2}{x^2}+1}}\right] = \frac{\sigma}{2\varepsilon_0}\left[1 - \left(1+\frac{R^2}{x^2}\right)^{-1/2}\right]$$

$$= \frac{\sigma}{2\varepsilon_0}\left[1 - 1 + \frac{1}{2}\frac{R^2}{x^2} + \text{higher order terms}\right]$$

$$= \frac{\sigma}{4\varepsilon_0}\frac{R^2}{x^2} = \frac{\sigma\pi R^2}{4\pi\varepsilon_0 x^2} = \frac{Q}{4\pi\varepsilon_0 x^2}$$

i.e. behaviour of the disc is like a point charge.

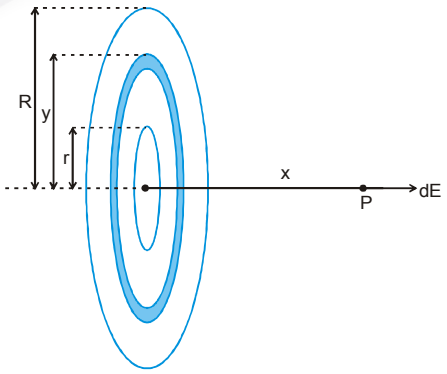
(ii) If $x << R$

$$E = \frac{\sigma}{2\varepsilon_0}[1 - 0] = \frac{\sigma}{2\varepsilon_0}$$

i.e. behaviour of the disc is like infinite sheet.

Ex. Calculate electric field at a point on axis, which at a distance x from centre of uniformly charged disc having surface charge density σ and R which also contains a concentric hole of radius r.

Sol. Consider a ring of radius y ($r < y < R$) and width dy concentric with disc and in the plane of the disc. Due to this ring, the electric field at the point P :



$$dE = \frac{K(dq)x}{[X^2 + Y^2]^{3/2}}$$

$$E_{net} = \int_r^R \frac{K\,x.\sigma(2\pi y)dy}{[x^2 + y^2]^{3/2}} \qquad [\because dq = \sigma 2\pi y dy]$$

$$E_{net} = \frac{2\pi\sigma kx}{2}\int_{x^2+r^2}^{x^2+R^2}\frac{dt}{t^{3/2}}, \quad \text{put } x^2 + y^2 = t,\ 2y.\,dy = dt$$

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$$= \frac{\sigma x}{2\varepsilon_0}\left[\frac{1}{\sqrt{x^2+r^2}} - \frac{1}{\sqrt{x^2+R^2}}\right] \quad \text{away from centre}$$

Alternate Method

We can also use superposition principle to solve this problem.

(i) Assume a disc without hole of radius R having surface charge density + σ.

(ii) Also assume a concentric disc of radius r in the same plane of first disc having charge density – σ.

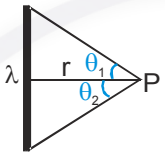
Now using derived formula in last example the net electric field at the centre is :

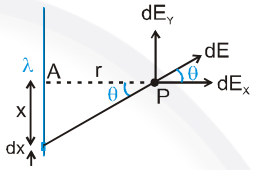
$$\vec{E}_{net} = \vec{E}_R + \vec{E}_r$$

$$= \frac{\sigma x}{2\varepsilon_0}\left[\frac{1}{\sqrt{r^2+x^2}} - \frac{1}{\sqrt{R^2+x^2}}\right] \text{ away from centre.}$$

Electric Field Due to Uniformly Charged Wire

(i) **Line Charge of Finite Length :** Derivation of expression for intensity of electric field at a point due to line charge of finite size of uniform linear charge density λ. The perpendicular distance of the point from the line charge is r and lines joining ends of line charge distribution make angle θ_1 and θ_2 with the perpendicular line.





Consider a small element dx on line charge distribution at distance x from point A (see fig.). The charge of this element will be dq = λdx. Due to this charge (dq), the intensity of electric field at the point P is dE.

Then $dE = \frac{K(dq)}{r^2+x^2} = \frac{K(\lambda dx)}{r^2+x^2}$



There will be two components of this field :

$$E_x = \int dE_x = \int dE\cos\theta = \int \frac{K\lambda dx}{r^2+x^2}.\cos\theta$$

Assuming, $x = r\tan\theta \Rightarrow dx = r\sec^2\theta.\, d\theta$

So $$E_x = \int_{-\theta_2}^{+\theta_1} \frac{K\lambda r\sec^2\theta\cdot\cos\theta\cdot d\theta}{r^2+r^2\tan^2\theta}$$

$$= \frac{K\lambda}{r}\int_{-\theta_2}^{+\theta_1}\cos\theta.d\theta = \frac{K\lambda}{r}[\sin\theta_1+\sin\theta_2] \quad \text{.....(1)}$$

Similarly y-component.

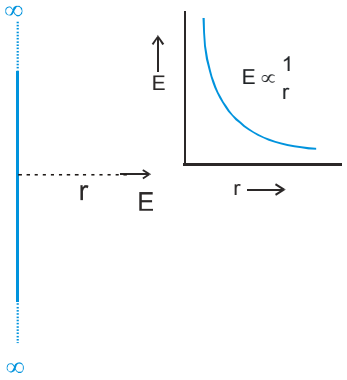
$$E_y = \frac{K\lambda}{r}\int_{-\theta_2}^{+\theta_1}\sin\theta.d\theta = \frac{K\lambda}{r}[\cos\theta_2 - \cos\theta_1]$$

Net electric field at the point:

$$E_{net} = \sqrt{E_x^2+E_y^2}$$

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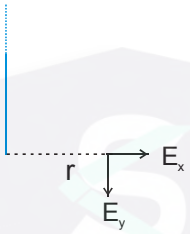
(ii) **We can derive a result for infinitely long line charge:**
In above eq. **(1)** & **(2)**, if we put $\theta_1 = \theta_2 = 90°$, we can get required result.



$$E_{net} = E_x = \frac{2K\lambda}{r}$$

(iii) **For Semi- infinite wire :**
$\theta_1 = 90°$ and $\theta_2 = 0°$, so,

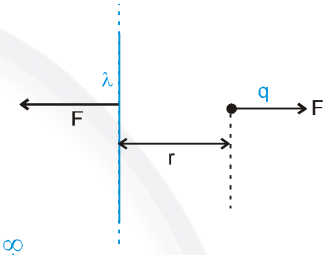
$$E_x = \frac{K\lambda}{r}, \; E_y = \frac{K\lambda}{r}$$



Ex. A point charge q is placed at a distance r from a very long charged thread of uniform linear charge density λ. Find out total electric force experienced by the line charge due to the point charge. (Neglect gravity).

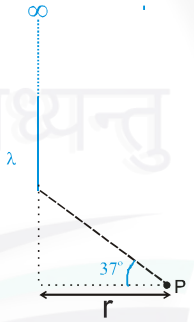
Sol. Force on charge q due to the thread,

$$F = \left(\frac{2K\lambda}{r}\right).q$$



By Newton's III law, every action has equal and opposite reaction So, force on the thread $= \frac{2K\lambda}{r}.q$ (away from point charge)

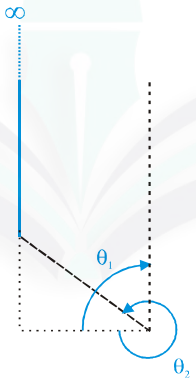
Ex. Figure shows a long wire having uniform charge density λ as shown in figure. Calculate electric field intensity at point P.



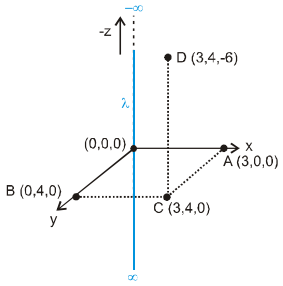
Sol. $\theta_1 = 90°$ and $\theta_2 = 360° - 37°$ So

$$E_x = \frac{K\lambda}{r}[\sin\theta_1 + \sin\theta_2]$$

$$E_y = \frac{K\lambda}{r}[\cos\theta_2 - \cos\theta_1]$$



Ex. Find electric field at point A, B, C, D due to infinitely long uniformly charged wire with linear charge density λ and kept along z-axis (as shown in figure).Assume that all the parameters are in S.I. units.



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Sol. $E_A = \frac{2K\lambda}{3}(\hat{i}) \Rightarrow E_B = \frac{2K\lambda}{4}(\hat{j})$

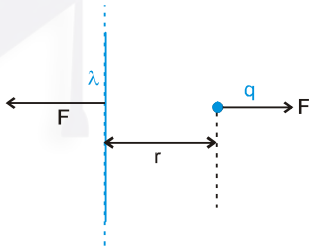
$$E_C = \frac{2K\lambda}{5}\hat{OC} = \frac{2K\lambda}{5}\left(\frac{3\hat{i}+4\hat{j}}{5}\right)$$

$$E_D = \frac{2K\lambda}{5}\left(\frac{3\hat{i}+4\hat{j}}{5}\right) \Rightarrow E_D = E_C$$

Ex. A point charge q is placed at a distance r from a very long charged thread of uniform linear charge density λ. Find out total electric force experienced by the line charge due to the point charge. (Neglect gravity).

Sol. Force on charge q due to the thread,

$$F = \left(\frac{2K\lambda}{r}\right).q$$



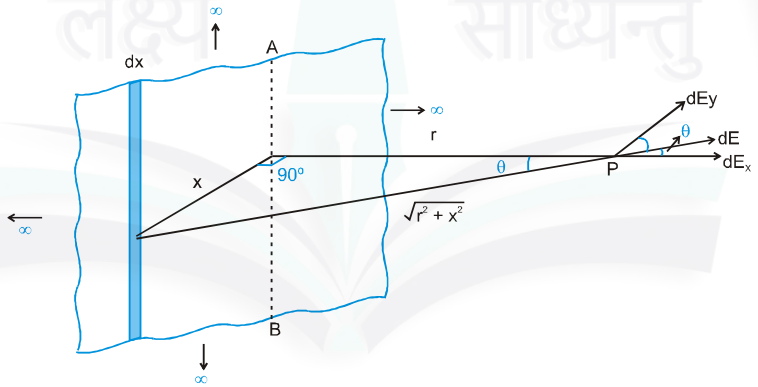
By Newton's III law, every action has equal and opposite reaction, so force on the thread = $\frac{2K\lambda}{r}.q$ (away from point charge)

Electric field due to uniformly charged infinite sheet

$$E_{net} = \frac{\sigma}{2\varepsilon_o} \text{ towards normal direction}$$

Electric field due to An infinitely large, uniformly charged sheet

Derivation of expression for intensity of electric field at a point which is at a perpendicular distance r from the thin sheet of large size having uniform surface charge density σ.



Assume a thin strip of width dx at distance x from line AB (see figure), which can be considered as a infinite line charge of charge density λ = σdx

Due to this line charge the electric field intensity at point P will be

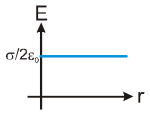
$$dE = \frac{\sigma K(dx)}{\sqrt{r^2+x^2}}$$

Take another element similar to the first element on the other side of AB. Due to symmetry, Y-component of all such elements will be cancelled out.

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So net electric field will be given by :

$$E_{net} = \int dE_x = \int dE\cos\theta = \int \frac{2K(\sigma dx)}{\sqrt{r^2+x^2}} \times \cos\theta$$



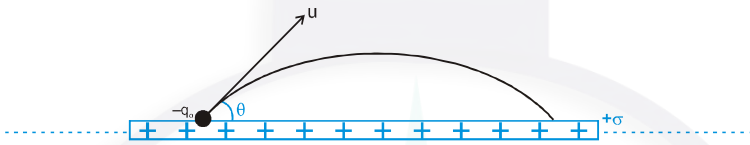
Assume, $x = r\tan\theta \Rightarrow dx = r\sec^2\theta.\, d\theta$

$$\therefore E_{net} = 2K\sigma \int_{-\pi/2}^{+\pi/2} \frac{r\sec^2\theta\, .d\theta .\cos\theta}{\sqrt{r^2+r^2\tan^2\theta}} = \frac{\sigma}{2\varepsilon_o}, \text{ away from sheet}$$

Note: **(1)** The direction of electric field is always perpendicular to the sheet.

(2) The magnitude of electric field is independent of distance from sheet.

Ex. An infinitely large plate of surface charge density $+\sigma$ is lying in horizontal xy plane. A particle having charge $-q_o$ and mass m is projected from the plate with velocity u making an angle θ with sheet. Find :

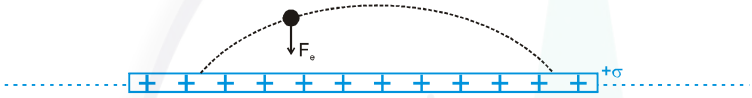


(i) The time taken by the particle to return on the plate..

(ii) Maximum height achieved by the particle.

(iii) At what distance will it strike the plate (Neglect gravitational force on the particle)

Sol.



Electric force acting on the particle $F_e = q_oE$: $F_e = (q_o)\left(\frac{\sigma}{2\varepsilon_o}\right)$ downward

So, acceleration of the particle : $a = \frac{F_e}{m} = \frac{q_o\sigma}{2\varepsilon_o m} = \text{uniform}$

This acceleration will act like 'g' (acceleration due to gravity)

So, the particle will perform projectile motion.

(i) $T = \frac{2u\sin\theta}{g} = \frac{2u\sin\theta}{\left(\frac{q_o\sigma}{2\varepsilon_o m}\right)}$.

(ii) $H = \frac{u^2\sin^2\theta}{2g} = \frac{u^2\sin^2\theta}{2\left(\frac{q_o\sigma}{2\varepsilon_o m}\right)}$.

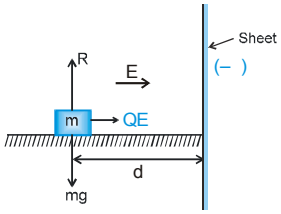
(iii) $R = \frac{u^2\sin 2\theta}{g} = \frac{u^2\sin 2\theta}{\left(\frac{q_o\sigma}{2\varepsilon_o m}\right)}$.

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Ex. A block having mass m and charge Q is resting on a frictionless plane at a distance d from fixed large non-conducting infinite sheet of uniform charge density $-\sigma$ as shown in Figure. Assuming that collision of the block with the sheet is perfectly elastic, find the time period of oscillatory motion of the block. Is it SHM ?

Sol. The situation is shown in Figure. Electric force produced by sheet will accelerate the block towards the sheet producing an acceleration. Acceleration will be uniform because electric field E due to the sheet is uniform.

$$a = \frac{F}{m} = \frac{QE}{m}, \text{ where } E = \sigma/2\varepsilon_0$$



As initially the block is at rest and acceleration is constant, from second equation of motion, time taken by the block to reach the wall

$$d = \frac{1}{2}at^2 \qquad \text{i.e.,} \qquad t = \sqrt{\frac{2L}{a}} = \sqrt{\frac{2md}{QE}} = \sqrt{\frac{4md\varepsilon_0}{Q\sigma}}$$

As collision with the wall is perfectly elastic, the block will rebound with same speed and as now its motion is opposite to the acceleration, it will come to rest after travelling same distance d in same time t. After stopping, it will again be accelerated towards the wall and so the block will execute oscillatory motion with 'span' d and time period.

$$T = 2t = 2\sqrt{\frac{2md}{QE}} = 2\sqrt{\frac{4md\varepsilon_0}{Q\sigma}}$$

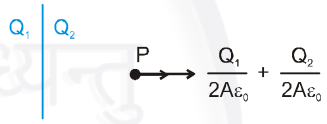
However, as the restoring force F = QE is constant and not proportional to displacement x, the motion is not simple harmonic.

Ex. If an isolated infinite sheet contains charge Q_1 on its one surface and charge Q_2 on its other surface then prove that electric field intensity at a point in front of sheet will be $\frac{Q}{2A\varepsilon_0}$, where $Q = Q_1 + Q_2$

Sol. Electric field at point P :

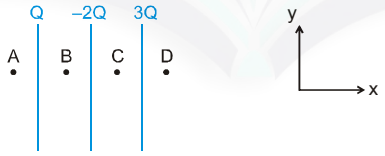
$$\vec{E} = \vec{E}_{Q_1} + \vec{E}_{Q_2}$$

$$= \frac{Q_1}{2A\varepsilon_0}\hat{n} + \frac{Q_2}{2A\varepsilon_0}\hat{n} = \frac{Q_1 + Q_2}{2A\varepsilon_0}\hat{n} = \frac{Q}{2A\varepsilon_0}\hat{n}$$

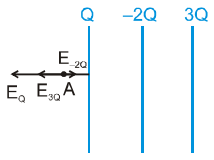


[This shows that the resultant field due to a sheet depends only on the total charge of the sheet and not on the distribution of charge on individual surfaces].

Ex. Three large conducting parallel sheets are placed at a finite distance from each other as shown in figure. Find out electric field intensity at points A, B, C & D.



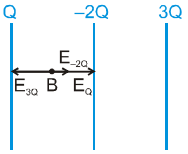
Sol. **For point A**



$$\vec{E}_{net} = \vec{E}_Q + \vec{E}_{3Q} + \vec{E}_{-2Q} = -\frac{Q}{2A\varepsilon_0}\hat{i} - \frac{3Q}{2A\varepsilon_0}\hat{i} + \frac{2Q}{2A\varepsilon_0}\hat{i} = -\frac{Q}{A\varepsilon_0}\hat{i}$$

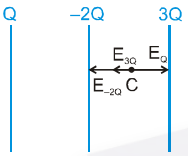
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For point B:



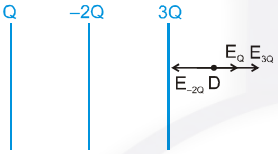
$$\vec{E}_{net} = \vec{E}_{3Q} + \vec{E}_{-2Q} + \vec{E}_{Q} = -\frac{3Q}{2A\varepsilon_0}\hat{i} + \frac{2Q}{2A\varepsilon_0}\hat{i} + \frac{Q}{2A\varepsilon_0}\hat{i} = 0$$

For point C :



$$\vec{E}_{net} = \vec{E}_{Q} + \vec{E}_{3Q} + \vec{E}_{-2Q} = +\frac{Q}{2A\varepsilon_0}\hat{i} - \frac{3Q}{2A\varepsilon_0}\hat{i} - \frac{2Q}{2A\varepsilon_0}\hat{i} = -\frac{2Q}{A\varepsilon_0}\hat{i}$$

For point D :

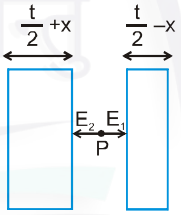


$$\vec{E}_{net} = \vec{E}_{Q} + \vec{E}_{3Q} + \vec{E}_{-2Q} = +\frac{Q}{2A\varepsilon_0}\hat{i} + \frac{3Q}{2A\varepsilon_0}\hat{i} - \frac{2Q}{2A\varepsilon_0}\hat{i} = \frac{Q}{A\varepsilon_0}\hat{i}$$

Ex. Determine and draw the graph of electric field due to infinitely large non-conducting sheet of thickness t and uniform volume charge density ρ as a function of distance x from its symmetry plane.

(a) $x \le \frac{t}{2}$ **(b)** $x \ge \frac{t}{2}$

Sol. We can consider two sheets of thickness $\left(\frac{t}{2}-x\right)$ and $\left(\frac{t}{2}+x\right)$.



Where the point P lies inside the sheet.

Now, net electric field at point P :

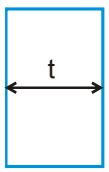
$E = E_1 - E_2$

$= \frac{Q_1}{2A\varepsilon_0} - \frac{Q_2}{2A\varepsilon_0}$ [Q_1 : charge of left sheet;

Q_2 : charge of right sheet.]

$= \frac{A\rho\left(\frac{t}{2}+x\right) - \rho A\left(\frac{t}{2}-x\right)}{2A\varepsilon_0} = \frac{\rho x}{\varepsilon_0}$

For point which lies outside the sheet we can consider a complete sheet of thickness t



$\longrightarrow \frac{Q}{2A\varepsilon_0}$ $E = \frac{\sigma tA}{2A\varepsilon_0} = \frac{\sigma t}{2\varepsilon_0}$

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Alternate

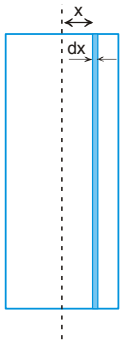
We can assume thick sheet to be made of large number of uniformly charged thin sheets. Consider an elementary thin sheet of width dx at a distance x from symmetry plane.

Charge in sheet = ρAdx

(A : assumed area of sheet)

Surface charge density,

$$s = \frac{\rho A dx}{A}$$



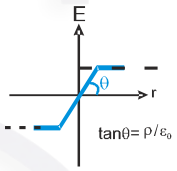
so, electric field intensity due to elementary sheet :

$$dE = \frac{\rho dx}{2\varepsilon_0}$$

(a) When $x < \frac{t}{2} \Rightarrow E_{Net} = \int_{-t/2}^{x} \frac{\rho dx}{2\varepsilon_0} - \int_{x}^{t/2} \frac{\rho dx}{2\varepsilon_0} = \frac{\rho x}{\varepsilon_0}$

(b) When $x > \frac{t}{2}$

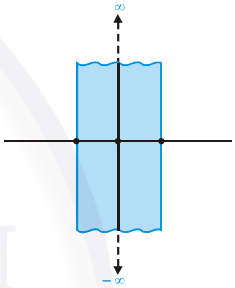
$$E_{Net} = \int_{-t/2}^{t/2} \frac{\rho dx}{2\varepsilon_0} = \frac{\rho t}{2\varepsilon_0}$$



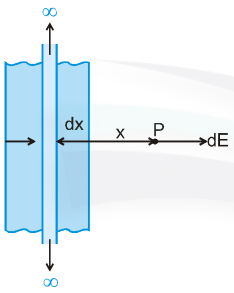
Ex. Thin infinite sheet of width w contains uniform charge distribution σ. Find out electric field intensity at following points :

(a) A point which lies in the same plane at a distance d from one of its edge.

(b) A point which is on the symmetry plane of sheet at a perpendicular distance d from it.



Sol. **(a)**



Consider a thin strip of width dx.

Linear charge density of strip :

$$\lambda = \sigma dx$$

So, electric field due to this strip at point P $dE = \frac{2k\sigma dx}{x}$

$$E_{net} = \int_{d}^{d+w} \frac{\sigma}{2\pi\varepsilon_0} \frac{dx}{x} = \frac{\sigma}{2\pi\varepsilon_0} \ell n\left(\frac{d+w}{d}\right)$$

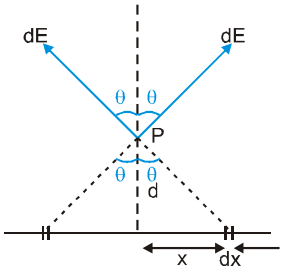
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(b) Consider a thin strip of width dx.

Linear charge density of strip :

$$\lambda = \sigma dx$$

$$\therefore \quad E_p = \int 2dE\cos\theta$$

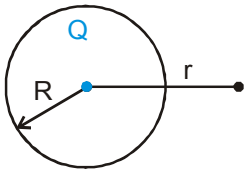


or $$E_p = 2.\int_0^{w/2} \frac{\sigma dx}{2\pi\varepsilon_0\sqrt{d^2+x^2}}.\frac{d}{\sqrt{d^2+x^2}}$$

$$= \frac{\sigma d}{\pi\varepsilon_0}\int_0^{w/2}\frac{dx}{d^2+x^2} = \frac{\sigma}{\pi\varepsilon_0}\tan^{-1}\frac{w}{2d}$$

Electric field due to uniformly charged spherical shell

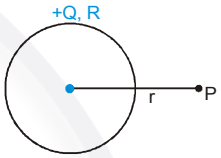
$E = \frac{KQ}{r^2}$ $r \geq R$ $\Rightarrow$ For the outside points & point on the surface the uniformly charged spherical shell behaves as a point charge placed at the centre



$E = 0$ $r < R$

Electric field due to spherical shell outside it is always along the radial direction.

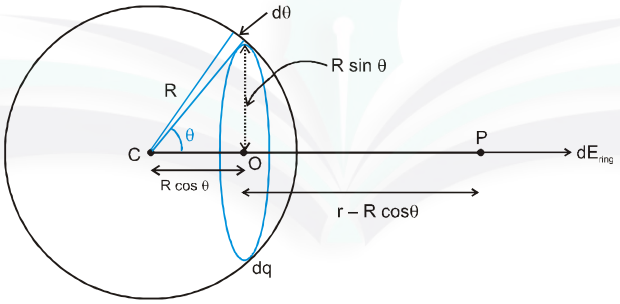
Finding electric field due to a uniformly charged spherical shell

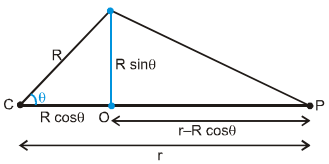


Suppose we have a spherical shell of radius R and charge +Q uniformly distributed on its surface. We have to find electric field at a point P, which is at a distance 'r' from the centre of the sphere.

For this, we can divide the shell into thin rings. Let's consider a ring making an angle θ with the axis and subtending a small angle dθ. Its width will be Rdθ.(arc = radius × angle = Rdθ).

For the points outside the sphere :





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Electric field due to this small ring element :

$$dE = \frac{K\,dq\,x}{[(\text{ring radius})^2 + x^2]^{3/2}} \qquad .....(1)$$

So, total electric field $E_{net} = \int \frac{K\,dq\,x}{[(\text{ring radius})^2 + x^2]^{3/2}}$

Here, radius of the ring element = R sinθ

& x = axial distance of point P from the ring = r – R cos θ

Area of the ring element = (length) (width) = (2π (radius of the ring)) Rdθ = (2πR sinθ) Rdθ

dq = charge of the small ring element. We can find dq by unitary method.

In $4\pi R^2$ Area, charge is Q

In unit Area, charge is $\frac{Q}{4\pi R^2}$.

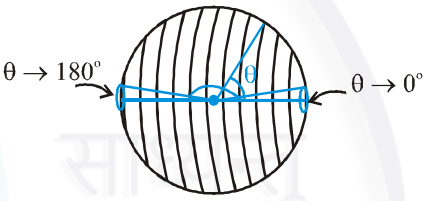
In (2πR sinθ) Rdθ Area, charge = $\frac{Q}{4\pi R^2} \times (2\pi R \sin\theta)\,Rd\theta = dq$

Putting values of r and dq in equation .(1)

We get $E_{out} = \int_{\theta=0}^{\theta=\pi} \frac{K\left(\frac{Q}{4\pi R^2} \times 2\pi (R\sin\theta)\,Rd\theta\right)(r - R\cos\theta)}{\left[(R\sin\theta)^2 + (r - R\cos\theta)^2\right]^{3/2}}$

(The first ring will make angle θ = 0 and the last ring will make θ = 180°.So, limit will be from θ = 0 to θ = 180°)

Steps of integration : From above integral :



$$E_{out} = \frac{KQ}{2}\int_0^{\pi} \frac{(r - R\cos\theta)\sin\theta d\theta}{(R^2 + r^2 - 2Rr\cos\theta)^{3/2}}$$

Now, let $z^2 = R^2 + r^2 - 2Rr\cos\theta$

$\Rightarrow$ $2zdz = 0 + 0 - 2Rr(-\sin\theta)\,d\theta$

$\therefore$ $zdz = Rr\sin\theta\,d\theta$

& $\cos\theta = \frac{R^2 + r^2 - z^2}{2Rr}$

Now, when $\theta = 0 \rightarrow z = (r - R)$

$\theta = \pi \rightarrow z = r + R$

$\therefore$ $E_{out} = \frac{KQ}{2}\int_{r-R}^{r+R} \frac{\left[r - R\frac{(R^2 + r^2 - z^2)}{2Rr}\right]\frac{zdz}{Rr}}{z^3} = \frac{KQ}{2}\int_{r-R}^{r+R} \frac{(2Rr^2 - R^3 - Rr^2 + Rz^2)\,dz}{2R^2r^2z^2}$

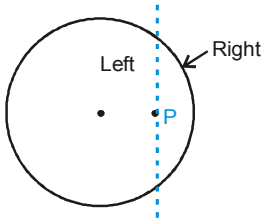
$$= \frac{KQ}{4R^2r^2}\left[\int_{r-R}^{r+R}\frac{Rr^2dz}{z^2} - \int_{r-R}^{r+R}\frac{R^3dz}{z^2} + \int_{r-R}^{r+R} Rdz\right] = \frac{KQ}{4R^2r^2}\left[-\frac{Rr^2}{z} + \frac{R^3}{z} + Rz\right]_{r-R}^{r+R}$$

On solving above, we will get :

$$E_{out} = \frac{KQ}{r^2} \quad \text{if } r > R$$

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For The Points Inside The Sphere :



Now lets derive the electric field due to uniformly charged solid sphere at a point 'P' inside it. The sphere is divided into two parts, the rings on the left part of point 'P' will produce electric field towards right and the rings on right part will produce electric field towards left and $E_{net} = E_{right} - E_{left}$. For this, limit of integration is divided into two parts.

$$E_{net} = \int_{\theta=0}^{\theta=\cos^{-1}\left(\frac{r}{R}\right)} \begin{pmatrix}\text{Electric}\\ \text{field due}\\ \text{to rings}\\ \text{of right}\\ \text{part}\end{pmatrix} - \int_{\theta=\cos^{-1}\left(\frac{r}{R}\right)}^{\theta=\pi} \begin{pmatrix}\text{Electric}\\ \text{field due}\\ \text{to rings}\\ \text{of left}\\ \text{part}\end{pmatrix}$$

As $z^2 = R^2 + r^2 - 2rR\cos\theta$

When $\theta = \cos^{-1}\left(\frac{r}{R}\right) \Rightarrow z = \sqrt{R^2 - r^2}$

When $\theta = 0 \Rightarrow z = R - r$

When $\theta = \pi \Rightarrow z = R + r$

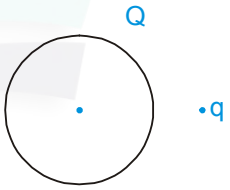
From the result of previous case and just by changing limits we can write

$$E_{in} = \left[-\frac{Rr^2}{z} + \frac{R^3}{z} + Rz\right]_{R-r}^{\sqrt{R^2-r^2}} - \left[-\frac{Rr^2}{z} + \frac{R^3}{z} + Rz\right]_{\sqrt{R^2-r^2}}^{R+r}$$

On solving this expression, we will get E and E = 0 if r < R.

Finding electric field due to shell by integration is very lengthy, so we will not use this method. The given hand-out was just for knowledge. The best method to find E due to shell is by Gauss theorem which we will study later.

Ex. Figure shows a uniformly charged sphere of radius R and total charge Q. A point charge q is situated outside the sphere at a distance r from centre of sphere. Find out the following :



(i) Force acting on the point charge q due to the sphere.

(ii) Force acting on the sphere due to the point charge.

Sol. **(i)** Electric field at the position of point charge

$$\vec{E} = \frac{KQ}{r^2}\hat{r}$$

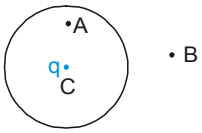
So, $\vec{F} = \frac{KqQ}{r^2}\hat{r} \Rightarrow |\vec{F}| = \frac{KqQ}{r^2}$

(ii) Since we know that every action has equal and opposite reaction so

$$\vec{F}_{sphere} = -\frac{KqQ}{r^2}\hat{r} \Rightarrow |\vec{F}_{sphere}| = \frac{KqQ}{r^2}.$$

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Ex. Figure shows a uniformly charged thin sphere of total charge Q and radius R. A point charge q is also situated at the centre of the sphere.



Find out the following :

(i) Force on charge q

(ii) Electric field intensity at A.

(iii) Electric field intensity at B.

Sol. **(i)** Electric field at the centre of the uniformly charged hollow sphere = 0

So force on charge q = 0

(ii) Electric field at A

$$\vec{E}_A = \vec{E}_{Sphere} + \vec{E}_q = 0 + \frac{Kq}{r^2} \quad ; \; r = CA$$

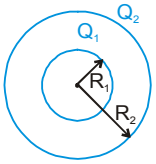
E due to sphere = 0 , because point lies inside the charged hollow sphere.

(iii) Electric field $\vec{E}_B$ at point B = $\vec{E}_{Sphere} + \vec{E}_q$

$$= \frac{KQ}{r^2}.\hat{r} + \frac{Kq}{r^2}.\hat{r} = \frac{K(Q+q)}{r^2}.\hat{r} \; ; \; r = CB$$

Note : Here, we can also assume that the total charge of sphere is concentrated at the centre, for calculation of electric field at B.

Ex. Two concentric uniformly charged spherical shells of radius R_1 and R_2 ($R_2 > R_1$) have total charges Q_1 and Q_2 respectively. Derive an expression of electric field as a function of r for following positions.



(i) $r < R_1$ **(ii)** $R_1 \le r < R_2$ **(iii)** $r \ge R_2$

Sol. **(i)** For $r < R_1$,

therefore, point lies inside both the spheres

$$E_{net} = E_{Inner} + E_{outer} = 0 + 0$$

(ii) For $R_1 \le r < R_2$,

point lies outside inner sphere but inside outer sphere:

$$\therefore \quad E_{net} = E_{inner} + E_{outer}$$

$$= \frac{KQ_1}{r^2}\hat{r} + 0 = \frac{KQ_1}{r^2}\hat{r}$$

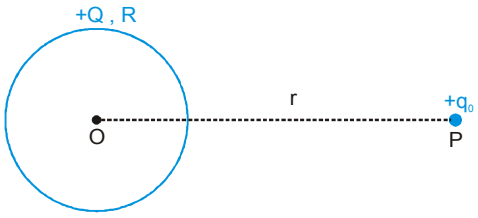
(iii) For $r \ge R_2$

point lies outside inner as well as outer sphere.

Therefore, $E_{Net} = E_{inner} + E_{outer}$

$$= \frac{KQ_1}{r^2}\hat{r} + \frac{KQ_2}{r^2}\hat{r} = \frac{K(Q_1+Q_2)}{r^2}\hat{r}$$

Ex. A spherical shell having charge +Q (uniformly distributed) and a point charge + q_0 are placed as shown.



Find the force between shell and the point charge(r>>R).

(i) Force on the point charge + q_0 due to the

$$\text{shell} = q_0\vec{E}_{shell} = (q_0)\left(\frac{KQ}{r^2}\right)\hat{r} = \frac{KQq_0}{r^2}\hat{r}$$

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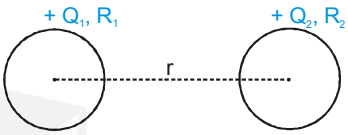
where $\hat{r}$, is unit vector along OP.

From action - reaction principle, force on the shell due to the point charge will

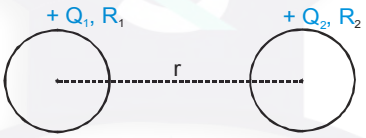
also be : $F_{shell} = \frac{KQq_0}{r^2}(-\hat{r})$

Conclusion :- To find the force on a hollow sphere due to outside charges , we can replace the sphere by a point charge kept at centre.

Ex. Find force acting between two shells of radius R_1 and R_2 which have uniformly distributed charges Q_1 and Q_2 respectively and distance between their centres is r.



Sol. The shells can be replaced by point charges kept at centre, so force between them



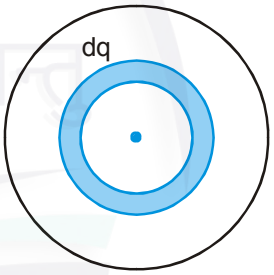
$$F = \frac{KQ_1Q_2}{r^2};$$



Electric field due to uniformly charged solid sphere

Derive an expression for electric field due to solid sphere of radius R and total charge Q which is uniformly distributed in the volume, at a point which is at a distance r from centre for given two cases.

(i) $r \geq R$ **(ii)** $r \leq R$



Assume an elementary concentric shell of charge dq. Due to this shell, the electric field at the point (r > R) will be:

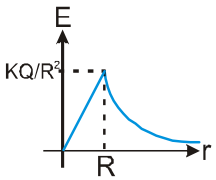
$$dE = \frac{Kdq}{r^2} \quad \text{[from above result of hollow sphere]}$$

$$E_{net} = \int dE = \frac{KQ}{r^2}$$

For r < R, there will be no electric field due to shell of radius greater than r, so electric field at the point will be present only due to shells having radius less than r.

$$E'_{net} = \frac{KQ'}{r^2}$$

Here, $Q' = \frac{Q}{\frac{4}{3}\pi R^3} \times \frac{4}{3}\pi r^3 = \frac{Qr^3}{R^3}$



$\therefore \quad E'_{net} = \frac{KQ'}{r^2} = \frac{KQr}{R^3};$ away from the centre.

NOTE : The electric field inside and outside the sphere is always in radial direction.

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Ex. A solid non conducting sphere of radius R and uniform volume charge density ρ has its centre at origin. Find out electric field intensity in vector form at following positions :

(i) (R/2, 0, 0) **(ii)** $\left(\frac{R}{\sqrt{2}}, \frac{R}{\sqrt{2}}, 0\right)$ **(iii)** (R, R, 0)

Sol. **(i)** At (R/2, 0, 0) : Distance of point from centre = $\sqrt{(R/2)^2 + 0^2 + 0^2}$ = R/2 < R, so point lies inside the sphere, so

$$\vec{E} = \frac{p\vec{r}}{3\varepsilon_0} = \frac{\rho}{3\varepsilon_0}\left[\frac{R}{2}\hat{i}\right]$$

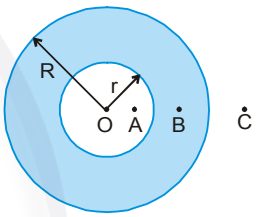
(ii) At $\left(\frac{R}{\sqrt{2}}, \frac{R}{\sqrt{2}}, 0\right)$; distance of point from centre = $\sqrt{(R/\sqrt{2})^2 + (R/\sqrt{2})^2 + 0^2}$ = R = R, so point lies at the surface of sphere, therefore

$$\vec{E} = \frac{KQ}{R^3}\vec{r} = \frac{K\frac{4}{3}\pi R^3\rho}{R^3}\left[\frac{R}{\sqrt{2}}\hat{i} + \frac{R}{\sqrt{2}}\hat{j}\right] = \frac{\rho}{3\varepsilon_0}\left[\frac{R}{\sqrt{2}}\hat{i} + \frac{R}{\sqrt{2}}\hat{j}\right]$$

(iii) The point is outside the sphere

So, $$\vec{E} = \frac{KQ}{r^3}\vec{r} = \frac{K\frac{4}{3}\pi R^3\rho}{(\sqrt{2}R)^3}\left[R\hat{i} + R\hat{j}\right] = \frac{\rho}{6\sqrt{2}\varepsilon_0}\left[R\hat{i} + R\hat{j}\right]$$

Ex. A Uniformly charged solid non-conducting sphere of uniform volume charge density ρ and radius R is having a concentric spherical cavity of radius r. Find out electric field intensity at following points, as shown in the figure :



(i) Point A **(ii)** Point B

(iii) Point C **(iv)** Centre of the sphere

Sol. **Method I :**

(i) **For point A :**

We can consider the solid part of sphere to be made of large number of spherical shells which have uniformly distributed charge on its surface. Now, since point A lies inside all spherical shells so electric field intensity due to all shells will be zero.

$$\overrightarrow{E_A} = 0$$

(ii) **For point B :**

All the spherical shells for which point B lies inside will make electric field zero at point B. So electric field will be due to charge present from radius r to OB.

So, $$\overrightarrow{E_B} = \frac{K\frac{4}{3}\pi(OB^3 - r^3)\rho}{OB^3}\overrightarrow{OB} = \frac{\rho}{3\varepsilon_0}\frac{[OB^3 - r^3]}{OB^3}\overrightarrow{OB}$$

(iii) **For point C,** similarly we can say that for all the shell points C lies outside the shell

So, $$\overrightarrow{E_C} = \frac{K[\frac{4}{3}\pi(R^3 - r^3)]}{[OC]^3}\overrightarrow{OC} = \frac{\rho}{3\varepsilon_0}\frac{R^3 - r^3}{[OC]^3}\overrightarrow{OC}$$

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Method : II

We can consider that the spherical cavity is filled with charge density ρ and also –ρ, thereby making net charge density zero after combining. We can consider two concentric solid spheres: One of radius R and charge density ρ and other of radius r and charge density –ρ. Applying superposition principle :



(i) $\vec{E_A} = \vec{E_\rho} + \vec{E_{-\rho}} = \frac{\rho(\vec{OA})}{3\varepsilon_0} + \frac{[-\rho(\vec{OA})]}{3\varepsilon_0} = 0$

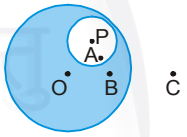
(ii) $\vec{E_B} = \vec{E_\rho} + \vec{E_{-\rho}} = \frac{\rho(\vec{OB})}{3\varepsilon_0} + \frac{K\left[\frac{4}{3}\pi r^3(-\rho)\right]}{(OB)^3}\vec{OB} = \left[\frac{\rho}{3\varepsilon_0} - \frac{r^3\rho}{3\varepsilon_0(OB)^3}\right]\vec{OB} = \frac{\rho}{3\varepsilon_0}\left[1 - \frac{r^3}{OB^3}\right]\vec{OB}$

(iii) $\vec{E_C} = \vec{E_\rho} + \vec{E_{-\rho}} = \frac{K\left(\frac{4}{3}\pi R^3\rho\right)}{OC^3}\vec{OC} + \frac{K\left(\frac{4}{3}\pi r^3(-\rho)\right)}{OC^3}\vec{OC} = \frac{\rho}{3\varepsilon_0(OC)^3}[R^3 - r^3]\vec{OC}$

(iv) $\vec{E_O} = \vec{E_\rho} + \vec{E_{-\rho}} = 0 + 0 = 0$

Ex. In above question, if cavity is not concentric and centered at point P then repeat all the steps.

Sol. Again assume ρ and –ρ in the cavity, (similar to the previous example) :



(i) $\vec{E_A} = \vec{E_\rho} + \vec{E_{-\rho}} = \frac{\rho[\vec{OA}]}{3\varepsilon_0} + \frac{(-\rho)\vec{PA}}{3\varepsilon_0}$

$= \frac{\rho}{3\varepsilon_0}[\vec{OA} - \vec{PA}] = \frac{\rho}{3\varepsilon_0}[\vec{OP}]$

Note : Here, we can see that the electric field intensity at point A is independent of position of point A inside the cavity. Also the electric field is along the line joining the centres of the sphere and the spherical cavity.

(ii) $\vec{E_B} = \vec{E_\rho} + \vec{E_{-\rho}} = \frac{\rho(\vec{OB})}{3\varepsilon_0} + \frac{K[\frac{4}{3}\pi r^3(-\rho)]}{[PB]^3}\vec{PB}$

(iii) $\vec{E_C} = \vec{E_\rho} + \vec{E_{-\rho}} = \frac{K[\frac{4}{3}\pi R^3\rho]}{[OC]^3}\vec{OC} + \frac{K[\frac{4}{3}\pi r^3(-\rho)]}{[PC]^3}\vec{PC}$

(iv) $\vec{E_O} = \vec{E_\rho} + \vec{E_{-\rho}} = 0 + \frac{K[\frac{4}{3}\pi r^3(-\rho)]}{[PO]^3}\vec{PO}$

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Ex. A non-conducting solid sphere has volume charge density that varies as $\rho = \rho_0 r$, where ρ_0 is a constant and r is distance from centre. Find out electric field intensities at following positions.

(i) $r < R$ **(ii)** $r \geq R$

Sol. **Method I :**

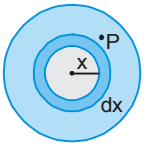
(i) For $r < R$:

The sphere can be considered to be made of large number of spherical shells. Each shell has uniform charge density on its surface. So. the previous results of the spherical shell can be used. Consider a shell of radius x and thickness dx as an element. Charge on shell $dq = (4\pi x^2 dx)\rho_0 x$

$\therefore$ Electric field intensity at point P due to shell,

$$dE = \frac{Kdq}{x^2}$$

Since all the shell will have electric field in same direction



$$\therefore \quad E = \int_0^R dE = \int_0^r dE + \int_r^R dE$$

Due to shells which lie between region $r < x \leq R$, electric field at point P will be zero.

$$\therefore \quad |\vec{E}| = \int_0^r \frac{Kdq}{r^2} + 0 = \int_0^r \frac{K.4\pi x^2 dx \rho_0 x}{r^2} = \frac{4\pi K\rho_0}{r^2}\left[\frac{x^4}{4}\right]_0^r = \frac{\rho_0 r^2}{4\varepsilon_0}\hat{r}$$

(ii) For $r \geq R$, $E = \int_0^R dE = \int_0^R \frac{K.4\pi x^2 dx \rho_0 x}{r^2} = \frac{\rho_0 R^4}{4\varepsilon_0 r^2}\hat{r}$

Method II :

(i) The sphere can be considered to be made of large number of spherical shells. Each shell has uniform charge density on its surface. So the previous results of the spherical shell can be used. we can say that all the shells for which point lies inside will make electric field zero at that point,

So $$\vec{E}_{(r<R)} = \frac{K\int_0^r (4\pi x^2 dx)\rho_0 x}{r^2} = \frac{\rho_0 r^2}{4\varepsilon_0}\hat{r}$$

(ii) Similarly, for $r \geq R$, all the shells will contribute in electric field, Therefore :

$$\vec{E}_{(r<R)} = \frac{K\int_0^R (4\pi x^2 dx)\rho_0 x}{r^2} = \frac{\rho_0 R^4}{4\varepsilon_0 r^2}\hat{r}$$

Electric Potential

In electrostatic field, the electric potential (due to some source charges) at a point P is defined as the work done by external agent in taking a unit point positive charge from a reference point (generally taken at infinity) to that point P without changing its kinetic energy..

Mathematical representation

If $(W_{\infty \to P})_{ext}$ is the work required in moving a point charge q from infinity to a point P, the electric potential of the point P is

$$V_p = \left.\frac{W_{\infty \to p})_{ext}}{q}\right]_{\Delta K=0} = \frac{(-W_{elc})_{\infty \to p}}{q}$$

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(i) $(W_{\infty \to P})_{ext}$ can also be called as the work done by external agent against the electric force on a unit positive charge due to the source charge.

(ii) Write both W and q with proper sign.

Properties

(i) Potential is a scalar quantity, its value may be positive, negative or zero.

(ii) S.I. Unit of potential is volt $= \frac{\text{joule}}{\text{coulmb}}$ and its dimensional formula is $[M^1L^2T^{-3}I^{-1}]$.

(iii) Electric potential at a point is also equal to the negative of the work done by the electric field in taking the point charge from reference point (i.e. infinity) to that point.

(iv) Electric potential due to a positive charge is always positive and due to negative charge it is always negative except at infinity. (taking $V_\infty = 0$).

(v) Potential decreases in the direction of electric field.

(vi) $V = V_1 + V_2 + V_3 + ...$

USE OF POTENTIAL

If we know the potential at some point (in terms of numerical value or in terms of formula) then we can find out the work done by electric force when charge moves from point 'P' to ∞ by the formula

$$W_{ep})_{p \to \infty} = qV_p$$

Ex. A charge 2μC is taken from infinity to a point in an electric field, without changing its velocity. If work done against electrostatic forces is –40μJ, then find the potential at that point.

Sol. $V = \frac{W_{ext}}{q} = \frac{-40\mu J}{2\mu C} = -20\ V$

Ex. When charge 10 μC is shifted from infinity to a point in an electric field, it is found that work done by electrostatic forces is –10 μJ. If the charge is doubled and taken again from infinity to the same point without accelerating it, then find the amount of work done by electric field and against electric field.

Sol. $W_{ext})_{\infty \to p} = -w_{el})_{\infty \to p} = w_{el})_{p \to \infty} = 10\ \mu J$

because $\Delta KE = 0$

$\therefore \quad V_p = \frac{(W_{ext})_{\infty \to p}}{20\mu C} = \frac{10\mu J}{10\mu C} = 1V$

So, if now the charge is doubled and taken from infinity then

$$1 = \frac{w_{ext})_{\infty \to p}}{20\mu C} \Rightarrow \text{ or } W_{ext})_{\infty \to P} = 20\ \mu J \Rightarrow W_{el})_{\infty \to P} = -20\ \mu J$$

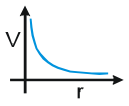
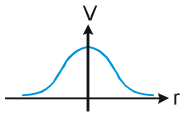
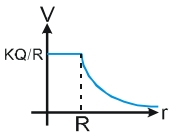
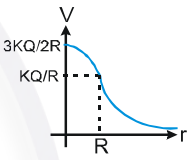
Ex. A charge 3μC is released from rest from a point P where electric potential is 20 V then its kinetic energy when it reaches infinity is :

Sol. $W_{el} = \Delta K = K_f - 0$

$\therefore \quad W_{el})_{P \to \infty} = qV_P = 60\ \mu J \quad$ So, $\quad K_f = 60\ \mu J$

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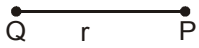
ELECTRIC POTENTIAL DUE TO VARIOUS CHARGE DISTRIBUTIONS

Name / Type	Formula	Note	Graph
Point charge	$\frac{Kq}{r}$	* q is source charge. * r is the distance of the point from the point charge.	
Ring (uniform/nonuniform charge distribution)	at centre: $\frac{KQ}{R}$ at the axis: $\frac{KQ}{\sqrt{R^2+x^2}}$	* Q is source chage. * x is the distance of the point on the axis from centre f ring	
Uniformly charged hollow conducting/nonconducting /solid conducting sphere	for $r \geq R$, $V = \frac{kQ}{r}$ for $r \leq R$, $V = \frac{kQ}{R}$	* R is radius of sphere * r is the distance from centre of sphere to the point * Q is total charge = $\sigma 4\pi R^2$.	
Uniformly charged solid nonconducting sphere .	For $r \geq R$, $V = \frac{kQ}{r}$ For $r \leq R$ $V = \frac{KQ(3R^2 - r^2)}{2R^3}$ $= \frac{\rho}{6\varepsilon_0}(3R^2 - r^2)$	* R is radius of sphere * r is distance from centre to the point * $V_{centre} = \frac{3}{2} V_{surface}$. * Q is total charge = $\rho \frac{4}{3}\pi R^3$. * Inside the sphere potential varies parabolically * Outside the sphere potential varies hyperbolically.	
Infinite line charge	Not defined	* Absolute potential is not defined. * Potential difference between two points is given by formula : $v_B - v_A = -2K\lambda \ln(r_B / r_A)$	
Infinite nonconducting thin sheet	Not defined	* Absolute potential is not defined. * Potential difference between two points is given by formula $V_B - V_A = -\frac{\sigma}{\varepsilon_0}(r_B - r_A)$	
Infinite charged conducting thin sheet	Not defined	* Absolute potential is not defined. * Potential difference between two points is given by formula $V_B - V_A = -\frac{\sigma}{\varepsilon_0}(r_B - r_A)$	

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(1) Potential due to a point charge

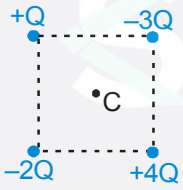
Derivation of expression for potential due to point charge Q, at a point which is at a distance r from the point charge.



From definition of potential

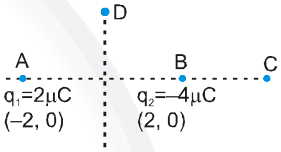
$$V = \frac{W_{ext(\infty \to p)}}{q_o} = \frac{-\int_{\infty}^{r} (q_0 \vec{E}) \cdot d\vec{r}}{q_o} = -\int_{\infty}^{r} \vec{E} \cdot \vec{dr} \quad \Rightarrow \quad V = -\int_{\infty}^{r} \frac{KQ}{r^2}(-dr)\cos 180^\circ = \frac{KQ}{r}$$

Ex. Four point charges are placed at the corners of a square of side ℓ Calculate potential at the centre of square.



Sol. $V = 0$ at 'C'. [Use $V = \frac{Kq}{r}$]

Ex. Two point charges 2μC and – 4μC are situated at points (–2m, 0m) and (2 m, 0 m) respectively. Find out potential at point C (4 m, 0 m) and D (0 m, $\sqrt{5}$ m).



Sol. Potential at point C

$$V_C = V_{q_1} + V_{q_2} = \frac{K(2\mu C)}{6} + \frac{K(-4\mu C)}{2} = \frac{9\times10^9 \times 2\times10^{-6}}{6} - \frac{9\times10^9 \times 4\times10^{-6}}{2} = -15000 \text{ V.}$$

Similarly, $V_D = V_{q_1} + V_{q_2} = \frac{K(2\mu C)}{\sqrt{(\sqrt{5})^2 + 2^2}} + \frac{K(-4\mu C)}{\sqrt{(\sqrt{5})^2 + 2^2}} = \frac{K(2\mu C)}{3} + \frac{K(-4\mu C)}{3} = -6000 \text{ V.}$

Finding potential due to continuous charges

If formula of E is tough, then we take a small element and integrate

$V = \int dv$

If formula of E is easy then, we use

$V = -\int_{r\to\infty}^{r=r} \vec{E}.d\vec{r}$

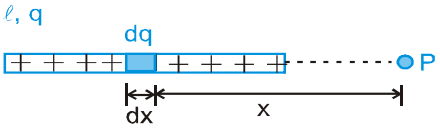
(i.e. for sphere, plate, infinite wire etc.)

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Ex. A rod of length ℓ is uniformly charged with charge q Calculate potential at point P.



Sol. Take a small element of length dx, at a distance x from left end. Potential due to this small element



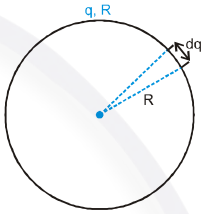
$$dV = \frac{K(dq)}{x} \quad \therefore \quad \text{Total potential} \quad \Rightarrow \quad V = \int_{x=0}^{x=\ell} \frac{k\,dq}{x}$$

Where $dq = \frac{q}{\ell}\,dx \quad \Rightarrow \quad V = \int_{x=r}^{x=r+\ell} \frac{K\left(\frac{q}{\ell}dx\right)}{x} = \frac{Kq}{\ell}\log_e\left(\frac{\ell + r}{r}\right)$

(2) Potential due to a ring

(i) Potential at the centre of uniformly charged ring :

Potential due to the small element dq



$$dV = \frac{Kdq}{R}$$

$\therefore$ Net potential: $V = \int \frac{K\,dq}{R}$

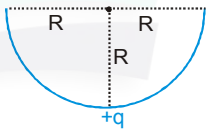
$\therefore \quad V = \frac{K}{R}\int dq = \frac{Kq}{R}$

(ii) For non-uniformly charged ring potential at the center is



$$V = \frac{Kq_{total}}{R}$$

(iii) Potential due to half ring at center is :



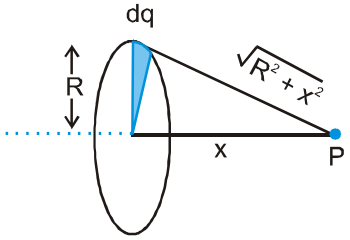
$$V = \frac{Kq}{R}$$

(iv) Potential at the axis of a ring:

Calculation of potential at a point on the axis which is a distance x from centre of uniformly charged (total charge Q) ring of radius R.

Consider an element of charge dq on the ring.

Potential at point P due to charge dq will be

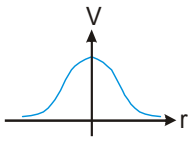


$$dV = \frac{K(dq)}{\sqrt{R^2 + x^2}}$$

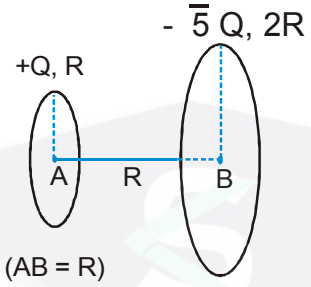
$\therefore$ Net potential at point P due to all such element will be:

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$$V = \int dv = \frac{KQ}{\sqrt{R^2 + x^2}}$$



Ex. Figure shows two rings having charges Q and $-\sqrt{5}$ Q. Find Potential difference between A and B i.e. $(V_A - V_B)$.



Sol. $V_A = \frac{KQ}{R} + \frac{K\left(-\sqrt{5}\,Q\right)}{\sqrt{(2R)^2 + (R)^2}}$; $V_B = \frac{K\left(-\sqrt{5}\,Q\right)}{2R} + \frac{K(Q)}{\sqrt{(R)^2 + (R)^2}}$

From above, we can easily find $V_A - V_B$.

Ex. A point charge q_0 is placed at the centre of uniformly charged ring of total charge Q and radius R. If the point charge is slightly displaced with negligible force along axis of the ring then find out its speed when it reaches a large distance.

Sol. Only electric force is acting on q_0

$$\therefore \quad W_{el} = \Delta K = \frac{1}{2}mv^2 - 0 \quad \Rightarrow \quad \text{Now } W_{el})_{c\to\infty} = q_0 V_c = q_0 \cdot \frac{KQ}{R}$$

$$\therefore \quad \frac{Kq_0Q}{R} = \frac{1}{2}mv^2 \quad \Rightarrow \quad v = \sqrt{\frac{2Kq_0Q}{mR}}$$

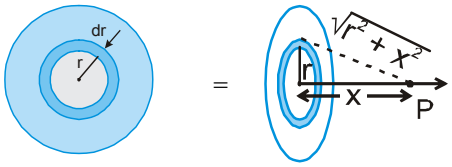
(3) Potential due to uniformly charged disc

$V = \frac{\sigma}{2\varepsilon_0}\left(\sqrt{R^2 + x^2} - x\right)$, where σ is the charge density and x is the distance of the point on the axis from the center of the disc & R is the radius of disc.

Finding potential due to a uniformly charged disc

A disc of radius 'R' has surface charge density (charge/area) = σ. We have to find potential at its axis, at point 'P' which is at a distance x from the centre.

For this, we can divide the disc into thin rings and let's consider a thin ring of radius r and thickness dr. Suppose charge on the small ring element = dq. Potential due to this ring at point 'P' is:



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$$dV = \frac{Kdq}{\sqrt{r^2 + x^2}}$$

So, net potential : $V_{net} = \int \frac{Kdq}{\sqrt{r^2 + x^2}}$

Here, σ = charge/area = $\frac{dq}{d(\text{area})}$

So, $dq = \sigma \times d(\text{area}) = \sigma\ (2\pi r\, dr)$

(Here, d (area) = area of the small ring element =(length of ring) × (width of the ring) = $(2\pi r)$. (dr)

So, $V_{net} = \int_{r=0}^{r=R} \frac{K\sigma(2\pi r\, dr)}{\sqrt{r^2 + x^2}}$

To integrate it, let $r^2 + x^2 = y^2$

$2r\, dr = 2y\, dy$. Substituting we will get:

$$V_{net} = \int_{r=0}^{r=R} \frac{1}{4\pi\varepsilon_0} \frac{\sigma(2\pi)\, y\, dy}{y} \quad \Rightarrow \quad V_{net} = \frac{\sigma}{2\varepsilon_0}[\, y\,]_{r=0}^{r=R}$$

$$V_{net} = \frac{\sigma}{2\varepsilon_0}\left(\sqrt{r^2 + x^2}\right)_{r=0}^{r=R} \quad \Rightarrow \quad V_{net} = \frac{\sigma}{2\varepsilon_0}\left(\sqrt{R^2 + x^2} - x\right)$$

If a test charge q_0 is placed at point P, then potential energy of this charge q_0 due to the disc = $U = q_0 V$

$$\Rightarrow\ U = q_0\left[\frac{\sigma}{2\varepsilon_0}\left(\sqrt{R^2 + x^2} - x\right)\right]$$

Graph of V v/s x :

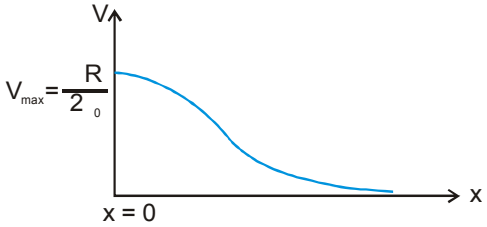
$$V = \frac{\sigma}{2\varepsilon_0}\left(\sqrt{R^2 + x^2} - x\right)$$

at $x = 0\ V = \frac{\sigma R}{2\varepsilon_0}$

to check whether V will increase with x or decrease, lets multiply and divide by conjugate.

$$V = \frac{\sigma}{2\varepsilon_0}\left(\sqrt{R^2 + x^2} - x\right) \times \frac{\left(\sqrt{R^2 + x^2} + x\right)}{\left(\sqrt{R^2 + x^2} + x\right)} \Rightarrow V = \frac{\sigma R^2}{2\varepsilon_0}\left(\frac{1}{\left(\sqrt{R^2 + x^2} + x\right)}\right)$$

Now, we can say that as $x \uparrow \Rightarrow V \downarrow$ so curve will be



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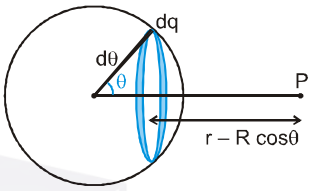
(4) Potential Due To Uniformly Charged Spherical shell

Derivation of expression for potential due to uniformly charged hollow sphere of radius R and total charge Q, at a point which is at a distance r from centre for the following situation

(i) $r > R$ **(ii)** $r < R$

Assume a ring of width $Rd\theta$ at angle θ from X axis (as shown in figure).

Potential due to the ring at the point P will be



$$dV = \frac{K(dq)}{\sqrt{(r - R\cos\theta)^2 + (R\sin\theta)^2}}$$

Where $dq = 2\pi R \sin\theta\,(Rd\theta)\sigma$

where $Q, = 4\pi R^2\sigma$

then, net potential

$$V = \int dV = \frac{KQ}{2}\int_0^{\pi} \frac{\sin\theta.d\theta}{\sqrt{(r - R\cos\theta)^2 + (R\sin\theta)^2}}$$

Solving this eq.we find

$$V = \frac{KQ}{r} \text{ (for } r > R)$$

& $$V = \frac{KQ}{R} \text{ for } (r < R)$$

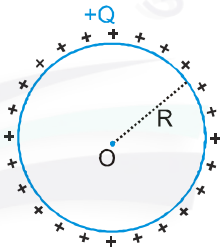
Alternate Method :

As the formula of E is easy , we use $V = -\int_{r\to\infty}^{r=r} \vec{E}\cdot d\vec{r}$

(i) At outside point (r > R):

$$V_{out} = -\int_{r\to\infty}^{r=r}\left(\frac{K\,Q}{r^2}\right)dr \Rightarrow V_{out} = \frac{KQ}{r} = \frac{KQ}{(\text{Distance from centre})}$$

For outside point, the hollow sphere acts like a point charge.



(ii) Potential at the centre of the sphere (r=0) :

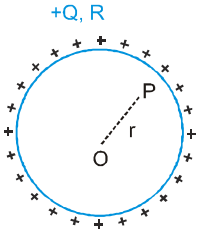
As all the charges are at a distance R from the centre ,

So, $V_{centre} = \frac{KQ}{R} = \frac{KQ}{(\text{Radius of the sphere})}$

(iii) Potential at inside point (r < R) :

Suppose we want to find potential at point P , inside the sphere.

∴ Potential difference between Point P and O :



$$V_P - V_O = -\int_O^P \vec{E}_{in}\cdot d\vec{r} \quad \text{Where, } E_{in} = 0$$

So $V_P - V_O = 0$

$\Rightarrow$ $V_P = V_O = \frac{KQ}{R}$

$\Rightarrow$ $V_{in} = \frac{KQ}{R} = \frac{KQ}{(\text{Radius of the sphere})}$

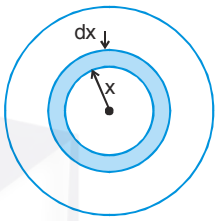
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(5) POTENTIAL DUE TO UNIFORMLY CHARGED SOLID SPHERE

Derivation of expression for potential due to uniformly charged solid sphere of radius R and total charge Q (distributed in volume), at a point which is at a distance r from centre for the following situations.

(i) $r \geq R$ **(ii)** $r \leq R$

Consider an elementary shell of radius x and width dx



(i) For $r \geq R$:

$$V = \int_0^R \frac{K \cdot 4\pi x^2 dx\rho}{r} = \frac{KQ}{r}$$

(ii) for $r \leq R$

$$V = \int_0^r \frac{K \cdot 4\pi x^2 dx\rho}{r} + \int_r^R \frac{K 4\pi x^2 dx\rho}{x}$$

$$= \frac{KQ}{2R^3}(3R^2 - r^2) \quad \Rightarrow \quad \left(\rho = \frac{Q}{\frac{4}{3}\pi R^3}\right)$$

From definition of potential

(i) For $r \geq R$:

$$V = -\int_\infty^r \frac{KQ}{r^2}\hat{r} \cdot dr = \frac{KQ}{r}$$

(ii) For $r \leq R$:

$$V = -\int_\infty^R \frac{KQ}{r^2}.dr - \int_R^r \frac{KQr}{R^3}dr$$

$$V = \frac{KQ}{R} - \frac{KQ}{2R^3}[r^2 - R^2] = \frac{KQ}{2R^3}[2R^2 - r^2 + R^2] = \frac{KQ}{2R^3}(3R^2 - r^2)$$

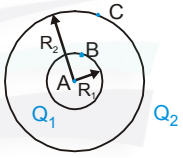
Ex. Two concentric spherical shells of radius R_1 and R_2 ($R_2 > R_1$) are having uniformly distributed charges Q_1 and Q_2 respectively. Find out potential

(i) at point A

(ii) at surface of smaller shell (i.e. at point B)

(iii) at surface of larger shell (i.e. at point C)

(iv) at $r \leq R_1$ **(v)** at $R_1 \leq r \leq R_2$ **(vi)** at $r \geq R_2$



Sol. Using the results of hollow sphere as given in the table 7.4.

(i) $V_A = \frac{KQ_1}{R_1} + \frac{KQ_2}{R_2}$ **(ii)** $V_B = \frac{KQ_1}{R_1} + \frac{KQ_2}{R_2}$

(iii) $V_C = \frac{KQ_1}{R_2} + \frac{KQ_2}{R_2}$ **(iv)** for $r \leq R_1$, $V = \frac{KQ_1}{R_1} + \frac{KQ_2}{R_2}$

(v) for $R_1 \leq r \leq R_2$, $V = \frac{KQ_1}{r} + \frac{KQ_2}{R_2}$

(vi) for $r \geq R_2$, $V = \frac{KQ_1}{r} + \frac{KQ_2}{r}$

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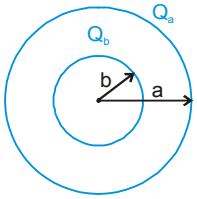
Ex. Two hollow concentric non-conducting spheres of radius the a and b (a > b) contain charges Q_a and Q_b respectively. Prove that potential difference between the two spheres is independent of charge on outer sphere. If outer sphere is given an extra charge, is there any change in potential difference?

Sol. $V_{\text{inner sphere}} = \frac{KQ_b}{b} + \frac{KQ_a}{a}$

$V_{\text{outer sphere}} = \frac{KQ_b}{a} + \frac{KQ_a}{a}$

$V_{\text{inner sphere}} - V_{\text{outer sphere}} = \frac{KQ_b}{b} - \frac{KQ_b}{a}$

$\therefore \Delta V = KQ_b\left[\frac{1}{b} - \frac{1}{a}\right]$



Which is independent of charge on outer sphere.

If outer sphere in given any extra charge, then there will be no change in potential difference.

Potential Difference

The potential difference between two points A and B is work done by external agent against electric field in taking a unit positive charge from A to B with no change in kinetic energy between initial and final points ie. $\Delta K = 0$ or $K_i = K_f$

(a) Mathematical Representation

If $(W_{A\to B})_{ext}$ = Work done by external agent against electric field in taking the unit charge from A to B

Then, $V_B - V_A = \left(\frac{(W_{A\to B})_{ext}}{q}\right)_{\Delta K=0} = \frac{-(W_{A\to B})_{electric}}{q} = \frac{U_B - U_A}{q} = \frac{-\int_A^B \vec{F}_e.\vec{dr}}{q} = -\int_A^B \vec{E}.\vec{dr}$

Note : **Take W and q both with sign**

(b) Properties

(i) The difference of potential between two points is called potential difference. It is also called voltage.

(ii) Potential difference is a scalar quantity. Its S.I. unit is also volt.

(iii) If V_A and V_B be the potential of two points A and B, then work done by an external agent in taking the charge q from A to B is

$$(W_{ext})_{AB} = q(V_B - V_A) \text{ or } (W_{el})_{AB} = q(V_A - V_B).$$

(iv) Potential difference between two points is independent of reference point.

(1) Potential difference in a uniform electric field

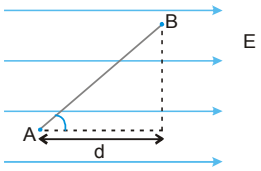
$V_B - V_A = -\vec{E}\cdot\overrightarrow{AB}$

$\Rightarrow \quad V_B - V_A = -|E||AB|\cos\theta$

$= -|E|\,d$

$= -Ed$

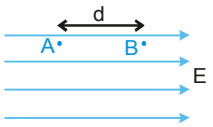
where d = effective distance between A and B along electric field.



or we can also say that $E = \frac{\Delta V}{\Delta d}$

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Special Cases :

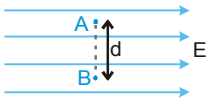


Case 1. Line AB is parallel to electric field.

$\therefore \quad V_A - V_B = Ed$

Case 2. Line AB is perpendicular to electric field.

$\therefore \quad V_A - V_B = 0 \quad \Rightarrow \quad V_A = V_B$



Note : **In the direction of electric field potential always decreases.**

Ex. 1μC charge is shifted from A to B and it is found that work done by an external force is 40μJ in doing so against electrostatic forces, then find potential difference $V_A - V_B$

Sol. $(W_{AB})_{ext} = q(V_B - V_A) \quad \Rightarrow \quad 40\ \mu J = 1\mu C\,(V_B - V_A) \quad \Rightarrow \quad V_A - V_B = -40\ V$

Ex. A uniform electric field is present in the positive x-direction. If the intensity of the field is 5N/C then find the potential difference $(V_B - V_A)$ between two points A (0m, 2 m) and B (5 m ,3 m)

Sol. $V_B - V_A = -\vec{E}.\vec{AB} \quad = -\hat{i}(5).(5\hat{i}+\hat{j}) = -25V.$

The electric field intensity in uniform electric field, $E = \dfrac{\Delta V}{\Delta d}$

Where ΔV = potential difference between two points.

Δd = effective distance between the two points.

(projection of the displacement along the direction of electric field.)

Ex. Find out following

(i) $V_A - V_B$

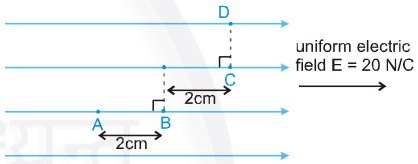
(ii) $V_B - V_C$

(iii) $V_C - V_A$

(iv) $V_D - V_C$

(v) $V_A - V_D$

(vi) Arrange the order of potential for points A, B, C and D.



Sol. **(i)** $|\Delta V_{AB}| = Ed = 20 \times 2 \times 10^{-2} = 0.4$

So, $V_A - V_B = 0.4\ V$

because **In the direction of electric field potential always decreases.**

(ii) $|\Delta V_{BC}| = Ed = 20 \times 2 \times 10^{-2} = 0.4 \quad$ so, $\quad V_B - V_C = 0.4\ V$

(iii) $|\Delta V_{CA}| = Ed = 20 \times 4 \times 10^{-2} = 0.8 \quad$ so, $\quad V_C - V_A = -0.8\ V$

because **In the direction of electric field potential always decreases.**

(iv) $|\Delta V_{DC}| = Ed = 20 \times 0 = 0 \quad$ so, $\quad V_D - V_C = 0$

because the effective distance between D and C is zero.

(v) $|\Delta V_{AD}| = Ed = 20 \times 4 \times 10^{-2} = 0.8 \quad$ so, $\quad V_A - V_D = 0.8\ V$

because **In the direction of electric field potential always decreases.**

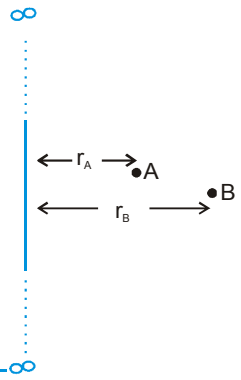
(vi) The order of potential is :

$V_A > V_B > V_C = V_D$.

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Potential difference due to infinitely long wire

Derivation of expression for potential difference between two points, which have perpendicular distance r_A and r_B from infinitely long line charge of uniform linear charge density λ. :



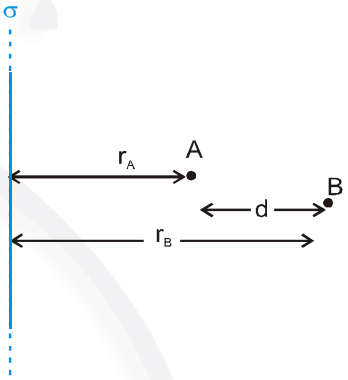
From definition of potential difference :

$$V_{AB} = V_B - V_A = -\int_{r_A}^{r_B} \vec{E}\cdot\vec{dr} = -\int_{r_A}^{r_B} \frac{2K\lambda}{r}\hat{r}\cdot\vec{dr}$$

$$\therefore\ V_{AB} = -2K\lambda\,\ell n\left(\frac{r_B}{r_A}\right)$$

Potential difference due to infinitely long thin sheet

Derivation of expression for potential difference between two points, having separation d in the direction perpendicularly to a very large uniformly charged thin sheet of uniform surface charge density σ.



Let the points A and B have perpendicular distance r_A and r_B respectively then from definition of potential difference.

$$V_{AB} = V_B - V_A = -\int_{r_A}^{r_B} \vec{E}\cdot\vec{dr} = -\int_{r_A}^{r_B} \frac{\sigma}{2\varepsilon_0}\hat{r}\cdot\vec{dr}$$

$$\Rightarrow \qquad V_{AB} = -\frac{\sigma}{2\varepsilon_o}(r_B - r_A) = -\frac{\sigma d}{2\varepsilon_o}$$

Equipotential Surface

Definition : If potential of a surface (imaginary or physically existing) is same throughout, then such surface is known as an equipotential surface.

Properties of equipotential surfaces

(i) When a charge is shifted from one point to another point on an equipotential surface, then work done against electrostatic forces is zero.

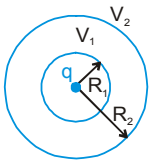
(ii) Electric field is always perpendicular to equipotential surfaces.

(iii) Two equipotential surfaces do not cross each other.

Examples of equipotential surfaces

(i) Point charge :

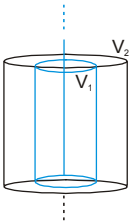
Equipotential surfaces are concentric and spherical as shown in figure. In figure, we can see that sphere of radius R_1 has potential V_1 throughout its surface and similarly for other concentric sphere potential is same.



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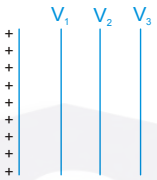
(ii) Line charge :

Equipotential surfaces have curved surfaces as that of coaxial cylinders of different radii.



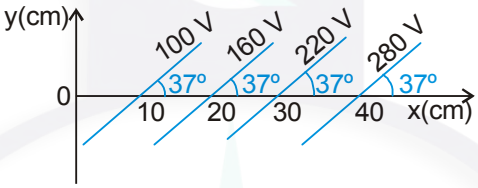
(iii) Uniformly charged large conducting / non conducting sheets:

Equipotential surfaces are parallel planes.



Note : In uniform electric field equipotential surfaces are always parallel planes.

Ex. Some equipotential surfaces are shown in figure. What can you say about the magnitude and the direction of the electric field ?



Sol. Here, we can say that the electric will be perpendicular to equipotential surfaces.

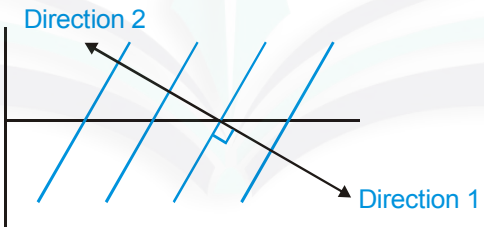
Also, $|\vec{E}| = \frac{\Delta V}{\Delta d}$

Where, ΔV = potential difference between two equipotential surfaces.
Δd = perpendicular distance between two equipotential surfaces.

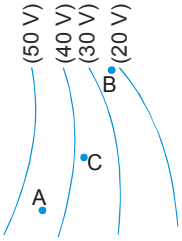
So $|\vec{E}| = \frac{60}{(10\sin 37°)\times 10^{-2}} = 1000 \text{ V/m}$

Now there are two perpendicular directions: either direction 1 or direction 2 as shown in figure, but since we know that in the direction of electric field, electric potential decreases, so the correct direction is direction 2.

Hence E = 1000 V/m, making an angle 127° with the x-axis



Ex. Figure shows some equipotential surfaces produce by some charges. At which point, the value of electric field is greatest?



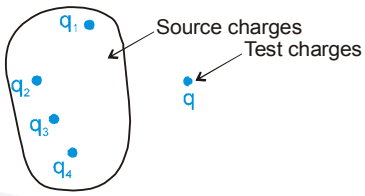
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Sol. E is larger where equipotential surfaces are closer. ELOF are ⊥ to equipotential surfaces. In the figure, we can see that for point B, they are closer so E at point B is maximum.

ELECTROSTATIC POTENTIAL ENERGY

Electrostatic potential energy of a point charge due to many charges

The electrostatic potential energy of a point charge at a point in electric field is the work done in taking the charge from reference point (generally at infinity) to that point without change in kinetic energy



Its Mathematical formula is

$$U = W_{\infty \to P)ext}\big|_{\Delta K = 0} = qV = -W_{P \to \infty)ele}$$

Here, q is the charge whose potential energy is being calculated and V is the potential at its position due to the source charges.

Note : Always put q and V with sign.

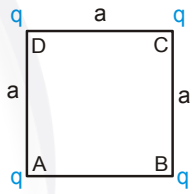
Properties

(i) Electric potential energy is a scalar quantity but may be positive, negative or zero.

(ii) Its unit is same as unit of work or energy i.e joule (in S.I. system).
Some times energy is also given in electron-volts.
Where, $1eV = 1.6 \times 10^{-19}\,J$

(iii) Electric potential energy depends on reference point. (Generally Potential Energy at r= ∞ is taken zero)

Ex. The four identical charges (q each) are placed at the corners of a square of side a.
Find the potential energy of one of the charges due to the remaining charges.



Sol. The electric potential of point A due to the charges placed at B, C and D is

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{a} + \frac{1}{4\pi\varepsilon_0}\frac{q}{\sqrt{2}a} + \frac{1}{4\pi\varepsilon_0}\frac{q}{a} = \frac{1}{4\pi\varepsilon_0}\left(2+\frac{1}{\sqrt{2}}\right)\frac{q}{a}$$

∴ Potential energy of the charge at A is = $qV = \frac{1}{4\pi\varepsilon_0}\left(2+\frac{1}{\sqrt{2}}\right)\frac{q^2}{a}$.

Ex. A particle of mass 40 mg and carrying a charge 5×10^{-9} C is moving directly towards a fixed positive point charge of magnitude 10^{-8} C. When it is at a distance of 10 cm from the fixed point charge it has speed of 50 cm/s. At what distance from the fixed point charge will the particle come momentarily to rest? Is the acceleration constant during the motion?

Sol. If the particle comes to rest momentarily at a distance r from the fixed charge, then from conservation of energy, we have ?

$$\frac{1}{2}mu^2 + \frac{1}{4\pi\varepsilon_0}\frac{Qq}{a} = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r}$$

Substituting the given data, we get:

$$\frac{1}{2} \times 40 \times 10^{-6} \times \frac{1}{2} \times \frac{1}{2} = 9 \times 10^9 \times 5 \times 10^{-8} \times 10^{-9}\left[\frac{1}{r} - 10\right]$$

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or, $\frac{1}{r} - 10 = \frac{5\times10^{-6}}{9\times5\times10^{-8}} = \frac{100}{9} \Rightarrow \frac{1}{r} = \frac{190}{9} \Rightarrow r = \frac{9}{190}$ m

or, i.e., $r = 4.7 \times 10^{-2}$ m

As here, $F = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r^2}$ So, acc. $= \frac{F}{m} \propto \frac{1}{r^2}$

i.e., Acceleration is not constant during the motion.

Ex. A proton moves from a large distance with a speed u m/s directly towards a free proton originally at rest. Find the distance of closest approach for the two protons in terms of mass of proton m and its charge e.

Sol. As here the particle at rest is free to move, when one particle approaches the other, due to electrostatic repulsion other will also start moving and so the velocity of first particle will decrease while of other will increase and at closest approach, both will move with same velocity. So, if v is the common velocity of each particle at closest approach, then by 'conservation of momentum' of the two proton system.

$$mu = mv + mv \quad \text{i.e.,} \quad v = \frac{1}{2}u$$

And by conservation of energy,

$$\frac{1}{2}mu^2 = \frac{1}{2}mv^2 + \frac{1}{2}mv^2 + \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

$$\Rightarrow \frac{1}{2}mu^2 - m\left(\frac{u}{2}\right)^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} \quad [\text{as } v = \frac{u}{2}] \Rightarrow \frac{1}{4}mu^2 = \frac{e^2}{4\pi\varepsilon_0 r}$$

$$\Rightarrow r = \frac{e^2}{\pi m\varepsilon_0 u^2}$$

Electrostatic potential energy of a system of charges

(This concept is useful when more than one charges move.)

It is the work done by an external agent against the internal electric field required to make a system of charges in a particular configuration from infinite separation without change in their kinetic energies.

Types of system of charges

(i) Point charge system

(ii) Continuous charge system.

Derivation for a system of point charges

(i) Keep all the charges at infinity. Now bring the charges one by one to its corresponding position and find work required. PE of the system is algebraic sum of all the works.

Let W_1 = Work done in bringing first charge.

W_2 = Work done in bringing second charge against force due to 1st charge.

W_3 = Work done in bringing third charge against force due to 1st and 2nd charge.

$PE = W_1 + W_2 + W_3 + \ldots\ldots$ (This will contain $\frac{n(n-1)}{2} = {}^nC_2$ terms)

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(ii) Method of calculation (to be used in problems) :

U = sum of the interaction energies of the charges.

$= (U_{12} + U_{13} + ... + U_{1n}) + (U_{23} + U_{24} + ... + U_{2n}) + (U_{34} + U_{35} + ... + U_{3n}) .... .$

(iii) Method of calculation useful for symmetrical point charge systems.

Find PE of each charge due to rest of the charges.

If U_1 = PE of first charge due to all other charges.

$= (U_{12} + U_{13} + ... + U_{1n})$

U_2 = PE of second charge due to all other charges.

$= (U_{21} + U_{23} + ... + U_{2n})$ then U = PE of the system = $\frac{U_1 + U_2 + ...U_n}{2}$

Ex. Find out potential energy of the two point charge system having charges q_1 and q_2 separated by distance r.

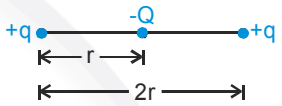
Sol. Let both the charges be placed at a very large separation initially.

Let, W_1 = work done in bringing charge q_1 in absence of $q_2 = q_1(V_f - V_i) = 0$

W_2 = work done in bringing charge q_2 in presence of $q_1 = q_2(V_f - V_i) = q_2(Kq_1/r - 0)$

$\therefore$ $PE = W_1 + W_2 = 0 + Kq_1q_2 / r = Kq_1q_2 / r$

Ex. Figure shows an arrangement of three point charges. The total potential energy of this arrangement is zero. Calculate the ratio $\frac{q}{Q}$.

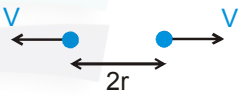


Sol. $U_{sys} = \frac{1}{4\pi\varepsilon_0}\left[\frac{-qQ}{r} + \frac{(+q)(+q)}{2r} + \frac{Q(-q)}{r}\right] = 0$

$-Q + \frac{q}{2} - Q = 0$ or $2Q = \frac{q}{2}$ or $\frac{q}{Q} = \frac{4}{1}$.

Ex. Two point charges, each of mass m and charge q are released when they are at a distance r from each other. What is the speed of each charged particle when they are at a distance 2r ?

Sol. According to momentum conservation, both the charge particles will move with same speed. Now applying energy conservation : →



$0 + 0 + \frac{Kq^2}{r} = 2\frac{1}{2}mv^2 + \frac{Kq^2}{2r}$ $\Rightarrow$ $v = \sqrt{\frac{Kq^2}{2rm}}$

Ex. Two charged particles each having equal charges 2×10^{-5} C are brought from infinity to within a separation of10 cm. Calculate the increase in potential energy during the process and the work required for this purpose.

Sol. $\Delta U = U_f - U_i = U_f - 0 = U_f$

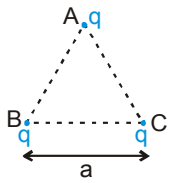
We have to simply calculate the electrostatic potential energy of the given system of charges

$\therefore$ $\Delta U = U_f = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r} = \frac{9\times10^9 \times 2\times10^{-5} \times 2\times10^{-5} \times 100}{10}$ J = 36 J

$\therefore$ Work required = 36 J = equal to change in potential energy of system

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Ex. Three equal charges q each are placed at the corners of an equilateral triangle of side a.

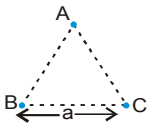


(i) Find out potential energy of charge system.

(ii) Calculate work required to decrease the side of triangle to a/2.

(iii) If the charges are released from the shown position and each of them has same mass m then find the speed of each particle when they lie on triangle of side 2a.

Sol. **(i) Method I** (Derivation)



Assume all the charges are at infinity initially.

Work done in putting charge q at corner A

$\Rightarrow \quad W_1 = q\,(v_f - v_i) = q\,(0-0)$

Since potential at A is zero in absence of charges, work done in putting q at corner B in presence of charge at A :

$$\Rightarrow \quad W_2 = \left(\frac{Kq}{a} - 0\right)q = \frac{Kq^2}{a}$$

Similarly work done in putting charge q at corner C in presence of charge at A and B.

$$\Rightarrow \quad W_3 = q(v_f - v_i) \quad = q\left[\left(\frac{Kq}{a} + \frac{Kq}{a}\right) - 0\right] \quad = \frac{2Kq^2}{a}$$

So, net potential energy $PE = W_1 + W_2 + W_3$

$$= 0 + \frac{Kq^2}{a} + \frac{2Kq^2}{a} \quad = \frac{3Kq^2}{a}$$

Method II (using direct formula):

$$U = U_{12} + U_{13} + U_{23} \quad = \frac{Kq^2}{a} + \frac{Kq^2}{a} + \frac{Kq^2}{a} = \frac{3Kq^2}{a}$$

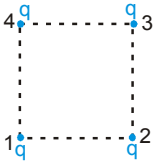
(ii) Work required to decrease the sides

$$W = U_f - U_i \quad = \frac{3Kq^2}{a/2} - \frac{3Kq^2}{a} = \frac{3Kq^2}{a} \text{ Joules}$$

(iii) Work done by electrostatic forces = Change is kinetic energy of particles.

$$U_i - U_f = K_f - K_i \quad \Rightarrow \quad \frac{3Kq^2}{a} - \frac{3Kq^2}{2a} = 3\left(\frac{1}{2}mv^2\right) - 0 \quad \Rightarrow \quad v = \sqrt{\frac{Kq^2}{am}}$$

Ex. Four identical point charges q each are placed at four corners of a square of side a.



Find out potential energy of the charge system

Sol. **Method 1 (using direct formula) :**

$$U = U_{12} + U_{13} + U_{14} + U_{23} + U_{24} + U_{34}$$

$$= \frac{Kq^2}{a} + \frac{Kq^2}{a\sqrt{2}} + \frac{Kq^2}{a} + \frac{Kq^2}{a} + \frac{Kq^2}{a\sqrt{2}} + \frac{Kq^2}{a}$$

$$= \left[\frac{4Kq^2}{a} + \frac{2Kq^2}{a\sqrt{2}}\right] \quad = \frac{2Kq^2}{a}\left[2 + \frac{1}{\sqrt{2}}\right]$$

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Method 2 [Using, $U = \frac{1}{2}(U_1 + U_2 + ...)$] :

U_1 = total P.E. of charge at corner 1 due to all other charges.

U_2 = total P.E. of charge at corner 2 due to all other charges.

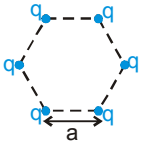
U_3 = total P.E. of charge at corner 3 due to all other charges.

U_4 = total P.E. of charge at corner 4 due to all other charges.

Since, due to symmetry, $U_1 = U_2 = U_3 = U_4$

$$U_{Net} = \frac{U_1 + U_2 + U_3 + U_4}{2} = 2U_1 = 2\left[\frac{Kq^2}{a} + \frac{Kq^2}{a} + \frac{Kq^2}{\sqrt{2}a}\right] = \frac{2Kq^2}{a}\left[2 + \frac{1}{\sqrt{2}}\right]$$

Ex. Six equal point charges q each are placed at six corners of a hexagon of side a. Find out potential energy of charge system



Sol. $U_{Net} = \frac{U_1 + U_2 + U_3 + U_4 + U_5 + U_6}{2}$

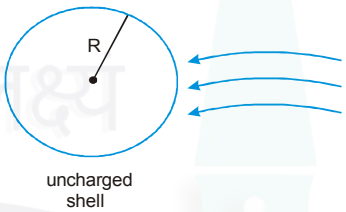
Due to symmetry $U_1 = U_2 = U_3 = U_4 = U_5 = U_6$ So $U_{net} = 3U_1 = \frac{3Kq^2}{a}\left[2 + \frac{2}{\sqrt{3}} + \frac{1}{2}\right]$

Derivation of electric potential energy for continuous charge system

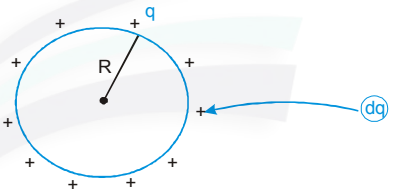
This energy is also known as self energy.

(i) Finding P.E., (Self Energy) of a uniformly Charged spherical shell

For this, lets use method 1 : Take an uncharged shell. Now bring charges one by one from infinity to the surface fo the shell. The work required in this process will be stored as potential Energy.



Suppose, we have given charge q to the sphere and now we are giving extra charge dq to it.
Work required to bring dq charge from infinity to the shell is



$$dW = (dq)(V_f - V_i)$$

$$\Rightarrow \quad dW = (dq)\left(\frac{Kq}{R} - 0\right) = \frac{Kq}{R}dq$$

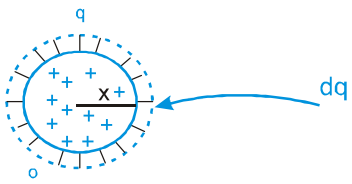
$\Rightarrow$ Total work required to give charge Q is $W = \int_{q=o}^{q=Q} \frac{Kq}{R}dq = \frac{KQ^2}{2R}$

This work will be stored in the form of P.E. (self energy)
So, P.E. of a charged spherical shell:

$$U = \frac{KQ^2}{2R}$$

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(ii) Self energy of uniformly charged solid sphere



In this case we have to assemble a solid charged sphere. So we bring the charges one-by-one from infinity to the sphere so that the size of the sphere increases.

Suppose we have given charge q to the sphere, and its radius becomes 'x' .Now we are giving extra charge dq to it, which will increase its radius by 'dx'

$\therefore$ Work required to bring charge dq from infinity to the sphere

$$= dq\,(V_f - V_i) = (dq)\left(\frac{Kq}{x} - o\right) = \frac{Kqdq}{x}$$

$\therefore$ Total work required to give charge Q to the sphere

$$W = \int \frac{Kqdq}{x}, \quad \text{where} \quad q = \rho\left(\frac{4}{3}\pi x^3\right)$$

$$\& \qquad dq = \rho\,(4\pi x^2\,dx) \Rightarrow \qquad W = 0\int_{x=o}^{x=R} K\frac{\rho\left(\frac{4}{3}\pi x^3\right)\rho(4\pi x^2 dx)}{x}$$

Solving, well get:

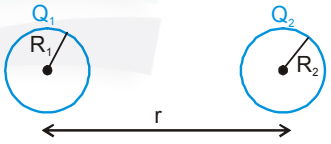
$$W = \frac{3}{5}\frac{KQ^2}{R} = U_{self}\,(\text{for a solid sphere})$$

Ex. A spherical shell of radius R with uniform charge q is expanded to a radius 2R. Find the work performed by the electric forces and external agent against electric forces in this process.

Sol. $W_{ext} = U_f - U_i = \frac{q^2}{16\pi\varepsilon_0 R} - \frac{q^2}{8\pi\varepsilon_0 R} = -\frac{q^2}{16\pi\varepsilon_0 R}$

$$W_{elec} = U_i - U_f = \frac{q^2}{8\pi\varepsilon_0 R} - \frac{q^2}{16\pi\varepsilon_0 R} = \frac{q^2}{16\pi\varepsilon_0 R}$$

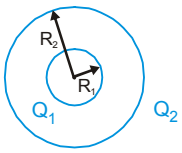
Ex. Two non-conducting hollow uniformly charged spheres of radii R_1 and R_2 with charge Q_1 and Q_2 respectively are placed at a distance r.



Find out total energy of the system.

Sol. $U_{total} = U_{self} + U_{Interaction} = \frac{Q_1^2}{8\pi\varepsilon_0 R_1} + \frac{Q_2^2}{8\pi\varepsilon_0 R_2} + \frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$

Ex. Two concentric spherical shells of radius R_1 and R_2 ($R_2 > R_1$) are having uniformly distributed charges Q_1 and Q_2 respectively. Find out total energy of the system.



Sol. $U_{total} = U_{self\,1} + U_{self\,2} + U_{Interaction} = \frac{Q_1^2}{8\pi\varepsilon_0 R_1} + \frac{Q_2^2}{8\pi\varepsilon_0 R_2} + \frac{Q_1 Q_2}{4\pi\varepsilon_0 R_2}$

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Energy density

Def : Energy density is defined as energy stored in unit volume in any electric field. Its mathematical formula is given as following :

$$\text{Energy density} = \frac{1}{2}\varepsilon E^2$$

where E = electric field intensity at that point

$\varepsilon = \varepsilon_0\varepsilon_r$ electric permittivity of medium

Ex. Find out energy stored in an imaginary cubical volume of side a in front of a infinitely large non-conducting sheet of uniform charge density σ.

Sol. Energy stored :

$$U = \int \frac{1}{2}\varepsilon_0 E^2\, dV \text{ ; where dV is small volume}$$

$$\therefore \quad U = \frac{1}{2}\varepsilon_0 E^2 \int dV$$

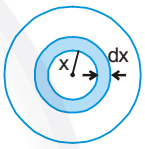
$\because$ E is constant .

$$\therefore \quad U = \frac{1}{2}\varepsilon_0 \frac{\sigma^2}{4\varepsilon_0^2} \cdot a^3 . = \frac{\sigma^2 a^3}{8\varepsilon_0}$$

Ex. Find out energy stored in the electric field of uniformly charged thin spherical shell of total charge Q and radius R.

Sol. We know that electric field inside the shell is zero, so the energy is stored only outside the shell, which can be calculated by using energy density formula.

$$U_{self} = \int_{x=R}^{x\to\infty} \frac{1}{2}\varepsilon_0 E^2 dV$$



Consider an elementary shell of thickness dx and radius x (x > R).

Volume of the shell = $(4\pi x^2 dx) = dV$

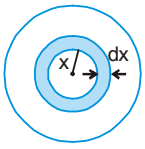
$$U = \int_R^\infty \frac{1}{2}\varepsilon_0 \left[\frac{KQ}{x^2}\right]^2 . 4\pi x^2\, dx = \frac{1}{2}\varepsilon_0\, K^2Q^2 4\pi \int_R^\infty \frac{1}{x^2}\, dx$$

$$= \frac{4\pi\varepsilon_0}{2} \frac{Q^2}{(4\pi\varepsilon_0)^2} \cdot \left(\frac{1}{R}\right) = \frac{Q^2}{8\pi\varepsilon_0 R} = \frac{KQ^2}{2R} .$$

Ex. Find out energy stored inside a solid non-conducting sphere of total charge Q and radius R. [Assume charge is uniformly distributed in its volume.]

Sol. We can consider solid sphere to be made of large number of concentric spherical shells. Also electric field intensity at the location of any particular shell is constant.

$$\therefore \quad U_{inside} = \int_0^R \frac{1}{2}\varepsilon_0 E^2 dV$$



Consider an elementary shell of thickness dx and radius x.

Volume of the shell = $(4\pi x^2 dx)$

$$U_{inside} = \int_0^R \frac{1}{2}\varepsilon_0 \left[\frac{KQx}{R^3}\right]^2 . 4\pi x^2\, dx = \frac{1}{2}\varepsilon_0 \frac{K^2Q^2 4\pi}{R^6} \int_0^R x^4 dx$$

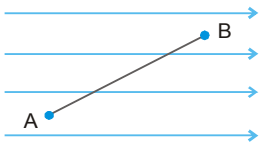
$$= \frac{4\pi\varepsilon_0}{2R^6} \frac{Q^2}{(4\pi\varepsilon_0)^2} \cdot \frac{R^5}{5} = \frac{Q^2}{40\pi\varepsilon_0 R} = \frac{KQ^2}{10R} .$$

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Relation between Electric Field Intensity and electric Potential

(i) For uniform electric field

Potential difference between two points A and B



$$V_B - V_A = -\vec{E} \cdot \vec{AB}$$

(ii) Non uniform electric field

$$E_x = -\frac{\partial V}{\partial x}, E_y = -\frac{\partial V}{\partial y}, E_z = -\frac{\partial V}{\partial z}$$

$$\Rightarrow \quad \vec{E} = E_x \hat{i} + E_y \hat{j} + E_z \hat{k}$$

$$= -\left[\hat{i}\frac{\partial}{\partial x}V + \hat{j}\frac{\partial}{\partial y}V + \hat{k}\frac{\partial}{\partial z}V\right] = \text{cancel}\left[\hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z}\right]V = -\nabla V = -\text{grad } V$$

Where, $\frac{\partial V}{\partial x}$ = derivative of V with respect to x (keeping y and z constant)

$\frac{\partial V}{\partial y}$ = derivative of V with respect to y (keeping z and x constant)

$\frac{\partial V}{\partial z}$ = derivative of V with respect to z (keeping x and y constant)

If electric potential and electric field depends only on one coordinate, say r

(i) $\vec{E} = -\frac{\partial V}{\partial r}\hat{r}$

where, $\hat{r}$ is a unit vector along increasing r.

(ii) $\int dV = -\int \vec{E} \cdot \vec{dr}$

$$\Rightarrow \quad V_B - V_A = -\int_{r_A}^{r_B} \vec{E}.\vec{dr}$$

$\vec{dr}$ is along the increasing direction of r.

(iii) The potential of a point

$$V = -\int_{\infty}^{r} \vec{E}.\vec{dr}$$

Ex. A uniform electric field is along x – axis . The potential difference $V_A - V_B = 10$ V is between two points A (2m , 3m) and B (4m, 8m). Find the electric field intensity.

Sol. $E = \frac{\Delta V}{\Delta d} = \frac{10}{2} = 5 \text{ V/m.}$ (It is along + ve x-axis)

Ex. $V = x^2 + y$, Find $\vec{E}$.

Sol. $\frac{\partial V}{\partial x} = 2x$, $\frac{\partial V}{\partial y} = 1$ and $\frac{\partial V}{\partial z} = 0$

$$\vec{E} = -\left(\hat{i}\frac{\partial V}{\partial x} + \hat{j}\frac{\partial V}{\partial y} + \hat{k}\frac{\partial V}{\partial z}\right) = -(2x\,\hat{i} + \hat{j})$$ $\therefore$ Electric field is non-uniform.

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Ex. For given $\vec{E} = 2x\hat{i} + 3y\hat{j}$, find the potential at (x, y) if V at origin is 5 volts.

Sol. $\int_5^V dV = -\int \vec{E}\cdot\overrightarrow{dr} = -\int_0^x E_x dx - \int_0^y E_y dy$

$\Rightarrow \quad V - 5 = -\frac{2x^2}{2} - \frac{3y^2}{2} \quad \Rightarrow \quad V = -\frac{2x^2}{2} - \frac{3y^2}{2} + 5.$

Electric Dipole

If two point charges, equal in magnitude 'q' and opposite in sign separated by a distance 'a' such that the distance of field point r>>a, the system is called a dipole. The electric dipole moment is defined as a vector quantity having magnitude p = (q × a) and direction from negative charge to positive charge.

[In chemistry, the direction of dipole moment is assumed to be from positive to negative charge.] The C.G.S unit of electric dipole moment is **debye** which is defined as the dipole moment of two equal and opposite point charges each having charge 10^{-10} Franklin and separation of 1 Å, i.e.,

1 debye (D) = $10^{-10} \times 10^{-8} = 10^{-18}$ Fr × cm

or $1\ D = 10^{-18} \times \frac{C}{3\times10^9} \times 10^{-2}\ m = 3.3 \times 10^{-30}\ C \times m.$

S.I. Unit is coulomb × metre = C . m

Ex. A system has two charges $q_A = 2.5 \times 10^{-7}$ C and $q_B = -2.5 \times 10^{-7}$ C located at points A : (0, 0, – 0.15 m) and B ; (0, 0, + 0.15 m) respectively. What is the net charge and electric dipole moment of the system ?

Sol. Net charge = $2.5 \times 10^{-7} - 2.5 \times 10^{-7} = 0$

Electric dipole moment,

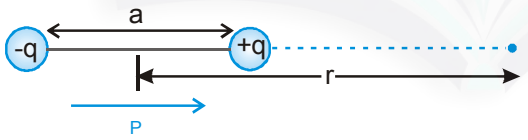
P = (Magnitude of charge) × (Separation between charges)

$= 2.5 \times 10^{-7}[0.15 + 0.15]$ C m $= 7.5 \times 10^{-8}$ C m

The direction of dipole moment is from B to A.

ELECTRIC FIELD INTENSITY DUE TO DIPOLE

(i) At the axial point :-



$\vec{E} = \frac{Kq}{\left(r-\frac{a}{2}\right)^2} - \frac{Kq}{\left(r+\frac{a}{2}\right)^2}$ (along the $\vec{P}$) $= \frac{Kq(2ra)}{\left(r^2-\frac{a^2}{4}\right)^2}\hat{P}$

If r >> a then,

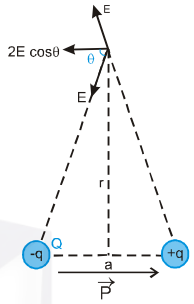
$\vec{E} = \frac{Kq\,2ra}{r^4}\hat{P} = \frac{2K\vec{P}}{r^3},$

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As the direction of electric field at axial position is along the dipole moment ($\vec{P}$)

So, $\vec{E}_{axial} = \frac{2K\vec{P}}{r^3}$

(ii) Electric field at perpendicular Bisector (Equatorial Position)



$E_{net} = 2\,E\cos\theta$ (along $-\hat{P}$)

$$\vec{E}_{net} = 2\left(\frac{Kq}{\left(\sqrt{r^2+\left(\frac{a}{2}\right)^2}\right)^2}\right)\frac{\frac{a}{2}}{\sqrt{r^2+\left(\frac{a}{2}\right)^2}}(-\hat{P}) = \frac{Kqa}{\left(r^2+\left(\frac{a}{2}\right)^2\right)^{3/2}}(-\hat{P})$$

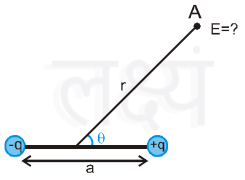
If r >> a then

$$\vec{E}_{net} = \frac{KP}{r^3}(-\hat{P})$$

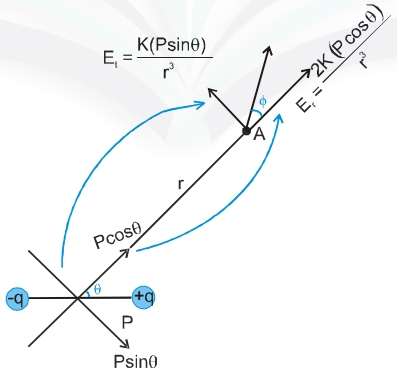
As the direction of $\vec{E}$ at equatorial position is opposite of $\vec{P}$ so we can write in vector form:

$$\vec{E}_{eqt} = -\frac{K\vec{P}}{r^3}$$

(iii) Electric field at general point (r, θ) :



For this, let's resolve the dipole moment $\vec{P}$ into components.



One component is along radial line (=P cosθ) and other component is $\perp_r$ to the radial line (=Psinθ)

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From the given figure $E_{net} = \sqrt{E_r^2 + E_t^2} = \sqrt{\left(\frac{2KP\cos\theta}{r^3}\right)^2 + \left(\frac{KP\sin\theta}{r^3}\right)^2} = \frac{KP}{r^3}\sqrt{1+3\cos^2\theta}$

$$\tan\phi = \frac{E_t}{E_r} = \frac{\frac{KP\sin\theta}{r^3}}{\frac{2KP\cos\theta}{r^3}} = \frac{\tan\theta}{2}$$

$$E_{net} = \frac{KP}{r^3}\sqrt{1+3\cos^2\theta} \; ; \qquad \tan\phi = \frac{\tan\theta}{2}$$

Ex. The electric field due to a short dipole at a distance r, on the axial line, from its mid point is the same as that of electric field at a distance r', on the equatorial line, from its mid-point. Determine the ratio $\frac{r}{r'}$.

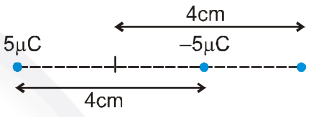
Sol. $\frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3} = \frac{1}{4\pi\varepsilon_0}\frac{p}{r'^3}$ or $\frac{2}{r^3} = \frac{1}{r'^3}$ or $\frac{r^3}{r'^3} = 2$ or, $\frac{r}{r'} = 2^{1/3}$

Ex. Two charges, each of 5 μC but opposite in sign, are placed 4 cm apart. Calculate the electric field intensity of a point that is at a distance 4 cm from the mid point on the axial line of the dipole.

Sol. We cannot use formula of short dipole here because distance of the point is comparable to the distance between the two point charges.

$q = 5 \times 10^{-6}$ C, $a = 4 \times 10^{-2}$ m, $r = 4 \times 10^{-2}$ m

$$E_{res} = E_+ + E_- = \frac{K(5\mu C)}{(2cm)^2} - \frac{K(5\mu C)}{(6cm)^2} = \frac{144}{144\times10^{-8}}\ NC^{-1} = 10^8\ N\,C^{-1}$$



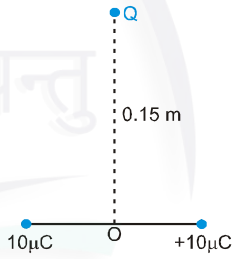
Ex. Two charges ± 10 μC are placed 5×10^{-3} m apart as shown in figure. Determine the electric field at a point Q which is 0.15 m away from O, on the equatorial line.

Sol. In the given problem, r >> a

$$\therefore \quad E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3} = \frac{1}{4\pi\varepsilon_0}\frac{q(a)}{r^3}$$

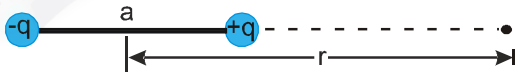
or $$E = 9\times10^9 \times \frac{10\times10^{-6}\times5\times10^{-3}}{0.15\times0.15\times0.15}\ NC^{-1}$$

$$= 1.33\times10^5\ NC^{-1}$$



ELECTRIC POTENTIAL DUE TO A SMALL DIPOLE

(i) Potential at axial position :



$$V = \frac{Kq}{\left(r-\frac{a}{2}\right)} + \frac{K(-q)}{\left(r+\frac{a}{2}\right)}$$

$$V = \frac{Kqa}{\left(r^2 - \left(\frac{a}{2}\right)^2\right)}$$

If r >> a then

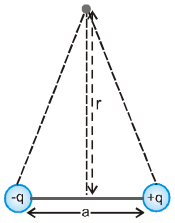
$$V = \frac{Kqa}{r^2}\ ; \qquad \text{where, } qa = p \qquad \therefore \quad V_{axial} = \frac{KP}{r^2}$$

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(ii) Potential at equatorial position :

$$V = \frac{Kq}{\sqrt{r^2 + \left(\frac{a}{2}\right)^2}} + \frac{K(-q)}{\sqrt{r^2 + \left(\frac{a}{2}\right)^2}} = 0$$

$$V_{eqt} = 0$$



(iii) Potential at general point (r,θ) :

Lets resolve the dipole moment $\vec{P}$ into components: Pcosθ along radial line and Psinθ $\perp_r$ to the radial line

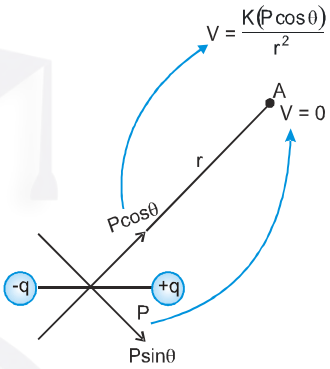
For the Pcosθ component, the point A is an axial point,

So, potential at A due to Pcosθ $= \frac{K(P\cos\theta)}{r^2}$

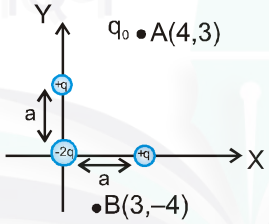
And for Psinθ component, the point A is an equatorial point,
So potential at A due to Psinθ $= 0$

$$V_{net} = \frac{K(P\cos\theta)}{r^2}$$

$$\therefore \quad V = \frac{K\left(\vec{P}.\vec{r}\right)}{r^3}$$



Ex. **(i)** Find potential at point A and B due to the small charge - system fixed near origin.(Distance between the charges is negligible).
(ii) Find work done to bring a test charge q_0 from point A to point B, slowly. All parameters are in S.I. units.



Sol. **(i)** Dipole moment of the system is

$$\vec{P} = (qa)\,\hat{i} + (qa)\,\hat{j}$$

Potential at point A due to the dipole

$$V_A = K\frac{(\vec{P}\cdot\vec{r})}{r^3} = \frac{K[(qa)\hat{i} + (qa)\hat{j}]\cdot(4\hat{i} + 3\hat{j})}{5^3} = \frac{k(qa)}{125}\,(7)$$

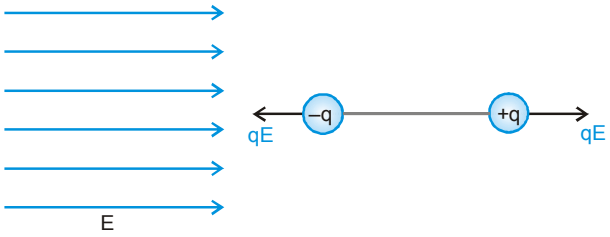
$$\Rightarrow \quad V_B = \frac{K\left[(qa)\hat{i} + (qa)\hat{j}\right]\cdot\left(3\hat{i} - 4\hat{j}\right)}{(5)^3} = \frac{-K(qa)}{125}$$

(ii) $$W_{A\to B} = U_B - U_A = q_0(V_B - V_A) = q_0\left[-\frac{K(qa)}{125} - \left(\frac{K(qa)(7)}{125}\right)\right] \Rightarrow W_{A\to B} = \frac{-K\,qq_0a}{125}\,(8)$$

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DIPOLE IN UNIFORM ELECTRIC FIELD

(i) Dipole is placed along electric field :



In this case, $F_{net} = 0$, $\tau_{net} = 0$, so it is an equilibrium state. And it is a stable equilibrium position.

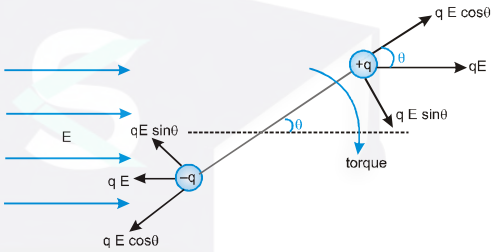
(ii) If the dipole is placed at angle θ from $\vec{E}$:-

In this case $F_{net} = 0$ but

Net torque $\tau = (qE\sin\theta)$ **(a)**

Here $qa = P \Rightarrow \tau = PE\sin\theta$

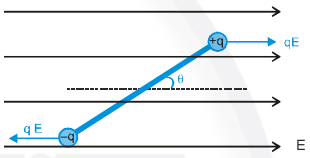
in vector form : $\vec{\tau} = \vec{P} \times \vec{E}$



Ex. A dipole is formed by two point charge –q and +q, each of mass m, and both the point charges are connected by a rod of length ℓ and mass m. This dipole is placed in uniform electric field $\vec{E}$. If the dipole is disturbed by a small angle θ from stable equilibrium position, prove that its motion will be almost SHM. Also find its time period.

Sol.

If the dipole is disturbed by θ angle,



$\tau_{net} = -PE\sin\theta$ (Here – ve sign indicates that direction of torque is opposite to θ)

If θ is very small, $\sin\theta \approx \theta$

$\therefore \quad \tau_{net} = -(PE)\theta$

$\tau_{net} \propto (-\theta)$ so motion will be almost SHM & C = PE (where, $P = q\ell$)

$\because \quad T = 2\pi\sqrt{\frac{I}{C}}$

$\therefore \quad T = 2m^{-}\sqrt{\frac{m\ell}{12} + 2m\left(\frac{\ell}{2}\right)^2}{P.E} = 2\pi\sqrt{\frac{\frac{m\ell}{12} + \frac{m\ell^2}{2}}{q\ell E}} = 2\pi\sqrt{\frac{7m\ell^2}{12q\ell E}} = 2\pi\sqrt{\frac{7m\ell}{12qE}} = T = \pi\sqrt{\frac{7m\ell}{3qE}}$

(iii) Potential energy of a dipole placed in uniform electric field :

$$U_B - U_A = -\int_A^B \vec{F}.\vec{dr} \qquad \text{(for translational motion)}$$

Here, $$U_B - U_A = -\int_A^B \vec{\tau}.d\vec{\theta} \qquad \text{(for rotational motion)}$$

In the case of dipole, at $\theta = 90°$, P.E. is assumed to be zero.

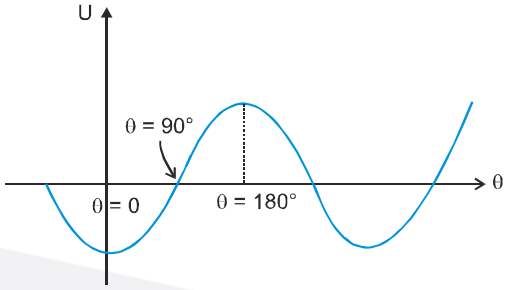
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$$U_\theta - U_{90^\circ} = -\int_{\theta=90^\circ}^{\theta=\theta} (-PE\sin\theta)(d\theta)$$ (As the direction of torque is opposite of θ)

$U_\theta - 0 = -PE\cos\theta$

$\theta = 90^\circ$ is chosen as reference,
so that the lower limit comes out to be zero.

$$U_\theta = -\vec{P}\cdot\vec{E}$$

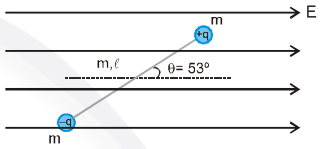


From the potential energy curve, we can conclude :

(i) At $\theta = 0$, there is minimum of P.E. so it is a stable equilibrium position.

(ii) At $\theta = 180^\circ$, there is maxima of P.E. so it is a position of unstable equilibrium.

Ex. Two point masses of mass m and equal and opposite charge of magnitude q are attached on the corners of a non-conducting uniform rod of mass m and the system is released from rest in uniform electric field E as shown in figure from $\theta = 53^\circ$



(i) Find angular acceleration of the rod just after releasing

(ii) What will be angular velocity of the rod when it passes through stable equilibrium.

(iii) Find work required to rotate the system by 180°.

Sol. **(i)** $\tau_{net} = PE\sin53^\circ = I\alpha$

$$\therefore \quad \alpha = \frac{(q\ell)E\left(\frac{4}{5}\right)}{\frac{m\ell^2}{12} + m\left(\frac{\ell}{2}\right)^2 + m\left(\frac{\ell}{2}\right)^2} = \frac{48qE}{35\,m\ell}$$

(ii) From energy conservation :

$K_i + U_i = K_f + U_f$

$$\therefore \quad 0 + (-PE\cos 53^\circ) = \frac{1}{2}I\omega^2 + (-PE\cos 0^\circ)$$

where $I = \frac{m\ell^2}{12} + m\left(\frac{\ell}{2}\right)^2 + m\left(\frac{\ell}{2}\right)^2 = \frac{7m\ell^2}{12}$ $\quad \therefore \quad \frac{1}{2}I\omega^2 = PE(1-3/5) = \frac{2}{5}PE$

$$\therefore \quad \frac{1}{2}\times\frac{7m\ell^2}{12}\times\omega^2 = \frac{2}{5}q\ell E \text{ or } \quad \omega = \sqrt{\frac{48qE}{35\,m\ell}}$$

(iii) $\because \quad W_{ext} = U_f - U_i$

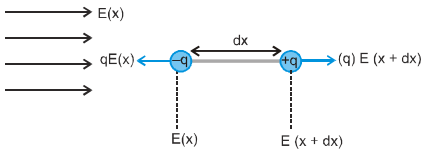
$$\therefore \quad W_{ext} = (-PE\cos(180^\circ + 53^\circ)) - (-PE\cos 53^\circ)$$

or $\quad W_{ext} = (q\ell)E\left(\frac{3}{5}\right) + (q\ell)E\left(\frac{3}{5}\right) \quad \Rightarrow \quad W_{ext} = \left(\frac{6}{5}\right)q\ell E$

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Dipole in Non-uniform Electric Field

If the dipole is placed along $\vec{E}$, (shown in figure)



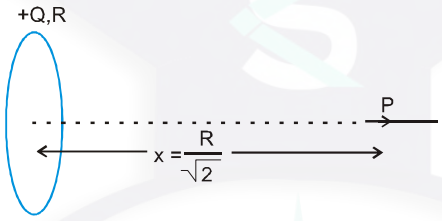
Then, Net force on the dipole :

$$F_{net} = q\,E(x+dx) - q\,E(x)$$

$$F_{net} = q\,\frac{E(x+dx)-E(x)}{dx}\,(dx) \quad ; \quad \text{here } (q\,(dx) = P)$$

$$\therefore\ F_{net} = P\left(\frac{dE}{dx}\right)$$

Ex. A short dipole is placed on the axis of a uniformly charged ring (total charge –Q, radius R) at a distance $\frac{R}{\sqrt{2}}$ from centre of ring as shown in figure. Find the Force on the dipole due to the ring



Sol. $\because \quad F = P\left(\frac{dE}{dx}\right)$

$$\therefore \quad F = P\,\frac{d}{dx}\left(\frac{KQx}{(R^2+x^2)^{3/2}}\right) ; \qquad \left(\text{at } x = \frac{R}{\sqrt{2}}\right)$$

Solving we get, $F = 0$

Force between a dipole and a point charge

Ex. A short dipole of dipole moment P is placed near a point charge Q as shown in figure. Find force on the dipole due to the point charge



Sol.



Force on the point charge due to the dipole

$$F = (Q)\,E_{dipole}$$

$$F = (Q)\left(\frac{2KP}{r^3}\right) \text{ (towards right)}$$

From action reaction concept, force on the dipole due to point charge will be equal to the force on charge due to dipole

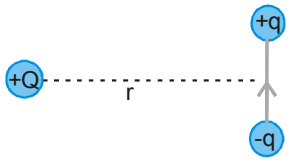
$$F = \frac{2KPQ}{r^3} \text{ (towards left)}$$

is force on dipole due to point Charge.

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FORCE BETWEEN TWO DIPOLES

Ex. A short dipole of dipole moment P is placed near a point charge Q as shown in figure. Find force on the dipole due to the point charge.



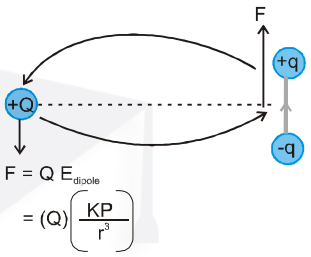
Sol. Force on the point charge due to dipole

$$F = (Q)(E_{dipole})$$

$$F = (Q)\left(\frac{KP}{r^3}\right)(\downarrow)$$

So force on the dipole due to the point charge will also be

$$F = \left(\frac{KPQ}{r^3}\right)(\uparrow)$$ (but in opposite direction) as shown



Ex. Find force on short dipole P_2 due to short dipole P_1 if they are placed at a distance r a part as shown in figure.



Sol. Force on P_2 due to P_1

$$F_2 = (P_2)\left(\frac{dE_1}{dr}\right)$$

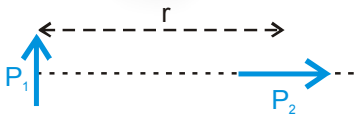


$$\therefore \quad F_2 = (P_2)\left(\frac{d}{dr}\left(\frac{2kP_1}{r^3}\right)\right)$$

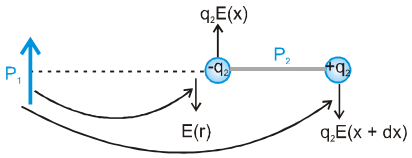
or $$F_2 = -\frac{6KP_1P_2}{r^4}$$

Here – sign indicates that this force will be attractive (opposite to r)

Ex. Find force on short dipole P_2 due to short dipole P_1 if they are placed a distance r apart as shown in figure.



Sol.



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$F_{net} = q_2 E(x+dx) - q_2 E(x)$

$F_{net} = q_2 \left(\frac{E(x+dx) - E(x)}{dx} \right) dx$ or $F_{net} = (P_2) \left(\frac{dE}{dx} \right)$

(Usually this formula is valid when the dipole is placed along $\vec{E}$. However, in this case also, we are getting the same formula)

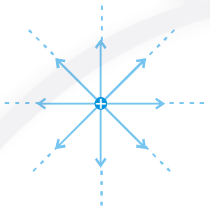
$\therefore F_{net} = (P_2) \left(\frac{d}{dr} \left(\frac{KP_1}{r^3} \right) \right) \Rightarrow F_{net} = \frac{3KP_1P_2}{r^4}$ (in magnitude) & (direction upwards)

Electric Lines of Force (ELOF)

The line of force in an electric field is an imaginary line, the tangent to which at any point on it represents the direction of electric field at the given point.

Properties

(i) Line of force originates out from a positive charge and terminates on a negative charge. If there is only one positive charge, then lines starts from positive charge and terminates at ∞. If there is only one negative charge, then lines starts from ∞ and terminates at negative charge.



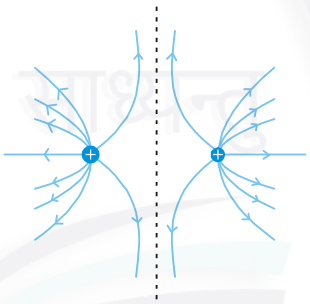
ELOF of Isolated positive charge



ELOF of Isolated negative charge



ELOF due to positive and negative charges



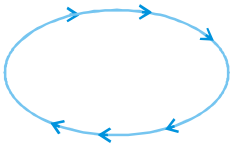
ELOF due to two positive charges

(ii) Two lines of force never intersect each other because there cannot be two directions of $\vec{E}$ at a single Point



impossilble

(iii) Electric lines of force produced by static charges do not form closed loop.
If lines of force make a closed loop, then work done to move a +q charge along the loop will be non-zero. So it will not be conservative field. So these type of lines of force are not possible in electrostatics.



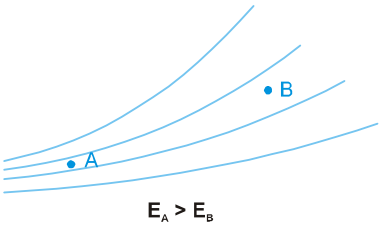
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(iv) The Number of lines per unit area (line density) represents the magnitude of electric field.

If lines are dense ⇒ E will be more

If Lines are rare ⇒ E will be less

and if E = O, no line of force will be found there



(v) Number of lines originating (terminating) at a charge is proportional to the magnitude of charge

Ex. If number of electric lines of force from charge q are 10, then find out number of electric lines of force from 2q charge.

Sol. No. of ELOF ∝ charge

$10 \propto q$

⇒ $20 \propto 2q$

So, number of ELOF will be 20.

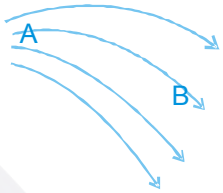
(vi) Electric lines of force end or start perpendicularly on the surface of a conductor.

(vii) Electric lines of force never enter into conductors.

Ex. Some electric lines of force are shown in figure. For points A and B

(A) $E_A > E_B$ **(B)** $E_B > E_A$

(C) $V_A > V_B$ **(D)** $V_B > V_A$

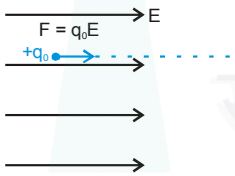


Sol. Lines are more dense at A, so $E_A > E_B$ In the direction of Electric field, potential decreases so $V_A > V_B$

Ex. If a charge is released in electric field, will it follow lines of force?

Sol. **Case I**

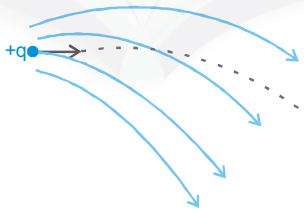
If lines of force are parallel (in uniform electric field) :-



In this type of field, if a charge is released, force on it will be q_oE and its direction will be along $\vec{E}$ .So the charge will move in a straight line , along the lines of force.

Case II

If lines of force are curved (in non-uniform electric field) :-



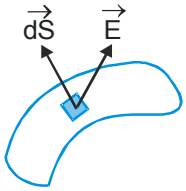
The charge will not follow lines of force

Ex. A charge + Q is fixed at a distance d in front of an infinite metal plate. Draw the lines of force indicating the directions clearly.

Sol. There will be induced charge on two surfaces of conducting plate, so ELOF will start from +Q charge and terminate at conductor and then will again start from other surface of conductor.

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Electric Flux



Consider some surface in an electric field $\vec{E}$. Let us select a small area element $\overrightarrow{dS}$ on this surface. The electric flux of the field over the area element is given by $d\phi_E = \vec{E}.\overrightarrow{dS}$

Direction of $\overrightarrow{dS}$ is normal to the surface. It is along $\hat{n}$

or $d\phi_E = EdS\cos\theta$

or $d\phi_E = (E\cos\theta)\,dS$

or $d\phi_E = E_n\,dS$

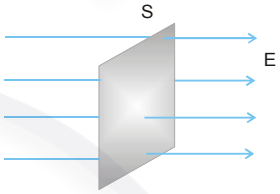
where E_n is the component of electric field in the direction of $\overrightarrow{dS}$.

The electric flux over the whole area is given by $\phi_E = \int_S \vec{E}.\overrightarrow{dS} = \int_S E_n dS$

If the electric field is uniform over that area then $\phi_E = \vec{E}\cdot\vec{S}$

Special Cases

Case I If the electric field is normal to the surface,

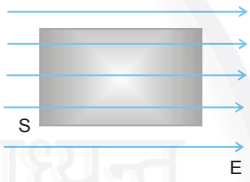


then angle of electric field $\vec{E}$ with normal will be zero

So $\phi = ES\cos 0$

or $\phi = ES$

Case II If electric field is parallel of the surface (grazing),



then angle made by $\vec{E}$ with normal = 90°

So $\phi = ES\cos 90° = 0$

Physical Meaning

The electric flux through a surface inside an electric field represents the total number of electric lines of force crossing the surface. It is a property of electric field

Unit

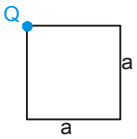
(i) The SI unit of electric flux is $Nm^2\,C^{-1}$ (Gauss) or $J\,m\,C^{-1}$.

(ii) Electric flux is a scalar quantity. (It can be positive, negative or zero)

Ex. The electric field in a region is given by $\vec{E} = \frac{3}{5}E_0\hat{i} + \frac{4}{5}E_0\hat{j}$ with $E_0 = 2.0\times10^3$ N/C. Find the flux of this field through a rectangular surface of area $0.2m^2$ parallel to the Y–Z plane.

Sol. $\phi_E = \vec{E}\cdot\vec{S} = \left(\frac{3}{5}E_0\hat{i} + \frac{4}{5}E_0\hat{j}\right).\left(0.2\hat{i}\right) = 240\frac{N-m^2}{C}$

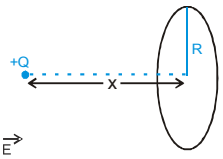
Ex. A point charge Q is placed at the corner of a square of side a, then find the flux through the square.



Sol. The electric field due to Q at any point of the square will be along the plane of square and the electric field lines are perpendicular to square ; so $\phi = 0$.
In other words we can say that no line is crossing the square so, flux = 0.

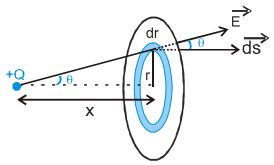
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Ex. Find the electric flux due to a point charge 'Q' through the circular region of radius R if the charge is placed on the axis of ring at a distance x.



Sol.

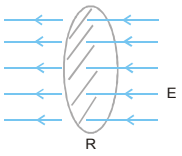
We can divide the circular region into small rings.
Lets take a ring of radius r and width dr.
Flux through this small element
$d\phi = E\, ds \cos\theta$



$$\therefore \quad \phi_{net} = \int E\, ds \cos\theta = \int_{r=0}^{r=R} \frac{KQ}{(x^2+r^2)} (2\pi r\, dr) \left(\frac{x}{\sqrt{x^2+r^2}}\right) = \frac{Q}{2\epsilon_0}\left[1 - \frac{x}{\sqrt{x^2+R^2}}\right]$$

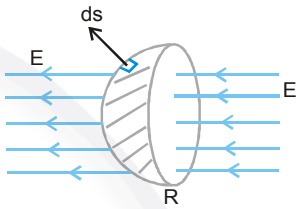
Case-III

Curved surface in uniform electric field
Suppose a circular surface of radius R is placed in a uniform electric field as shown.



Flux passing through the surface $\phi = E(\pi R^2)$

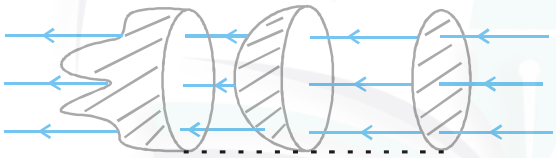
(ii) Now suppose, a hemispherical surface, is placed in the electric field. Flux through hemispherical surface:
$\phi = \int E ds \cos\theta$
$\phi = E \int ds \cos\theta$
where, $\int ds \cos\theta$ is
projection of the spherical surface Area on base.



& $\int ds \cos\theta = \pi R^2$

So, $\phi = E(\pi R^2)$ = same Ans. as in previous case
So, we can conclude that

If the number of electric field lines passing through two surfaces are same, then flux passing through these surfaces will also be same, irrespective of the shape of surface

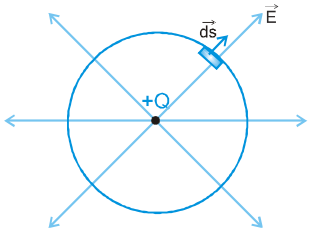


$\phi_1 = \phi_2 = \phi_3 = E(\pi R^2)$

Case IV

Flux through a closed surface

Suppose there is a spherical surface and a charge 'q' is placed at centre.
$\therefore$ Flux through the spherical surface



$$\phi = \int \vec{E} \cdot \vec{ds} = \int E\, ds \quad (\text{as } \vec{E} \text{ is along } \vec{ds} \text{ (normal)})$$

$$\therefore \quad \phi = \frac{1}{4\pi\varepsilon_o} \frac{Q}{R^2} \int ds \qquad \text{where,} \int ds = 4\pi R^2$$

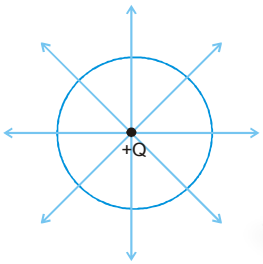
$$\phi = \left(\frac{1}{4\pi\varepsilon_0} \frac{Q}{R^2}\right)(4\pi R^2) \Rightarrow \phi = \frac{Q}{\varepsilon_o}$$

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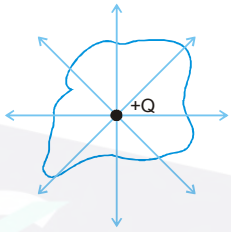
Now if the charge Q is enclosed by any other closed surface, still same no of lines of force will pass through the surface.

So, here also flux will be $\phi = \frac{Q}{\varepsilon_o}$. That's what Gauss Theorem is.

$\phi = \frac{Q}{\varepsilon_o}$



$\phi = \frac{Q}{\varepsilon_o}$



Gauss's Law in Electrostatics or Gauss's theorem

This law was stated by a mathematician Karl F Gauss. This law gives the relation between the electric field at a point on a closed surface and the net charge enclosed by that surface. This surface is called Gaussian surface. It is a closed hypothetical surface. Its validity is shown by experiments. It is used to determine the electric field due to some symmetric charge distributions.

Statement and Details

Gauss's law is stated as given below :

The surface integral of the electric field intensity over any closed hypothetical surface (called Gaussian surface) in free space is equal to $\frac{1}{\varepsilon_0}$ times the total charge enclosed within the surface. Here, ε_0 is the permittivity of free space.

If S is the Gaussian surface and $\sum_{i=1}^{n} q_i$ is the total charge enclosed by the Gaussian surface, then according to Gauss's law,

$$\phi_E = \oint \vec{E} \cdot \overrightarrow{dS} = \frac{1}{\varepsilon_0} \sum_{i=1}^{n} q_i .$$

The circle on the sign of integration indicates that the integration is to be carried out over the closed surface.

(i) Flux through Gaussian surface is independent of its shape.

(ii) Flux through Gaussian surface depends only on total charge present inside Gaussian surface.

(iii) Flux through Gaussian surface is independent of position of charges inside Gaussian surface.

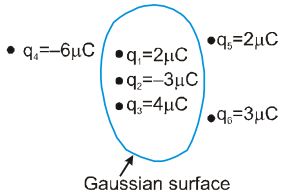
(iv) Electric field intensity at the Gaussian surface is due to all the charges present inside as well as outside the Gaussian surface.

(v) In a closed surface incoming flux is taken negative, while outgoing flux is taken positive, because $\hat{n}$ is taken positive in outward direction.

(vi) In a Gaussian surface, $\phi = 0$ does not imply $E = 0$ at every point of the surface but $E = 0$ at every point implies $\phi = 0$.

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Ex. Find out flux through the given Gaussian surface.



Sol. $\phi = \frac{Q_{in}}{\varepsilon_0} = \frac{2\mu C - 3\mu C + 4\mu C}{\varepsilon_0} = \frac{3\times10^{-6}}{\varepsilon_0}$ Nm²/C

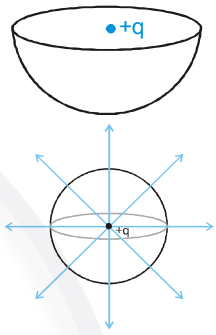
Ex. If a point charge q is placed at the centre of a cube, then find out flux through any one face of cube.

Sol. Flux through all 6 faces = $\frac{q}{\varepsilon_0}$. Since, all the surfaces are symmetrical

So, flux through one face = $\frac{1}{6}\frac{q}{\varepsilon_0}$

Flux through open surfaces using Gauss's Theorem

Ex. A point charge +q is placed at the centre of curvature of a hemisphere. Find flux through the hemispherical surface.



Sol. Lets put an upper half hemisphere.

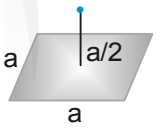
Now, flux passing through the entire sphere = $\frac{q}{\varepsilon_0}$

As the charge q is symmetrical to the upper half and lower half hemi-spheres , so half-half flux will emit from both the surfaces.

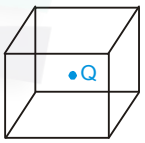
Flux emitting from lower half surface = $\frac{q}{2\varepsilon_0}$

Flux emitting from upper half surface = $\frac{q}{2\varepsilon_0}$

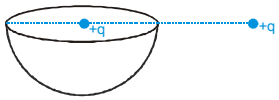
Ex. A charge Q is placed at a distance a/2 above the centre of a horizontal, square surface of edge a as shown in figure. Find the flux of the electric field through the square surface.



Sol. We can consider imaginary faces of cube such that the charge lies at the centre of the cube. Due to symmetry, we can say that flux through the given area (which is one face of cube), $\phi = \frac{Q}{6\varepsilon_0}$

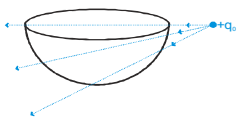


Ex. Find flux through the hemispherical surface



Sol. **(i)** Flux through the hemispherical surface due to +q = $\frac{q}{2\varepsilon_0}$ (we have seen in previous examples)

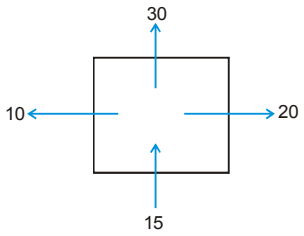
(ii) Flux through the hemispherical surface due to $+q_0$ is 0, because due to $+q_0$, field lines entering the surface = field lines coming out of the surface.



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Finding q_{in} from flux

Ex. Flux (in S.I.units) coming out and entering a closed surface is shown in the figure . Find charge enclosed by the closed surface.



Sol. Net flux through the closed surface = + 20 + 30 + 10 -15 = 45 N.m²/c
From Gauss`s theorem :

$$\phi_{net} = \frac{q_{in}}{\varepsilon_0} \quad \text{or} \quad 45 = \frac{q_{in}}{\varepsilon_0}$$

$$\therefore \quad q_{in} = (45)\varepsilon_0$$

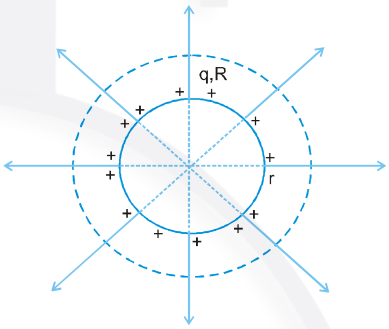
Finding electric field from Gauss`s Theorem

From Gauss`s theorem, we can say

$$\int \vec{E}.\vec{ds} = \phi_{net} = \frac{q_{in}}{\varepsilon_0}$$

Finding E due to a spherical shell

(a) Electric field outside the Sphere



Since, electric field due to a shell will be radially outwards.
So lets choose a spherical Gaussian surface Applying Gauss`s theorem for this spherical Gaussian surface,

$$\int \vec{E}\,\vec{ds} = \phi_{net} = \frac{q_{in}}{\varepsilon_o} = \frac{q}{\varepsilon_o}$$

$$\downarrow$$

$$\int |\vec{E}||\vec{ds}|\cos 0 \quad \text{(because } \vec{E} \text{ is normal to the surface)}$$

$$\downarrow$$

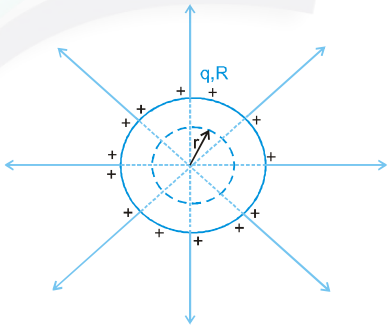
$$E\int ds \quad \text{(because value of E is constant at the surface)}$$

$$E\,(4\pi r^2) \; (\therefore \int ds \text{ total area of the spherical surface} = 4\,\pi r^2)$$

$$\Rightarrow \quad E\,(4\pi r^2) = \frac{q_{in}}{\varepsilon_0} \quad \Rightarrow \quad \therefore E_{out} = \frac{q}{4\pi\varepsilon_o r^2}$$

(b) Electric field inside a spherical shell

Lets choose a spherical Gaussian surface inside the shell.
Applying Gauss`s theorem for this surface



$$\int \vec{E}\,\vec{ds} = \phi_{net} = \frac{q_{in}}{\varepsilon_0} = 0$$

$$\downarrow$$

$$\int |\vec{E}||\vec{ds}|\cos 0$$

$$\downarrow$$

$$E\int ds$$

$$\downarrow$$

$$E\,(4\pi r^2)$$

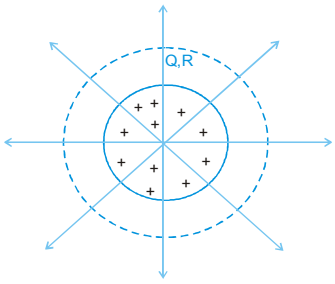
$$\Rightarrow \quad E\,(4\pi r^2) = 0 \qquad \therefore \quad E_{in} = 0$$

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Electric field due to solid sphere (having uniformly distributed charge Q and radius R)

(a) Electric field outside the sphere

Direction of electric field is radially outwards, so we will choose a spherical Gaussian surface Applying Gauss`s theorem



$$\int \vec{E}\,\vec{ds} = \phi_{net} = \frac{q_{in}}{\varepsilon_o} = \frac{Q}{\varepsilon_o}$$

$$\downarrow$$

$$\int |\vec{E}||\vec{ds}|\cos 0$$

$$\downarrow$$

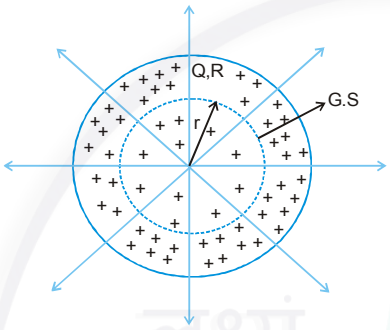
$$E\int ds$$

$$\downarrow$$

$$E(4\pi r^2)$$

$$\Rightarrow \quad E(4\pi r^2) = \frac{Q}{\varepsilon_o} \quad \Rightarrow \quad \text{or} \quad E_{out} = \frac{Q}{4\pi\varepsilon_o r^2}$$

(b) Electric field inside a solid sphere :



Q = Total charges contained by solid sphere
R = Radins of sphere

For this choose a spherical Gaussian surface inside the solid sphere Applying Gauss`s theorem for this surface

$$\int \vec{E}\,\vec{ds} = \phi_{net} = \frac{q_{in}}{\varepsilon_o} = \frac{\frac{Q}{\frac{4}{3}\pi R^3}\times\frac{4}{3}\pi r^3}{\varepsilon_o} = \frac{Qr^3}{\varepsilon_o R^3}$$

$$\downarrow$$

$$\int E\,ds$$

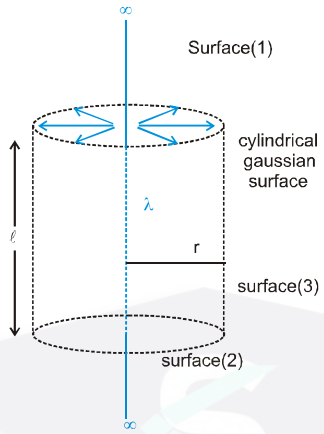
$$\downarrow$$

$$E(4\pi r^2) \quad \Rightarrow \quad E(4\pi r^2) = \frac{Qr^3}{\varepsilon_o R^3}$$

$$E = \frac{Q\ r}{4\pi\varepsilon_o R^3} \quad \Rightarrow \quad \therefore E_{in} = \frac{kQ}{R^3}\ r$$

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Electric field due to infinite line charge (having uniformly distributed charged of charge density l)



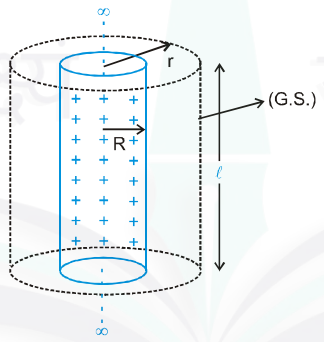
Electric field due to infinitely wire is radial so we will choose cylindrical Gaussian surface as shown is figure:

$$\phi_{net} \quad (\phi_1 = 0 \quad \phi_2 = 0 \quad \phi_3 \neq 0) \quad = \frac{q_{in}}{\varepsilon_o} = \frac{\lambda \ell}{\varepsilon_o}$$

$$\phi_3 = \int \vec{E}.\vec{ds} = \int E\, ds = E\int ds = E\,(2\pi r\ell)$$

$$\because E\,(2\pi r\ell) = \frac{\lambda \ell}{\varepsilon_o} \quad \Rightarrow \quad \therefore \quad E = \frac{\lambda}{2\pi\varepsilon_o r} = \frac{2k\lambda}{r}$$

Electric field due to infinitely long charged tube (having uniform surface charge density s and radius R))



(i) E outside the tube :- Lets choose a cylindrical Gaussian surface of length ℓ :

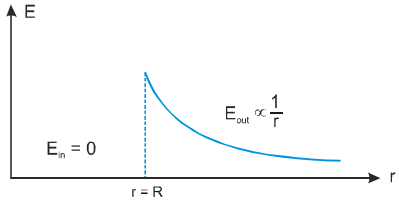
$$\therefore \phi_{net} = \frac{q_{in}}{\varepsilon_o} = \frac{\sigma 2\pi R\ell}{\varepsilon_o} \quad \Rightarrow \quad E_{out} \times 2\pi r\ell = \frac{\sigma 2\pi R\ell}{\varepsilon_o} \quad \therefore \quad E = \frac{\sigma R}{r\,\varepsilon_0}$$

(ii) E inside the tube :

Lets choose a cylindrical Gaussian surface inside the tube.

$$\phi_{net} = \frac{q_{in}}{\varepsilon_o} = 0$$

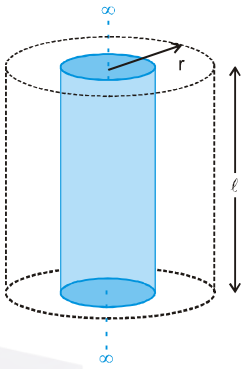
So $E_{in} = 0$



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E due to infinitely long solid cylinder of radius R (having uniformly distributed charge in volume (volume charge density ρ)) :

(i) E at outside point :-



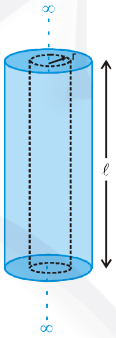
Lets choose a cylindrical Gaussian surface.
Applying Gauss`s theorem :

$$E \times 2\pi r\ell = \frac{q_{in}}{\varepsilon_o} = \frac{\rho \times \pi R^2 \ell}{\varepsilon_o}$$

$$E_{out} = \frac{\rho R^2}{2r\,\varepsilon_0}$$

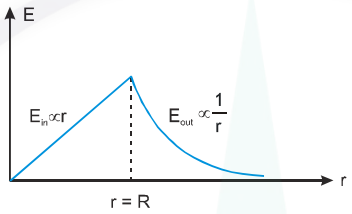
(ii) E at inside point :

Lets choose a cylindrical Gaussian surface inside the solid cylinder.
Applying Gauss`s theorem :



$$E \times 2\pi r\ell = \frac{q_{in}}{\varepsilon_o} = \frac{\rho \times \pi r^2 \ell}{\varepsilon_o}$$

$$E_{in} = \frac{\rho r}{2\varepsilon_0}$$



Conductor and it's properties [For electrostatic condition]

(i) Conductors are materials which contain large number of free electrons which can move freely inside the conductor.

(ii) In electrostatics conductors are always equipotential surfaces.

(iii) Charge always resides on outer surface of conductor.

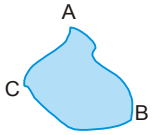
(iv) If there is a cavity inside the conductor having no charge then charge will always reside only on outer surface of conductor.

(v) Electric field is always perpendicular to conducting surface.

(vi) Electric lines of force never enter into conductors.

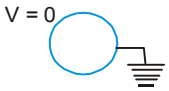
(vii) Electric field intensity near the conducting surface is given by formula

$$\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{n}$$



$$\vec{E_A} = \frac{\sigma_A}{\varepsilon_0}\hat{n} \;;\; \vec{E_B} = \frac{\sigma_B}{\varepsilon_0}\hat{n} \text{ and } \vec{E_C} = \frac{\sigma_C}{\varepsilon_0}\hat{n}$$

(viii) When a conductor is grounded its potential becomes zero.



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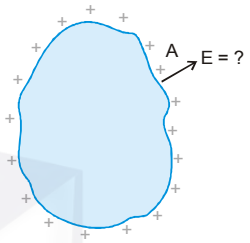
(ix) When an isolated conductor is grounded then its charge becomes zero.

(x) When two conductors are connected there will be charge flow till their potentials become equal.

(xi) Electric pressure : Electric pressure at the surface of a conductor is given by formula

$$P = \frac{\sigma^2}{2\varepsilon_0}, \text{ where } \sigma \text{ is the local surface charge density.}$$

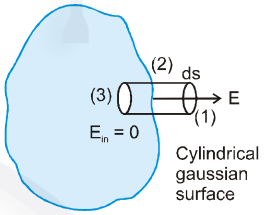
Finding field due to a conductor



Suppose we have a conductor and at any 'A', local surface charge density = σ. We have to find electric field just outside the conductor surface.

For this, let's consider a small cylindrical Gaussian surface, which is partly inside and partly outside the conductor surface, as shown in figure.

It has a small cross section area ds and negligible height.



Applying Gauss's theorem for this surface :

$\phi_{net} = \frac{q_{in}}{\varepsilon_0} = \frac{\sigma\, ds}{\varepsilon_0}$

- flux through surface (1) $\phi_1 = Eds$ (because $\vec{E}$ is normal to the surface of conductor)
- flux through surface (2) $\phi_2 = 0$ ($\vec{E}$ is normal to curved Gaussian surface)
- flux through surface (3) $\phi_3 = 0$ (as E inside the conductor = 0)

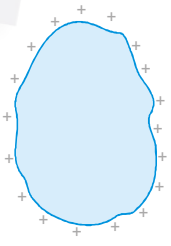
So, $Eds = \frac{\sigma ds}{\varepsilon_0} \Rightarrow E = \frac{\sigma}{\varepsilon_0}$

Electric field just outside the surface of conductor :

$$E = \frac{\sigma}{\varepsilon_0} \text{ (direction will be normal to the surface)}$$

in vector form: $\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{n}$ (Here, $\hat{n}$ = unit vector normal to the conductor surface)

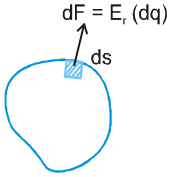
Electrostatic pressure at the surface of the conductor



uppose a conductor is given some charge. Due to repulsion, all the charges will reach the surface of the conductor. But the charges will still repel each other. So an outward force will be felt by each charge due to others. Due to this force, there will be some pressure at the surface, which is called electrostatic pressure.

To find the electrostatic pressure, lets take a small surface element having Area 'ds'.

Force on this element due to the remaining charges :



$$dF = \begin{pmatrix}\text{electric field at}\\ \text{that place due to}\\ \text{remainig charges}\end{pmatrix}\begin{pmatrix}\text{charge of}\\ \text{the small}\\ \text{element}\end{pmatrix}$$

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Let electric field at that point due to the remaining charges = E_r

and charge of the small element = dq = σds

$\Rightarrow$ $dF = (E_r)(dq) = (E_r)(\sigma ds)$

So, pressure on this small element

$$P = \frac{dF}{ds} = \frac{(E_r)(\sigma ds)}{ds}$$

$\Rightarrow$ $P = (E_r)(\sigma)$ .....(1)

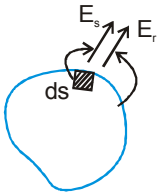
Now to find pressure, we have to find E_r (electric field at that position due to the remaining charges)

Suppose,

Electric field due to the small element near the surface = E_s

Electric field due to the remaining part near the surface = E_r

At a point just outside the surface, electric field due to the small element (E_s) will be normally out wards, and electric field due to the remaining part (E_r) will also be normally out wards.

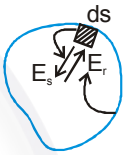


So Net electric field just outside the surface = $E_s + E_r$ and we have proved that

electric field just outside the conductor surface = $\frac{\sigma}{\varepsilon_o}$

$\Rightarrow$ $E_s + E_r = \frac{\sigma}{\varepsilon_o}$ .....(2)

Now, lets see the electric field just inside the metal surface. Here, electric field due to the remaining charges (E_r) will be in the same direction (normally outward), but the electric field due to the small element will be in opposite direction (normally inward)



So net electric field just inside the metal surface = $E_r - E_s$ and we know that electric field inside a conductor = 0

So, $E_r - E_s = 0$ $\Rightarrow$ $E_r = E_s$ .....(3)

from eqn. (2) and eqn. (3), we can say that :

$$2E_r = \frac{\sigma}{\varepsilon_o} \quad \Rightarrow \quad E_r = \frac{\sigma}{2\varepsilon_o}$$

Now, we can easily find the pressure from eqn. (1)

$$P = (E_r)(\sigma) = \frac{\sigma}{2\varepsilon_o}(\sigma) = \frac{\sigma^2}{2\varepsilon_o}$$

So, electrostatic pressure at the surface of the conductor $P = \frac{\sigma^2}{2\varepsilon_o}$

where, σ = local surface charge density.

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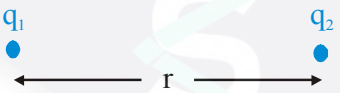
TIPS & FORMULA

1. Electric Charge

Charge of a material body is that property due to which it interacts with other charges. There are two kinds of charges-positive and negative. S.I. unit is coulomb. Charge is quantized, conserved, and additive.

2. Coulomb`s law

Force between two charges $\vec{F} = \frac{1}{4\pi \in_0 \in_r} \frac{q_1 q_2}{r^2} \hat{r}$ $\in_r$ = dielectric constant



Note : The Law is applicable only for static and point charges. Moving charges may result in magnetic interaction. And if charges are extended, induction may change the charge distribution.

3. Principle Of Superposition

Force on a point charge due to many charges is given by

$$\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + ...$$

Note : The force due to one charge is not affected by the presence of other charges.

4. Electric Field or Electric Intensity or Electric Field Strength (Vector Quantity)

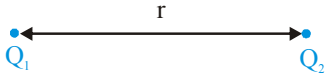
In the surrounding region of a charge there exist a physical property due to which other charge experiences a force. The direction of electric field is direction of force experienced by a positively charged particle and the magnitude of the field (electric field intensity) is the force experienced by a unit charge.

$$\vec{E} = \frac{\vec{F}}{q} \text{ unit is N/C or V/m.}$$

5. Electric field intensity due to charge Q

$$\vec{E} = \lim_{q_0 \to 0} \frac{\vec{F}}{q_0} = \frac{1}{4\pi \in_0} \frac{Q}{r^2} \hat{r}$$

6. Null point for two charges



If $|Q_1| > |Q_2|$

$\Rightarrow$ Null point near Q2

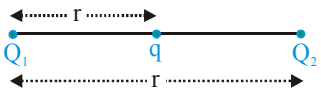
$$x = \frac{\sqrt{Q_1}\, r}{\sqrt{Q_1} \pm \sqrt{Q_2}}$$

(+) for like charges

(–) for unlike charges

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7. Equilibrium of three point charges

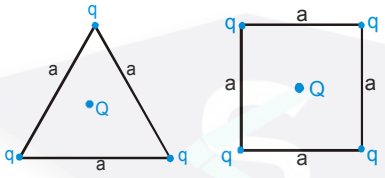


(i) Two charges must be of like nature.

(ii) Third charge should be unlike nature.

$$x = \frac{\sqrt{Q_1}}{\sqrt{Q_1} \pm \sqrt{Q_2}} r \qquad \text{and} \qquad q = \frac{-Q_1 Q_2}{\left(\sqrt{Q_1} + \sqrt{Q_2}\right)^2}$$

8. Equilibrium of symmetric geometrical point charged system



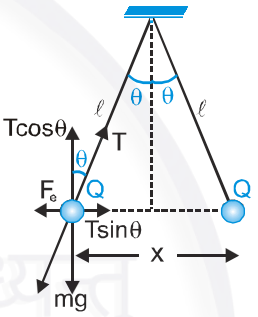
Value of Q at centre for which system to be in state of equilibrium

(a) For equilateral triangle $Q = \frac{-q}{\sqrt{3}}$ **(b)** For square $Q = \frac{-q\left(2\sqrt{2}+1\right)}{4}$

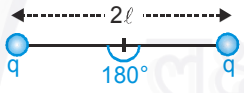
9. Equilibrium of suspended point charge system

For equilibrium position

$$T\cos\theta = mg \;\&\; T\sin\theta = F_e = \frac{kQ^2}{x^2} \Rightarrow \tan\theta = \frac{F_e}{mg} = \frac{kQ^2}{x^2 mg}$$



If whole set up is taken into an artifical satelite ($g_{eff} \simeq 0$)



$$T = F_e = \frac{kq^2}{4\ell^2}$$

10. Electric potential difference $\Delta V = \frac{\text{work}}{\text{charge}} = W/q$

11. Electric potential $V_p = -\int_{\infty}^{P} \vec{E}.\vec{dr}$

It is the work done against the field to take a unit positive charge from infinity (reference point) to the given point

(i) For point charge : $V = K\frac{q}{r}$ **(ii)** For several point charges : $V = K\sum\frac{q_1}{r_1}$

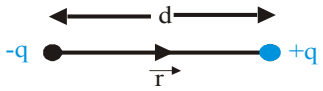
12. Relation between $\vec{E}$ & V

$$\vec{E} = -\text{grad } V = -\nabla V \;,\; E = -\frac{\partial V}{\partial r};\; \vec{E} = -\frac{\partial V}{\partial x}\hat{i} - \frac{\partial V}{\partial y}\hat{j} - \frac{\partial V}{\partial z}\hat{k} \;,\; V = \int -\vec{E}.\vec{dr}$$

13. Electrical potential energy of two charges : $U = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r}$

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14. Electric dipole



(a) Electric dipole moment $p = qd$

(b) Torque on dipole placed in uniform electric field $\vec{\tau} = \vec{p} \times \vec{E}$

(c) Work done in rotating dipole placed in uniform electric field

$$W = \int \tau d\theta = \int_{\theta_0}^{\theta} PE \sin\theta d\theta = pE(\cos\theta_0 - \cos\theta)$$

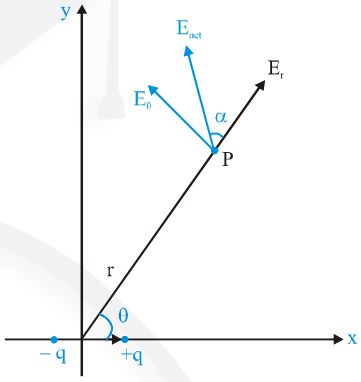
(d) Potential energy of dipole placed in an uniform field $U = -\vec{p}.\vec{E}$

(e) At a point which is at a distance r from dipole midpoint and making angle θ with dipole axis.

(1) Potential $V = \frac{1}{4\pi \in_0} \frac{p\cos\theta}{r^2}$

(2) Electric field $E = \frac{1}{4\pi \in_0} \frac{p\sqrt{1+3\cos^2\theta}}{r^3}$

(3) Direction $\tan\alpha = \frac{E_\theta}{E_r} = \frac{1}{2}\tan\theta$



(f) Electric field at axial point (or End-on) $\vec{E} = \frac{1}{4\pi \in_0} \frac{2\vec{p}}{r^3}$ of dipole

(g) Electric field at equatorial position (Broad-on) of dipole $\vec{E} = \frac{1}{4\pi \in_0} \frac{(-\vec{p})}{r^3}$

15. Equipotential Surface And Equipotential Region

In an electric filed the locus of points of equal potential is called an equipotential surface. An equipotential surface and the electric field line meet at right angles. The region where E = 0, Potential of the whole region must remains constant as no work is done in displacement of charge in it. It is called as equipotential region like conducting bodies.

16. Mutual Potential Energy Or Interaction Energy

"The work to be done to integrate the charge system".

For 2 particle system $U_{mutual} = \frac{q_1 q_2}{4\pi\varepsilon_0 r}$

For 3 particle system $U_{mutual} = \frac{q_1 q_2}{4\pi\varepsilon_0 r_{12}} + \frac{q_2 q_3}{4\pi\varepsilon_0 r_{23}} + \frac{q_3 q_1}{4\pi\varepsilon_0 r_{31}}$

For n particle there will be $\frac{n(n-1)}{2}$ terms.

Total energy of a system $= U_{self} + U_{mutual}$

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17. Electric flux : $\phi = \int \vec{E}.\vec{ds}$

(a) For uniform electric field ; $\phi = \vec{E}.\vec{A} = EA\cos\theta$ where θ = angle between $\vec{E}$ & area vector $\left(\vec{A}\right)$. Flux is contributed only due to the component of electric field which is perpendicular to the plane.

(b) If $\vec{E}$ is not uniform throughout the area A, then $\phi = \int \vec{E}.d\vec{A}$

18. Gauss`s Law : $\oint \vec{E}.d\vec{s} = \frac{\sum q}{\epsilon_0}$ (Applicable only to closed surface)

Net flux emerging out of a closed surface is $\frac{q_{en}}{\varepsilon_0}$.

$\phi = \oint \vec{E}.d\vec{A} = \frac{q_{en}}{\varepsilon_0}$ where q_{en} = net charge enclosed by the closed surface ϕ does not depend on the

(a) Shape and size of the closed surface

(b) The charges located outside the closed surface.

19. For a conducting sphere

(a) For $r \geq R : E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}, V = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$

(b) For $r < R : E = 0, V = \frac{1}{4\pi\epsilon_0}\frac{q}{R}$

20. For a non - conducting sphere

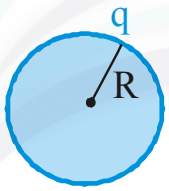
(a) For $r \geq R : E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}, V = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$

(b) For $r < R : E = \frac{1}{4\pi\epsilon_0}\frac{qr}{R^3}, V = \frac{1}{4\pi\epsilon_0}\frac{q\left(3R^2 - r^2\right)}{2R^3}$

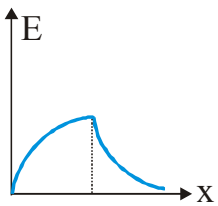
21. For a conducting/non conducting spherical shell

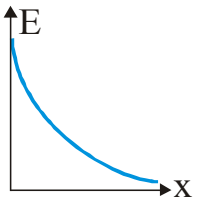
(i) For $r \geq R : E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}, V = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$

(ii) For $r < R : E = 0, V = \frac{1}{4\pi\epsilon_0}\frac{q}{R}$

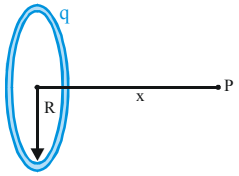


22. For a charged circular ring





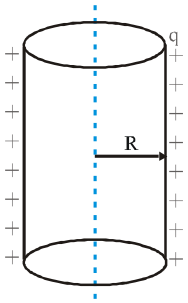
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$$E_P = \frac{1}{4\pi \in_0}\frac{qx}{\left(x^2+R^2\right)^{3/2}},\ V_P = \frac{1}{4\pi \in_0}\frac{q}{\left(x^2+R^2\right)^{1/2}}$$

Electric field will be maximum at $x = \frac{\pm R}{\sqrt{2}}$

23. For a charge long conducting cylinder



(a) For $r \geq R : E = \frac{q}{2\pi \in_0 r}$

(b) For $r < R : E = 0$

24. Electric field intensity at a point near a charged conductor $E = \frac{\sigma}{\in_0}$

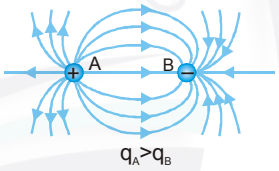
25. Mechanical pressure on a charged conductor $P = \frac{\sigma^2}{2 \in_0}$

26. For non-conducting long sheet of surface charge density σ $E = \frac{\sigma}{2 \in_0}$

27. For conducting long sheet of surface charge density $E = \frac{\sigma}{\in_0}$

28. Energy density in electric field

29. Electric lines of force



Electric lines of electrostatic field following properties

(a) Imaginary

(b) Can never be closed each other

(c) Can never be closed loops

(d) The number of lines originating or terminating on a charge is proportional to the magnitude of charge. In rationalised MKS system $(1/\varepsilon_0)$ electric lines are associated with it (called flux) will be q/ε_0.

(e) Lines of force ends or starts normally at the surface of a conductor.

(f) If there is no electric field there will be no lines of force.

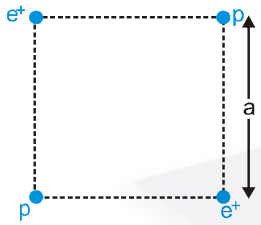
(g) Lines of forceper unit area normal to the area at a point represents magnitude of intensity, crowded lines represent strong field while distant lines weak field.

(h) Tangent to the line of force at a point is an electric field gives the direction of intensity.

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SOLVED EXAMPLE

Ex. 1 Two positrons (e^+) and two protons (P) are kept on four corners of a square of side a as shown in figure. The mass of proton is much larger than the mass of positron. Let q denotes the charge on the proton as well as the positron then the kinetic energies of one of the positrons and one of the protons respectively after a very long time will be –



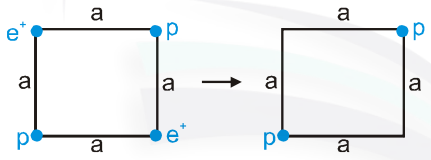
(A) $\frac{q^2}{4\pi\epsilon_0 a}\left(1+\frac{1}{2\sqrt{2}}\right), \frac{q^2}{4\pi\epsilon_0 a}\left(1+\frac{1}{2\sqrt{2}}\right)$

(B) $\frac{q^2}{2\pi\epsilon_0 a}, \frac{q^2}{4\sqrt{2}\pi\epsilon_0 a}$

(C) $\frac{q^2}{4\pi\epsilon_0 a}, \frac{q^2}{4\pi\epsilon_0 a}$

(D) $\frac{q^2}{2\pi\epsilon_0 a}\left(1+\frac{1}{4\sqrt{2}}\right), \frac{q^2}{8\sqrt{2}\pi\epsilon_0 a}$

Sol. As mass of proton >>> mass of positron so initial acceleration of positron is much larger than proton. Therefore positron reach far away in very short time as compare to proton.



$$2K_{e^+} = \left(\frac{4kq^2}{a}+\frac{2kq^2}{a\sqrt{2}}\right)-\frac{kq^2}{a\sqrt{2}}$$

$$\Rightarrow K_{e^+} = \frac{q^2}{2\pi\epsilon_0 a}\left(1+\frac{1}{4\sqrt{2}}\right) \text{ and}$$

$$2K_p = \frac{kq^2}{a\sqrt{2}} - 0 \Rightarrow K_p = \frac{q^2}{8\sqrt{2}\pi\epsilon_0 a}$$

Ex. 2 For a spherically symmetrical charge distribution, electric field at a distance r from the centre of sphere is $\vec{E} = kr^7\hat{r}$, where k is a constant. What will be the volume charge density at a distance r from the centre of sphere ?

(A) $\rho = 9k\varepsilon_0 r^6$ **(B)** $\rho = 5k\varepsilon_0 r^3$

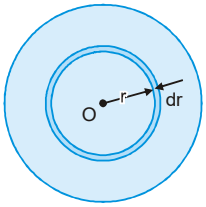
(C) $\rho = 3k\varepsilon_0 r^4$ **(D)** $\rho = 9k\varepsilon_0 r^0$

Sol. By using Gauss law $\oint\vec{E}\cdot d\vec{S} = \frac{q}{\epsilon_0}$

$$\Rightarrow (E)(4\pi r^2) = \frac{\int\rho(4\pi r^2 dr)}{\epsilon_0}$$

(Note : Check dimensionally that $\rho \propto r^6$)

$$(kr^7)(4\pi r^2) = \frac{\int\rho(4\pi r^2 dr)}{\epsilon_0}$$



$$\Rightarrow k\varepsilon_0 r^9 = \int\rho r^2 dr$$

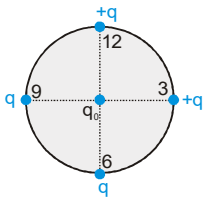
Ex. 3 Four charges are placed at the circumference of a dial clock as shown in figure. If the clock has only hour hand, then the resultant force on a charge q_0 placed at the centre, points in the direction which shows the time as :–

(A) 1:30

(B) 7:30

(C) 4:30

(D) 10:30



Sol. **(B)**

Ex. 4 A small electric dipole is placed at origin with its dipole moment directed along positive x-axis. The direction of electric field at point $(2, 2\sqrt{2}, 0)$ is

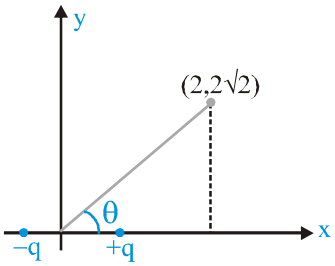
(A) along z-axis

(B) along y-axis

(C) along negative y-axis

(D) along negative z-axis

Sol.



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$$\tan\theta = \frac{y}{x} = \sqrt{2}; \cot\theta = \frac{1}{\sqrt{2}} \text{ Also}$$

$$\tan\alpha = \frac{\tan\theta}{2} = \frac{1}{\sqrt{2}} = \cot\theta$$

$\Rightarrow \theta + \alpha = 90°$ i.e., $\vec{E}$ is along positive y-axis.

Ex. 5 Uniform electric field of magnitude 100 V/m in space is directed along the line y= 3 + x. Find the potential difference between point A (3, 1) & B (1,3).

(A) 100 V **(B)** 200√2V

(C) 200 V **(D)** zero

Sol. Slope of line AB $= \frac{3-1}{1-3} = -1$ which is perpendicular to direction of electric field.

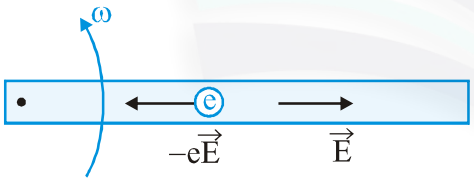
Ex. 6 A metallic rod of length *l* rotates at angular velocity ω about an axis passing through one end and perpendiuclar to the rod. If mass of electron is m and its charge is –e then the magnitude of potential difference between its two ends is

(A) $\frac{m\omega^2\ell^2}{(2e)}$ **(B)** $\frac{m\omega^2\ell^2}{e}$

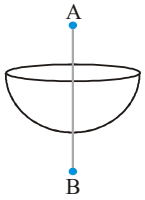
(C) $\frac{m\omega^2\ell}{e}$ **(D)** None of these

Sol. When rod rotates the centripetal acceleration of electron comes from electric field $E = \frac{mr\omega^2}{e}$

Thus, $\Delta V = -\int \vec{E}.d\vec{r} = -\int_0^{\ell} \frac{mr\omega^2}{e} dr = \frac{m\omega^2\ell^2}{2e}$



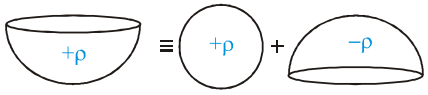
Ex. 7 The diagram shows a uniformly charged hemisphere of radius R. It has volume charge density ρ. If the electric field at a point 2R distance above its centre is E then what is the electric field at the point which is 2R below its centre?



(A) $\frac{\rho R}{6\varepsilon_0} + E$ **(B)** $\frac{\rho R}{12\varepsilon_0} - E$

(C) $\frac{-\rho R}{6\varepsilon_0} + E$ **(D)** $\frac{\rho R}{24\varepsilon_0} + E$

Sol.

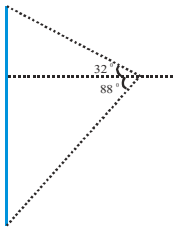


Apply principle of superposition

Electric field due to a uniformly charged sphere =

$$\frac{\rho R}{12\varepsilon_0}; E_{resultant} = \frac{\rho R}{12\,\epsilon_0} - E$$

Ex. 8 Consider a finite charged rod. Electric field at Point P (shown) makes an angle θ with horizontal dotted line then angle θ is :-



(A) 60°

(B) 28°

(C) 44°

(D) information insufficient

Sol. Required angle $= \frac{\theta_2 - \theta_1}{2} = \frac{88^0 - 32^0}{2} = \frac{56^0}{2}$

$= 28^0$

Ex. 9 The electric potential in a region is given by the relation $V(x) = 4 + 5x^2$. If a dipole is placed at position (–1,0) with dipole moment $\vec{p}$ pointing along positive Y-direction, then

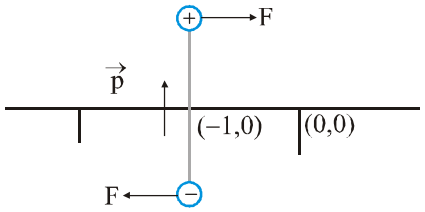
(A) Net force on the dipole is zero.

(B) Net torque on the dipole is zero

(C) Net torque on the dipole is not zero and it is in clockwise direction

(D) Net torque on the dipole is not zero and it is in anticlockwise direction

Sol. $V(x) = 4 + 5x^2 \Rightarrow \vec{E} = 10x\hat{i}$

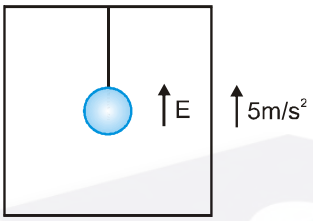


∴ Net force will be zero and torque not zero and rotation will be along clockwise direction

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Ex. 10 A simple pendulum is suspended in a lift which is going up with an acceleration of 5 m/s^2 . An electric field of magnitude 5 N/C and directed vertically upward is also present in the lift . The charge of the bob is 1 μC and mass is 1 mg . Taking g = π^2 and length of the simple pendulum 1m, find the time period of the simple pendulum (in sec).

Sol. $T = 2\pi\sqrt{\frac{\ell}{g_{eff}}}$



$g_{eff} = g - \frac{qE}{M} + 5$

$= 15 - \frac{1\times5\times10^{-6}}{1\times10^{-6}}$

$g_{eff} = 10 = \pi^2$

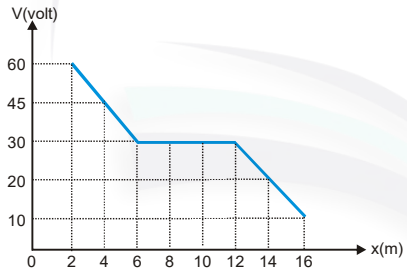
T = 2 sec

Ex. 11 The energy density u is plotted against the distance r from the centre of a spherical charge distribution on a log-log scale. Find the magnitude of slope of obtained straight line.

Sol. $u = \frac{1}{2}\epsilon_0 E^2 = \frac{1}{2}\epsilon_0\left(\frac{q}{4\pi\epsilon_0 r}\right)^2 = \frac{q^2}{32\pi^2\epsilon_0 r^2}$

$\Rightarrow \log u = \log\left(\frac{q^2}{32\pi^2\epsilon_0 r^2}\right) = \log k - 2\log r$

Ex.12 The variation of potential with distance x from a fixed point is shown in figure. Find the magnitude of the electric field (in V/m) at x =13m.



Sol. $E = -\frac{dV}{dx} = \frac{20}{4} = 5$ volt/meter

Ex. 13 An electric field is given by $\vec{E} = (y\hat{i} + x\hat{j})\frac{N}{C}$. Find the work done (in J) in moving a 1C charge from $\vec{r}_A = (2\hat{i} + 2\hat{j})$ m to $\vec{r}_B = (4\hat{i} + \hat{j})$ m .

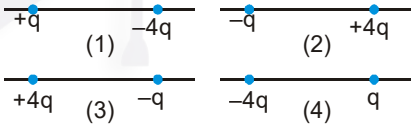
Sol. A= (2,2) and B = (4, 1);

$W_{A\to B} = q(V_B - V_A) = q\int_A^B dV = -\int_A^B q\vec{E}.d\vec{r}$

$= q\int_A^B (y\hat{i} + x\hat{j}).(dx\hat{i} + dy\hat{j}) = q\int_A^B (ydx + xdy)$

$= -q\int_{(2,2)}^{(4,1)} d(xy) = -q[xy]_{(2,2)}^{(4,1)} = -q[4-4] = 0$

Ex. 14 The figure shows four situations in which charges as indicated (q>0) are fixed on an axis. How many situations is there a point to the left of the charges where an electron would be in equilibrium?



Sol. **For (1)**

Let the electron be held at a distance x from +q charge.

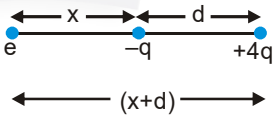


For equilibrium $\frac{q(-e)}{4\pi\epsilon_0 x^2} = \frac{(-e)(-4q)}{4\pi\epsilon_0 (x+d)^2}$

We can find value of x for which $F_{net} = 0$ which means that electron will be in equilibrium.

For (2) :

For equilibrium $\frac{(-e)(-q)}{4\pi\epsilon_0 x^2} = \frac{(-e)4q}{4\pi\epsilon_0 (x+d)^2}$



We can find value of x for which $F_{net} = 0$ which means that electron will be in equilibrium.

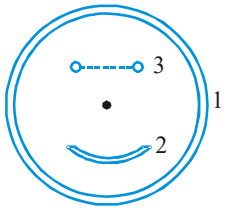
In case (3) and (4) the electron will not remain at rest, since it experiences a net non–zero force.

OR

Equilibrium is always found near the smaller charge

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Ex. 15 The arrangement shown consists of three elements.



(i) A thin rod of charge –3.0 μC that forms a full circle of radius 6.0 cm.

(ii) A second thin rod of charge 2.0 μC that forms a circular arc of radius 4.0 cm and concentric with the full circle, subtending an angle of 90° at the centre of the full circle.

(iii) An electric dipole with a dipole moment that is perpendicular to a radial line and has magnitude 1.28×10^{-21}C-m.

Find the net electric potential in volts at the centre.

Sol. Potential due to dipole at the centre of the circle is zero.

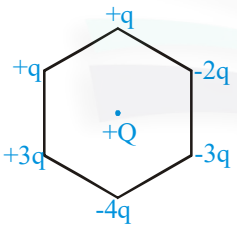
Potentials due to charge on circle = V_1

$$= \frac{K.(-3\times10^{-6})}{6\times10^{-2}}$$

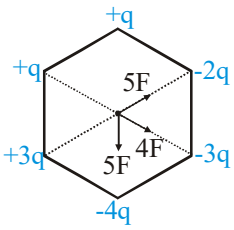
Potential due to arc $V_2 = \frac{K.(2\times10^{-6})}{4\times10^{-2}}$ Net potential

$= V_1 + V_2 = 0$

Ex. 16 Six charges are kept at the vertices of a regular hexagon as shown in the figure. If magnitude of force applied by +Q on +q charge is F, then net electric force on the +Q is nF. Find the value of n.



Sol.



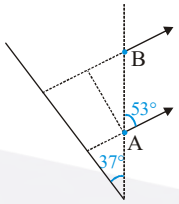
$F_{net} = 9F$

Ex. 17 An infinite plane of charge with $\sigma = 2\epsilon_0 \frac{C}{m^2}$ is tilted at a 37° angle to the vertical direction as shown below.



Find the potential difference, $V_A - V_B$ in volts, between points A and B at 5 m distance apart. (where B is vertically above A).

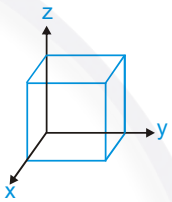
Sol.



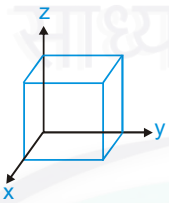
$$E = \frac{\sigma}{2\varepsilon_0} = 1 \text{ N/C}$$

$$\therefore V_B - V_A = -\int \vec{E}.d\vec{\ell} = \left(\frac{\sigma}{2\epsilon_0}\right)(5\cos53°) = 3V$$

Ex. 18 Electric field in a region is given by $\vec{E} = -4x\hat{i} + 6y\hat{j}$. The charge enclosed in the cube of side 1m oriented as shown in the diagram is given by $\alpha\epsilon_0$. Find the value of α.



Sol.



$\phi = (6y)\text{Area} - (4x)\text{Area} = 6\times1\times(1)^2 - 4\times1\times(1)^2$

$= 2$ therefore $\frac{q}{\varepsilon_0} = 2 \Rightarrow q = 2\varepsilon_0$

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Exercise # 1 SINGLE OBJECTIVE NEET LEVEL

1. The law, governing the force between electric charges is known as

(A) Ampere's law **(B)** Ohm's law

(C) Faraday's law **(D)** Coulomb's law

2. When the distance between the charged particles is halved, the force between them becomes

(A) One-fourth **(B)** Half

(C) Double **(D)** Four times

3. There are two charges +1 microcoulombs and +5 microcoulombs. The ratio of the forces acting on them will be

(A) 1 : 5 **(B)** 1 : 1

(C) 5 : 1 **(D)** 1 : 25

4. A charge q_1 exerts some force on a second charge q_2. If third charge q_3 is brought near, the force q_1 of exerted on q_2

(A) Decreases

(B) Increases

(C) Remains unchanged

(D) Increases if q_3 is of the same sign as q_1 and decreases if q_3 is of opposite sign

5. F_g and F_3 represents gravitational and electrostatic force respectively between electrons situated at a distance 10 cm. The ratio of F_g/F_e is of the order of

(A) 1042 **(B)** 10

(C) 1 **(D)** 10^{-43}

6. The ratio of the forces between two small spheres with constant charge (a) in air (b) in a medium of dielectric constant K is

(A) 1 : K **(B)** K : 1

(C) $1 : K^2$ **(D)** $K^2 : 1$

7. A soap bubble is given a negative charge, then its radius

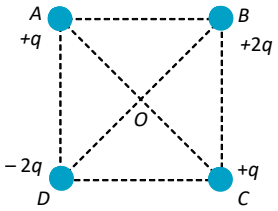
(A) Decreases

(B) Increases

(C) Remains unchanged

(D) Nothing can be predicted as information is insufficient

8. Four charges are arranged at the corners of a square ABCD, as shown in the adjoining figure. The force on the charge kept at the centre O is



(A) Zero

(B) Along the diagonal AC

(C) Along the diagonal BD

(D) Perpendicular to side AB

9. In the absence of other conductors, the surface charge density

(A) Is proportional to the charge on the conductor and its surface area

(B) Inversely proportional to the charge and directly proportional to the surface area

(C) Directly proportional to the charge and inversely proportional to the surface area

(D) Inversely proportional to the charge and the surface area

10. A body can be negatively charged by

(A) Giving excess of electrons to it

(B) Removing some electrons from it

(C) Giving some protons to it

(D) Removing some neutrons from it

11. A charge q is placed at the centre of the line joining two equal charges Q. The system of the three charges will be in equilibrium, if q is equal to

(A) $-\frac{Q}{2}$ **(B)** $-\frac{Q}{4}$

(C) $+\frac{Q}{4}$ **(D)** $+\frac{Q}{2}$

12. Inside a hollow charged spherical conductor, the potential

(A) Is constant

(B) Varies directly as the distance from the centre

(C) Varies inversely as the distance from the centre

(D) Varies inversely as the square of the distance from the centre

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13. Two small spheres each carrying a charge q are placed r metre apart. If one of the spheres is taken around the other one in a circular path of radius r, the work done will be equal to

(A) Force between them × r

(B) Force between them × 2πr

(C) Force between them / 2πr

(D) Zero

14. The electric charge in uniform motion produces

(A) An electric field only

(B) A magnetic field only

(C) Both electric and magnetic field

(D) Neither electric nor magnetic field

15. Two charged spheres of radii 10 *cm* and 15 *cm* are connected by a thin wire. No current will flow, if they have

(A) The same charge on each

(B) The same potential

(C) The same energy

(D) The same field on their surfaces

16. The electric field inside a spherical shell of uniform surface charge density is

(A) Zero

(B) Constant, less than zero

(C) Directly proportional to the distance from the centre

(D) None of the above

17. The electric potential V at any point O (x, y, z all in metres) in space is given by $V = 4x^2$ volt. The electric field at the point $(1m, 0, 2m)$ in $volt/metre$ is

(A) 8 along negative X – axis

(B) 8 along positive X – axis

(C) 16 along negative X – axis

(D) 16 along positiveZ – axis

18. A hollow metal sphere of radius 5 cm is charged so that the potential on its surface is 10 V. The potential at the centre of the sphere is

(A) 0 V

(B) 10 V

(C) Same as at point 5 cm away from the surface

(D) Same as at point 25 cm away from the surface

19. If a unit positive charge is taken from one point to another over an equipotential surface, then

(A) Work is done on the charge

(B) Work is done by the charge

(C) Work done is constant

(D) No work is done

20. Electric lines of force about negative point charge are

(A) Circular, anticlockwise **(B)** Circular, clockwise

(C) Radial, inward **(D)** Radial, outward

21. Charges of $+\frac{10}{3}\times 10^{-9}\,C$ are placed at each of the four corners of a square of side . The potential at the intersection of the diagonals is

(A) $1500\sqrt{2}$ volt **(B)** $1500\sqrt{2}$ volt

(C) $900\sqrt{2}\ volt$ **(D)** 900 volt

22. A uniform electric field having a magnitude and direction along the positive axis exists. If the potential is zero at , then its value at will be

(A) $V_{(x)} = +xE_0$ **(B)** $V_x = -xE_0$

(C) $V_x = +x^2E_0$ **(D)** $V_x = -x^2E_0$

23. Three charges are located at the vertices of an equilateral triangle. At the centre of the triangle

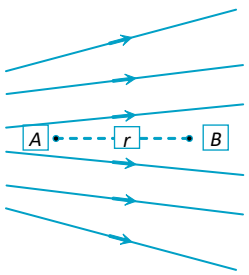
(A) The field is zero but potential is non-zero

(B) The field is non-zero but potential is zero

(C) Both field and potential are zero

(D) Both field and potential are non-zero

24. Figure shows the electric lines of force emerging from a charged body. If the electric field at A and B are and respectively and if the displacement between A and B is then



(A) $E_A > E_B$

(B) $E_A < E_B$

(C) $E_A = \frac{E_B}{r}$

(D) $E_A = \frac{E_B}{r^2}$

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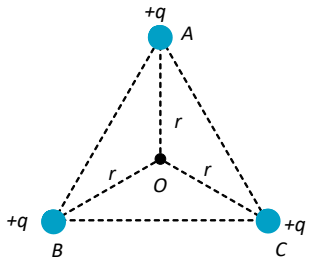
25. ABC is an equilateral triangle. Charges are placed at each corner. The electric intensity at will be

(A) $\frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$

(B) $\frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

(C) Zero

(D) $\frac{1}{4\pi\varepsilon_0}\frac{3q}{r^2}$



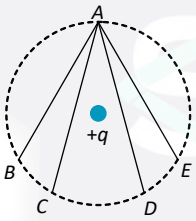
26. In the electric field of a point charge q, a certain charge is carried from point A to B, C, D and E. Then the work done

(A) Is least along the path AB

(B) Is least along the path AD

(C) Is zero along all the paths AB, AC, AD and AE

(D) Is least along AE



27. The magnitude of electric field intensity E is such that, an electron placed in it would experience an electrical force equal to its weight is given by

(A) mge **(B)** $\frac{mg}{e}$

(C) $\frac{e}{mg}$ **(D)** $\frac{e^2}{m^2}g$

28. A conductor with a positive charge

(A) Is always at +ve potential

(B) Is always at zero potential

(C) Is always at negative potential

(D) May be at +ve, zero or –ve potential

29. An electron and a proton are in a uniform electric field, the ratio of their accelerations will be

(A) Zero **(B)** Unity

(C) The ratio of the masses of proton and electron

(D) The ratio of the masses of electron and proton

30. Two parallel plates have equal and opposite charge. When the space between them is evacuated, the electric field between the plates is $2\times10^5\ V/m$. When the space is filled with dielectric, the electric field becomes $1\times10^5\ V/m$. The dielectric constant of the dielectric material

(A) 1/2 **(B)** 1

(C) 2 **(D)** 3

31. An electric dipole when placed in a uniform electric field $\boldsymbol{E}$ will have minimum potential energy, if the positive direction of dipole moment makes the following angle with E

(A) π **(B)** π/2

(C) Zero **(D)** $3\pi/2$

32. A given charge is situated at a certain distance from an electric dipole in the end-on position experiences a force F. If the distance of the charge is doubled, the force acting on the charge will be

(A) $2F$ **(B)** $F/2$

(C) $F/4$ **(D)** $F/8$

33. The electric potential at a point on the axis of an electric dipole depends on the distance of the point from the dipole as

(A) $\propto\frac{1}{r}$ **(B)** $\propto\frac{1}{r^2}$

(C) $\propto$ r **(D)** $\propto\frac{1}{r^3}$

34. An electric dipole of moment p is placed in the position of stable equilibrium in uniform electric field of intensity E. It is rotated through an angle θ from the initial position. The potential energy of electric dipole in the final position is

(A) $pE\cos\theta$ **(B)** $pE\sin\theta$

(C) $pE(1-\cos\theta)$ **(D)** $-pE\cos\theta$

35. An electric dipole is kept in non-uniform electric field. It experiences

(A) A force and a torque

(B) A force but not a torque

(C) A torque but not a force

(D) Neither a force nor a torque

36. An electric dipole consisting of two opposite charges of $2\times10^{-6}\ C$ each separated by a distance of is placed in an electric field of $2\times10^5\ N/C$. The maximum torque on the dipole will be

(A) $12\times10^{-1}\ N\,m$ **(B)** $12\times10^{-3}\ N\,m$

(C) $24\times10^{-1}\ N\,m$ **(D)** $24\times10^{-3}\ N\,m$

37. An electric dipole of moment $\vec{p}$ is placed normal to the lines of force of electric intensity $\vec{E}$, then the work done in deflecting it through an angle of is

(A) pE **(B)** + 2pE

(C) – 2pE **(D)** Zero

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38. The distance between the two charges +q and –q of a dipole is r . On the axial line at a distance d from the centre of dipole, the intensity is proportional to

(A) $\frac{q}{d^2}$ **(B)** $\frac{qr}{d^2}$

(C) $\frac{q}{d^3}$ **(D)** $\frac{qr}{d^3}$

39. An electron and a proton are at a distance of 1Å . The moment of this dipole will be $(C \times m)$

(A) 1.6×10^{19} **(B)** 1.6×10^{-29}

(C) 3.2×10^{19} **(D)** 3.2×10^{29}

40. The electric field due to a dipole at a distance r on its axis is

(A) Directly proportional to r^3

(B) Inversely proportional to r^3

(C) Directly proportional to r^2

(D) Inversely proportional to r^2

41. A cylinder of radius R and length L is placed in a uniform electric field E parallel to the cylinder axis. The total flux for the surface of the cylinder is given by

(A) $2\pi R^2 E$ **(B)** $\pi R^2 / E$

(C) $(\pi R^2 - \pi R)/E$ **(D)** Zero

42. Electric field at a point varies as r^0 for

(A) An electric dipole

(B) A point charge

(C) A plane infinite sheet of charge

(D) A line charge of infinite length

43. An electric charge q is placed at the centre of a cube of side α . The electric flux on one of its faces will be

(A) $\frac{q}{6\varepsilon_0}$ **(B)** $\frac{q}{\varepsilon_0 a^2}$

(C) $\frac{q}{4\pi\varepsilon_0 a^2}$ **(D)** $\frac{q}{\varepsilon_0}$

44. Total electric flux coming out of a unit positive charge put in air is

(A) ε_0 **(B)** ε_0^{-1}

(C) $(4p\varepsilon_0)^{-1}$ **(D)** $4\pi\varepsilon_0$

45. For a given surface the Gauss's law is stated as $\oint \boldsymbol{E} \cdot \boldsymbol{ds} = 0$. From this we can conclude that

(A) E is necessarily zero on the surface

(B) is perpendicular to the surface at every point

(C) The total flux through the surface is zero

(D) The flux is only going out of the surface

46. A cube of side is placed in a uniform field , where . The net electric flux through the cube is

(A) Zero **(B)** l^2 E

(C) $4l^2$E **(D)** $6l^2$E

47. Eight dipoles of charges of magnitude e are placed inside a cube. The total electric flux coming out of the cube will be

(A) $\frac{8e}{\varepsilon_0}$ **(B)** $\frac{16e}{\varepsilon_0}$

(C) $\frac{e}{\varepsilon_0}$ **(D)** Zero

48. A point charge +q is placed at the centre of a cube of side L . The electric flux emerging from the cube is

(A) $\frac{q}{\varepsilon_0}$ **(B)** Zero

(C) $\frac{6qL^2}{\varepsilon_0}$ **(D)** $\frac{q}{6L^2\varepsilon_0}$

49. A charge q is placed at the centre of the open end of cylindrical vessel. The flux of the electric field through the surface of the vessel is

(A) Zero **(B)** $\frac{q}{\varepsilon_0}$

(C) $\frac{q}{2\varepsilon_0}$ **(D)** $\frac{2q}{\varepsilon_0}$

50. It is not convenient to use a spherical Gaussian surface to find the electric field due to an electric dipole using Gauss's theorem because

(A) Gauss's law fails in this case

(B) This problem does not have spherical symmetry

(C) Coulomb's law is more fundamental than Gauss's law

(D) Spherical Gaussian surface will alter the dipole moment

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Exercise # 2 SINGLE OBJECTIVE AIIMS LEVEL

1. Two point charges + 9e and +e are kept 16 cm. apart from each other. Where should a third charge q be placed between them so that the system is in equilibrium state :

(A) 24 cm from + 9e **(B)** 12 cm from +9e

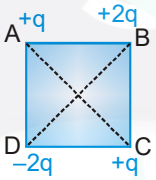
(C) 24 cm from + e **(D)** 12 cm from + e

2. Using mass (M), length (L), time (T) and current (A) as fundamental quantities, the dimension of permittivity is :

(A) $ML^{-2}T^{2}A$ **(B)** $M^{-1}L^{-3}T^{4}A^{2}$

(C) $MLT^{-2}A$ **(D)** $ML^{2}T^{-1}A^{2}$

3. Four charges are arranged at the corners of a square ABCD as shown in the figure. The force on the charge kept at the centre O will be :



(A) perpendicular to side AB

(B) along the diagonal BD

(C) along the diagonal AC

(D) zero

4. Two equal negative charges –q are fixed at point (0, –a) and (0, a) on y–axis. A positive charge Q is released from rest at the point (2a, 0) on the x–axis. The charge Q will :

(A) execute simple harmonic motion about the origin

(B) move to the origin and remain at rest

(C) move to infinity

(D) execute oscillatory but not simple harmonic motion

5. When charge is given to a soap bubble, it shows

(A) an increase in size

(B) sometimes an increase and sometimes a decrease in size

(C) no change in size

(D) none of these

6. An electron of mass m_e, initially at rest, moves through a certain distance in a uniform electric field in time t_1. A proton of mass m_p, also, initially at rest, takes time t_2 to move through an equal distance in this uniform electric field. Neglecting the effect of gravity, the ratio t_2/t_1 is nearly equal to :

(A) 1 **(B)** $(m_p/m_e)^{1/2}$

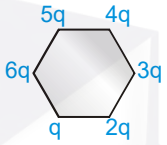
(C) $(m_e/m_p)^{1/2}$ **(D)** 1836

7. Two infinite linear charges are placed parallel to each other at a distance 0.1 m from each other. If the linear charge density on each is 5 μC/m, then the force acting on a unit length of each linear charge will be

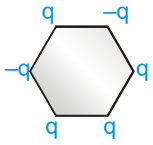
(A) 2.5 N/m **(B)** 3.25 N/m

(C) 4.5 N/m **(D)** 7.5 N/m

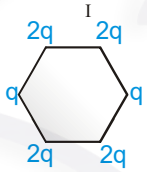
8. Figures below show regular hexagon, the charges are placed at the vertices. In which of the following cases the electric field at the centre is zero.



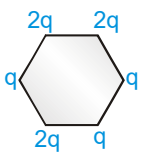
I



II



III

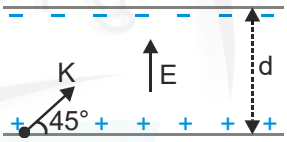


IV

(A) IV **(B)** III

(C) I **(D)** II

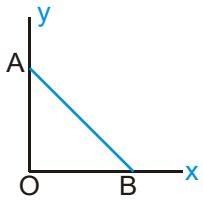
9. An electron is projected as in figure with kinetic energy K, at an angle θ = 45° between two charged plates. The magnitude of the electric field so that the electron just fails to strike the upper plate, should be greater than:



(A) $\frac{K}{qd}$ **(B)** $\frac{2K}{qd}$

(C) $\frac{K}{2qd}$ **(D)** Infinite

10. As per this diagram a point charge +q is placed at the origin O. Work done in taking another point charge –Q from the point A (0, a) to another point B (a,0) along the straight path AB is :



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(A) $\left(\frac{-qQ}{4\pi \in_0}\frac{1}{a^2}\right)\sqrt{2}\,a$ **(B)** zero

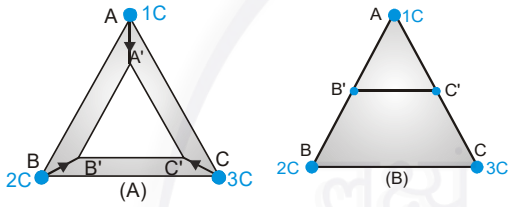
(C) $\left(\frac{qQ}{4\pi \in_0}\frac{1}{a^2}\right)\frac{1}{\sqrt{2}}$ **(D)** $\left(\frac{qQ}{4\pi \in_0}\frac{1}{a^2}\right)\sqrt{2}\,a$

11. A point charge 50 μC is located in the XY plane at the point of position vector $\vec{r}_0 = (2\hat{i} + 3\hat{j})$ meter. What is the electric field at the point of position vector $\vec{r} = (8\hat{i} - 5\hat{j})$ meter:

(A) 1200 V/m **(B)** 0.04 V/m

(C) 900 V/m **(D)** 4500 V/m

12. Three point charges 1C, 2C and 3C are placed at the corners of an equilateral triangle of side 1m. The work required to move these charges to the corners of a smaller equilateral triangle of side 0.5m in two different ways as in fig. **(A)** and fig. **(B)** are W_a and W_b then:



(A) $W_a > W_b$ **(B)** $W_a < W_b$

(C) $W_a = W_b$ **(D)** $W_a = 0$ and $W_b = 0$

13. Two identical particles of mass m carry a charge Q each. Initially one is at rest on a smooth horizontal plane and the other is projected along the plane directly towards first particle from a large distance with speed v. The closest distance of approach be

(A) $\frac{1}{4\pi\varepsilon_0}\frac{Q^2}{mv}$ **(B)** $\frac{1}{4\pi\varepsilon_0}\frac{4Q^2}{mv^2}$

(C) $\frac{1}{4\pi\varepsilon_0}\frac{2Q^2}{mv^2}$ **(D)** $\frac{1}{4\pi\varepsilon_0}\frac{3Q^2}{mv^2}$

14. Two identical thin rings, each of radius R meter are coaxially placed at distance R meter apart. If Q_1 and Q_2 coulomb are respectively the charges uniformly spread on the two rings, the work done in moving a charge q from the centre of one ring to that of the other is :

(A) zero

(B) $\frac{q(Q_1 - Q_2)(\sqrt{2}-1)}{(4\sqrt{2}\pi \in_0 R)}$

(C) $\frac{q\sqrt{2}(Q_1 + Q_2)}{4\pi \in_0 R}$

(D) $\frac{q(Q_1 - Q_2)(\sqrt{2}+1)}{(4\sqrt{2}\pi \in_0 R)}$

15. An alpha particle of energy 5 MeV is scattered through 180° by a fixed uranium nucleus. The distance of closest approach is of the order :

(A) 1 Å **(B)** 10^{-10} cm

(C) 10^{-12} cm **(D)** 10^{-15} cm

16. In a regular polygon of n sides, each corner is at a distance r from the center. Identical charges are placed at (n–1) corners. At the centre, the intensity is E and the potential is V. The ratio V/E has magnitude :

(A) nr **(B)** (n–1)r

(C) (n–1) /r **(D)** r (n–1)/n

17. A charge 3 coulomb experiences a force 300 N when placed in a uniform electric field. The potential difference between two points separated by a distance of 10 cm along the field line is :

(A) 10 V **(B)** 90 V

(C) 1000 V **(D)** 9000 V

18. The equation of an equipotential line in an electric field is y=2x, then the electric field strength vector at (1, 2) may be :

(A) $4\hat{i} + 3\hat{j}$ **(B)** $4\hat{i} + 8\hat{j}$

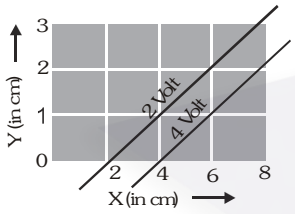
(C) $8\hat{i} + 4\hat{j}$ **(D)** $-8\hat{i} + 4\hat{j}$

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19. Uniform electric field of magnitude 100 V/m in space is directed along the line y=3 +x. Find the potential difference between point A (3,1) & B (1,3) :

(A) 100 V **(B)** 200 $\sqrt{2}$ V
(C) 200V **(D)** 0

20. The figure below shows two equipotential lines in XY plane for an electric field. The scales are marked. The X–component E_x and Y–component E_y of the electric field in the space between these equipotential lines are respectively



(A) +100 V/m, –200 V/m
(B) +200 V/m, +100 V/m
(C) –100 V/m, +200 V/m
(D) –200 V/m, –100 V/m

21. In a certain region of space, the potential is given by $V=k(2x^2 - y^2 + z^2)$. The electric field at the point (1, 1, 1) has magnitude :

(A) $k\sqrt{6}$ **(B)** $2k\sqrt{6}$
(C) $2k\sqrt{3}$ **(D)** $4k\sqrt{3}$

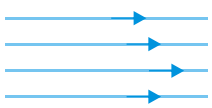
22. Two point charges + q and –q are held fixed at (–d, 0) and (d, 0) respectively of a x–y co–ordinate system. Then which of the following statement is incorrect :

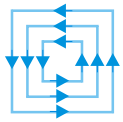
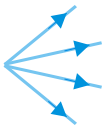
(A) The electric field E at all points on the x–axis has the same direction
(B) No work has to be done in bringing a test charge from ∞ to the origin
(C) Electric field at all point on y–axis is parallel to x–axis
(D) The dipole moment is 2 qd along the –ve x–axis

23. A non–conducting ring of radius 0.5 m carries a total charge 1.11×10^{-10} C distributed non–uniformly on its circumference producing an electric field E every where in space. The value of the integral $\int_{\ell=\infty}^{\ell=0} -\vec{E}\cdot\vec{d}\ell$ (ℓ= 0 being centre of the ring) in volt is :

(A) +2 **(B)** –1
(C) –2 **(D)** zero

24. Which one of the following pattern of electric line of force can't possible :

(A)  **(B)** 

(C)  **(D)** 

25. The work done in rotating an electric dipole of dipole moment p in an electric field E through an angle θ from the direction of electric field, is :

(A) pE (1 – cosθ) **(B)** pE
(C) zero **(D)** – pE cosθ

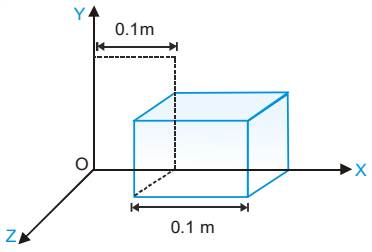
26. A sphere of radius R and charge Q is placed inside an imaginary sphere of radius 2R whose centre coincides with the given sphere. The flux related to imaginary sphere is :

(A) $\frac{Q}{\epsilon_0}$ **(B)** $\frac{Q}{2\epsilon_0}$
(C) $\frac{4Q}{\epsilon_0}$ **(D)** $\frac{2Q}{\epsilon_0}$

27. Electric flux through a surface of area 100 m^2 lying in the xy plane is (in V–m) if $E = \hat{i} + \sqrt{2}\hat{j} + \sqrt{3}\hat{k}$:

(A) 100 **(B)** 141.4
(C) 173.2 **(D)** 200

28. Due to a charge inside a cube the electric field is $E_x = 600\, x^{1/2}$, $E_y = 0$, $E_z = 0$. The charge inside the cube is (approximately) :



(A) 600 μC **(B)** 60 μC
(C) 7 μμC **(D)** 6 μμC

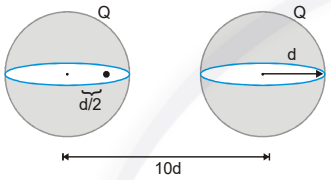
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29. A solid metallic sphere has a charge + 3Q. Concentric with this sphere is a conducting spherical shell having charge –Q. The radius of the sphere is a and that of the spherical shell is b (b > a). What is the electric field at a distance R (a < R < b) from the centre ?

(A) $\frac{4Q}{2\pi\varepsilon_0 R^2}$ **(B)** $\frac{3Q}{4\pi\varepsilon_0 R^2}$

(C) $\frac{3Q}{2\pi\varepsilon_0 R^2}$ **(D)** $\frac{Q}{2\pi\varepsilon_0 R}$

30. Two spherical, nonconducting, and very thin shells of uniformly distributed positive charge Q and radius d are located at a distance 10d from each other. A positive point charge q is placed inside one of the shells at a distance d/2 from the center, on the line connecting the centers of the two shells, as shown in the figure. What is the net force on the charge q?



(A) $\frac{qQ}{361\pi\varepsilon_0 d^2}$ to the left

(B) $\frac{qQ}{361\pi\varepsilon_0 d^2}$ to the right

(C) $\frac{362qQ}{361\pi\varepsilon_0 d^2}$ to the left

(D) $\frac{360qQ}{361\pi\varepsilon_0 d^2}$ to the right

31. A cube of metal is given a charge (+ Q), which of the following statements is true :

(A) Potential at the surface of cube is zero

(B) Potential within the cube is zero

(C) Electric field is normal to the surface of the cube

(D) Electric field varies within the cube

32. A hollow metal sphere of radius 5 cm is charged such that the potential on its surface is 10V. The potential at the distance 3 cm from the centre of the sphere is :

(A) zero

(B) 10 V

(C) same as at a point 5 cm away from the surface

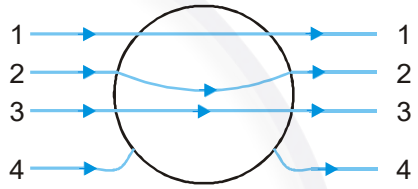
(D) same as at a point 25 cm away from the surface

33. A solid conducting sphere having a charge Q is surrounded by an uncharged concentric conducting hollow spherical shell. Let the potential difference between the surface of the solid sphere and that of the outer surface of the hollow shell be V. If the shell is now given a charge of –3Q, the new potential difference between the same two surfaces is :

(A) V **(B)** 2V

(C) 4V **(D)** –2V

34. A metallic solid sphere is placed in a uniform electric field. The lines of force follow the path(s) shown in figure as :



(A) 1 **(B)** 2

(C) 3 **(D)** 4

35. A charged particle having some mass is resting in equilibrium at a height H above the centre of a uniformly charged non–conducting horizontal ring of radius R. The force of gravity acts downwards.; The equilibrium of the particle will be stable :

(A) for all values of H

(B) only if $H > \frac{R}{\sqrt{2}}$

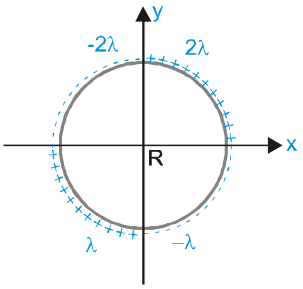
(C) only if $H < \frac{R}{\sqrt{2}}$

(D) only if $H = \frac{R}{\sqrt{2}}$

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36. The charge per unit length of the four quadrant of the ring is 2λ, -2λ, λ and $-\lambda$ respectively.

The electric field at the centre is



(A) $\frac{-\lambda}{2\pi\varepsilon_0 R}\hat{i}$

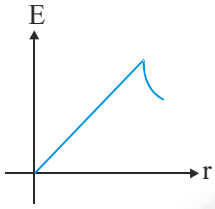
(B) $\frac{\lambda}{2\pi\varepsilon_0 R}\hat{j}$

(C) $\frac{\sqrt{2}\lambda}{4\pi\varepsilon_0 R}\hat{i}$

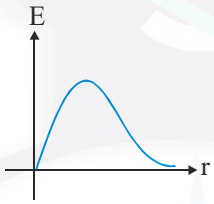
(D) None

37. A circular ring carries a uniformly distributed positive charge. The electric field (E) and potential (V) varies with distance (R) from the centre of the ring along its axis as :

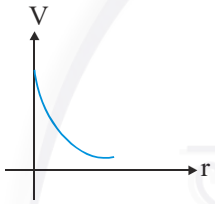
(A)



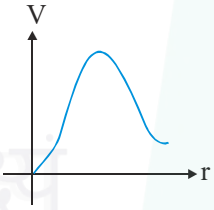
(B)



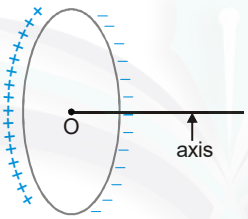
(C)



(D)



38. The figure shows a nonconducting ring which has positive and negative charge non uniformly distributed on it such that the total charge is zero. Which of the following statements is true?



(A) The potential at all the points on the axis will be zero.

(B) The electric field at all the points on the axis will be zero.

(C) The direction of electric field at all points on the axis will be along the axis.

(D) If the ring is placed inside a uniform external electric field then net torque and force acting on the ring would be zero.

39. An electric charge 10^{-8} C is placed at the point (4m, 7m, 2m). At the point (1m, 3m, 2m), the electric :

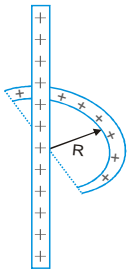
(A) potential will be 18 V

(B) field has no Y–component

(C) field will be along Z–axis

(D) potential will be 1.8 V

40. Find the force experienced by the semicircular rod charged with a charge q, placed as shown in figure. Radius of the wire is R and the infinite line of charge with linear charge density λ is passing through its centre and perpendicular to the plane of rod.



(A) $\frac{-\lambda q}{2\pi^2\varepsilon_0 R}$

(B) $\frac{\lambda q}{\pi^2\varepsilon_0 R}$

(C) $\frac{\lambda q}{4\pi^2\varepsilon_0 R}$

(D) $\frac{\lambda q}{4\pi\varepsilon_0 R}$

41. In a uniform electric field, the potential is 10V at the origin of coordinates, and 8V at each of the points (1, 0, 0), (0, 1, 0) and (0, 0, 1). The potential at the point (1, 1, 1) will be :

(A) 0 **(B)** 4V

(C) 8V **(D)** 10V

42. Two positively charged particles X and Y are initially far away from each other and at rest. X begins to move towards Y with some initial velocity. The total momentum and energy of the system are p and E :

(A) If Y is fixed, both p and E are conserved

(B) If Y is fixed, E is conserved, but not p

(C) If both are free to move, p is conserved but not E

(D) If both are free, E is conserved, but not p

43. Two particles X and Y, of equal mass and with unequal positive charges, are free to move and are initially far away from each other. With Y at rest, X begins to move towards it with initial velocity u. After a long time, finally :

(A) X will stop, Y will move with velocity u

(B) X and Y will both move with velocities u/2 each

(C) X will stop, Y will move with velocity < u

(D) both will move with velocities < u/2

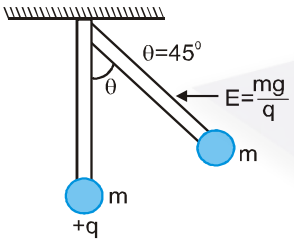
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44. A particle of charge 1μC & mass 1 gm moving with a velocity of 4 m/s is subjected to a uniform electric field of magnitude 300 V/m for 10 sec. Then it's final speed cannot be :

(A) 0.5 m/s **(B)** 4 m/s

(C) 3 m/s **(D)** 6 m/s

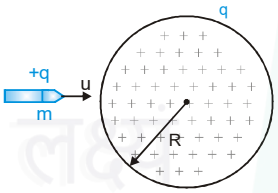
45. A horizontal electric feild (E = (mg)/q) exists as shown in figure and a mass m attached at the end of a light rod. If mass m is released from the position shown in figure find the angular velocity of the rod when it passes through the bottom most position :



(A) $\sqrt{\frac{g}{\ell}}$ **(B)** $\sqrt{\frac{2g}{\ell}}$

(C) $\sqrt{\frac{3g}{\ell}}$ **(D)** $\sqrt{\frac{5g}{\ell}}$

46. A bullet of mass m and charge q is fired towards a solid uniformly charged sphere of radius R and total charge + q.

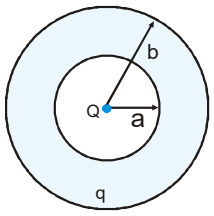


If it strikes the surface of sphere with speed u, find the minimum value of u so that it can penetrate through the sphere. (Neglect all resistnace forces or friction acting on bullet except electrostatic forces)

(A) $\frac{q}{\sqrt{2\pi\varepsilon_0 mR}}$ **(B)** $\frac{q}{\sqrt{4\pi\varepsilon_0 mR}}$

(C) $\frac{q}{\sqrt{8\pi\varepsilon_0 mR}}$ **(D)** $\frac{\sqrt{3}q}{\sqrt{4\pi\varepsilon_0 mR}}$

47. Shown in the figure a spherical shell with an inner radius 'a' and an outer radius 'b' is made of conducting material. A point charge +Q is placed at the centre of the spherical shell and a total charge –q is placed on the shell. Charge –q is distributed on the surfaces as :



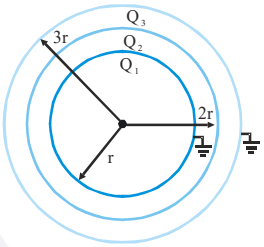
(A) –Q on the inner surface, –q, on outer surface

(B) –Q on the inner surface, –q+Q on the outer surface

(C) +Q on the inner surface, –q–Q on the outer surface

(D) The charge –q is spread uniformly between the inner and outer surface

48. Three concentric conducting spherical shells have radius r, 2r and 3r and Q_1, Q_2 and Q_3 are final charges respectively. Innermost and outermost shells are already earthed as shown in figure. choose the wrong statement.



(A) $Q_1 + Q_3 = -Q_2$

(B) $Q_1 = \frac{-Q_2}{4}$

(C) $\frac{Q_3}{Q_1} = 3$

(D) $\frac{Q_3}{Q_2} = \frac{-1}{3}$

49. There are four concentric shells A, B, C and D of radii a, 2a, 3a and 4a respectively. Shells B and D are given charges +q and –q respectively. Shell C is now earthed. The potential difference $V_A - V_C$ is :

(A) $\frac{Kq}{2a}$ **(B)** $\frac{Kq}{3a}$

(C) $\frac{Kq}{4a}$ **(D)** $\frac{Kq}{6a}$

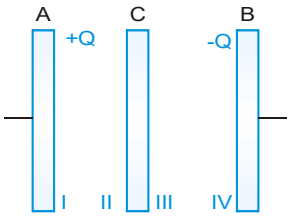
50. In the previous question assume that the electrostatic potential is zero at an infinite distance from the spherical shell. The electrostatic potential at a distance R (a < R < b) from the centre of the shell is where $\left(K = \frac{1}{4\pi\varepsilon_0}\right)$

(A) 0 **(B)** $\frac{KQ}{a}$

(C) $K\frac{Q-q}{R}$ **(D)** $K\frac{Q-q}{b}$

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51. Plates A and B constitutes an isolated, charge parallel plate capacitor. The inner surfaces (I and IV) of A and B have charges + Q and –Q respectively. A third plate C with charge + Q is now introduced midway between A and B. Which of the following statements is not correct?



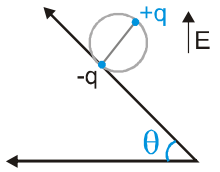
(A) The surface I and II will have equal and opposite charges

(B) The surfaces III and IV will have equal and opposite charges

(C) The charge on surace III will be greater than Q

(D) The potential difference between A and C will be equal to the potential difference between C and B

52. A wheel having mass m has charges +q and –q on diametrically opposite points. It remains in equilibrium on a rough inclined plane in the presence of uniform vertical electric field E. The value of E is



(A) $\frac{mg}{q}$

(B) $\frac{mg}{2q}$

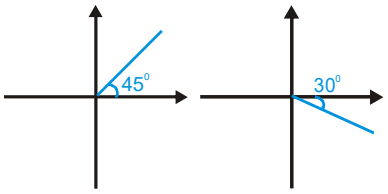
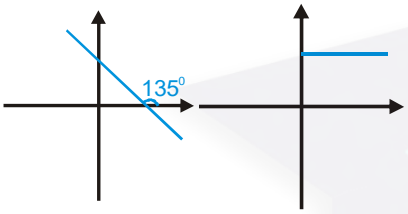
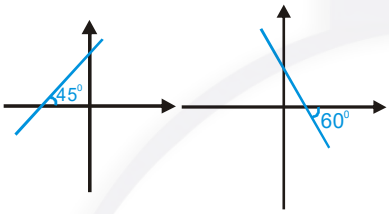
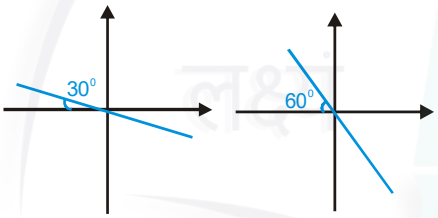
(C) $\frac{mg\tan\theta}{2q}$

(D) None

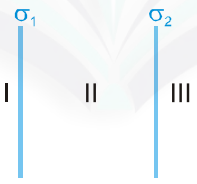
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Exercise # 3 PART - 1 MATRIX MATCH COLUMN

1. Column–I shows graphs of electric potential V versus x and y in a certain region for four situations. Column–II shows the range of angle which the electric field vector makes with poisitive x–direction

Column–I : V versus x, V versus y		Column–II : Range of angle	
(A)		(P)	$0^0 \le \theta < 45^0$
(B)		(Q)	$45^0 \le \theta < 90^0$
(C)		(R)	$90^0 \le \theta < 135^0$
(D)		(S)	$135^0 \le \theta < 180^0$

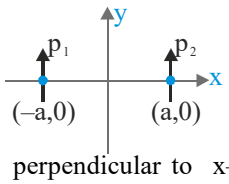
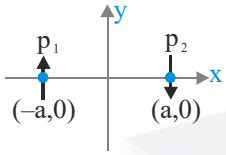
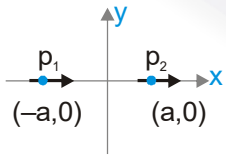
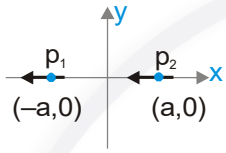
2. Two parallel metallic plates have surface charge densities σ_1 and σ_2 as shown in figure.



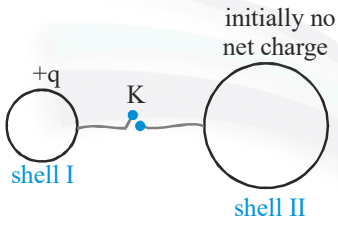
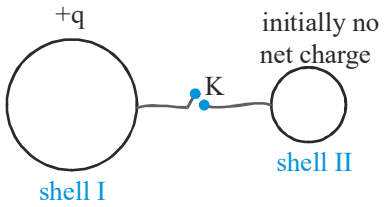
Column–I		Column–II	
(A)	If $\sigma_1 + \sigma_2 = 0$	(P)	Electric field in region III is towards right
(B)	If $\sigma_1 + \sigma_2 > 0$	(Q)	Electric field in region I is zero
(C)	If $\sigma_1 + \sigma_2 < 0$	(R)	Electric field in region I is towards right
		(S)	Nothing can be said

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3. In each situation of column–I, two electric dipoles having dipole moments $\vec{p}_1$ and $\vec{p}_2$ of same magnitude (that is, $p_1 = p_2$) are placed on x–axis symmetrically about origin in different orientations as shown. In column–II certain inferences are drawn for these two dipoles. Then match the different orientations of dipole in column–I with the corresponding results in column–II.

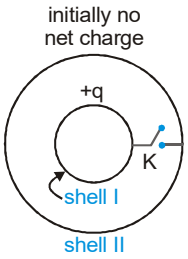
Column I		Column II	
(A)	 ($\vec{p}_1$ and $\vec{p}_2$ are perpendicular to x–axis as shown)	(P)	The torque on one dipole due to other is zero
(B)	 ($\vec{p}_1$ and $\vec{p}_2$ are perpendicular to x–axis as shown)	(Q)	The potential energy of one dipole in electric field of other dipole is negative
(C)	 ($\vec{p}_1$ and $\vec{p}_2$ are parallel to x–axis as shown)	(R)	There is one straight line in x-y plane (not at infinity) which is equipotential
(D)	 ($\vec{p}_1$ and $\vec{p}_2$ are parallel to x–axis as shown)	(S)	Electric field at origin is zero.

4. Column–I gives certain situations involving two thin conducting shells connected by a conducting wire via a key K. In all situations one sphere has net charge +q and other sphere has no net charge. After the key K is pressed, column–II gives some resulting effect.

Column I		Column II	
(A)		(P)	Charge flows through connecting wire
(B)		(Q)	Potential energy of system of spheres decreases

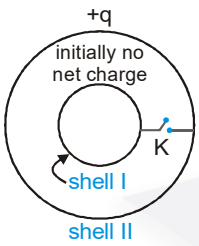
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(C)



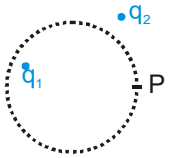
(R) No heat is produced

(D)



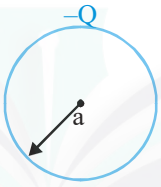
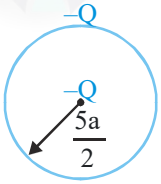
(S) The sphere I has no charge after equilibrium is reached

5. In the figure shown P is a point on the surface of an imaginary sphere.



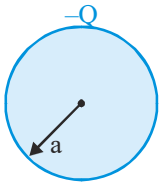
Column–I		Column–II	
(A)	Electric field at point P	**(P)**	due to q_1 only
(B)	Electric flux through a small area at P	**(Q)**	due to q_2 only
(C)	Electric flux through whole sphere	**(R)**	due to both q_1 and q_2

6. In each situation of column–I, some charge distributions are given with all details explained. The electrostatic potential energy and its nature is given situation in column–II.

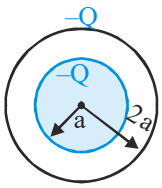
Column I		Column II	
(A)	A thin shell of radius a and having a charge –Q uniformly distributed over its surface as shown 	**(P)**	$\frac{1}{8\pi \epsilon_0}\frac{Q^2}{a}$ in magnitude
(B)	A thin shell of radius $\frac{5a}{2}$ and having a charge –Q uniformly distributed over its surface and a point charge –Q placed at its centre as shown 	**(Q)**	$\frac{3}{20\pi \epsilon_0}\frac{Q^2}{a}$ in magnitude

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(C) A solid sphere of radius a and having a charge –Q uniformly distributed throughout its volume as shown



(D) A solid sphere of radius a and having a charge –Q uniformly distributed throughout its volume. The solid sphere is surrounded by a concentric thin uniformly charged spherical shell of radius 2a and carrying charge –Q as shown



(R) $\frac{2}{5\pi\epsilon_0}\frac{Q^2}{a}$ in magnitude

(S) Positive in sign

7. A spherical metallic conductor has a spherical cavity. A positive charge is placed inside the cavity at its centre. Another positive charge is placed outside it. The conductor is initially electrically neutral.

Column I (Cause)		Column II (Effect)	
(A)	If outside charge is shifted to other position of cavity changes	**(P)**	Distribution of charge on inner surface
(B)	If inside charge is shifted to other position within cavity	**(Q)**	Distribution of charge on outer surface of conductor changes
(C)	If magnitude of charge inside cavity is increased	**(R)**	Electric potential at the centre of conductor changes due to charges present on outer surface of conductor
(D)	If conductor is earthed	**(S)**	Force on the charge placed inside cavity changes

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Exercise # 3 PART - 2 ASSERTION & REASONING

These questions contains, Statement I (assertion) and Statement II (reason).

(A) If both assertion and reason are true and the reason is the correct explanation of the assertion.

(B) If both assertion and reason are true but reason is not the correct explanation of the assertion.

(C) If assertion is true but reason is false.

(D) If assertion is false but reason is true.

(E) If the assertion and reason both are false.

1. **Assertion :** Mass of ion is slightly differed from its element.
Reason : Ion is formed, when some electrons are removed or added so the mass changes

2. **Assertion :** Charge is invariant.
Reason : Charge does not depends on speed or frame of reference.

3. **Assertion :** Charge is quantized
Reason : Charge, which is less than 1 C is not possible

4. **Assertion :** If a point charge q is placed in front of an infinite grounded conducting plane surface, the point charge will experience a force.
Reason : This force is due to the induced charge on the conducting surface which is at zero potential

5. **Assertion :** In electrostatic electric lines of force can never be closed loops, as a line can never start and end on the same charge.
Reason : The number of electric lines of force originating or terminating on a charge is proportional to the magnitude of charge.

6. **Assertion :** When charges are shared between two bodies, there occurs no loss of charge, but there does occur a loss of energy.
Reason : In case of sharing of charges conservation of energy fails.

7. **Assertion :** The particles such as photon or neutrino which have no (rest) mass can never have a charge.
Reason : Charge can not exist without mass.

8. **Assertion :** When two charged spheres are touched, then total charge is always devides equally.
Reason : Flow of charge take place untill potential equals.

9. **Assertion :** Induced charge does not contribute to electric field or potential at a given point.
Reason : A point charge q_0 is kept outside a solid metallic sphere, the electric field inside the sphere is zero.

10. **Assertion :** Electric field intensity at surface of uniformly charge spherical shell is E. If shell is punchered at a point then intensity at punchered point become E/2.
Reason : Electric field intensity due to spherical charge distribution can be found out by using Gauss law.

11. **Assertion :** A conducting sphere charged upto 50V is placed at the centre of a conducting shell charged upto 100V and connected by a wire. All the charge of the shell flows to the sphere.
Reason : The positive charge always flows from higher to lower potential.

12. **Assertion :** When a charged particle is placed in the cavity in a conducting sphere, the induced charge on the outer surface of the sphere is found to be uniformly distributed.
Reason : Conducting surface is equipotential surface.

13. **Assertion :** A metallic shield in form of a hollow shell may be built to block an electric field.
Reason : In a hollow spherical shield, the electric field inside it is zero at every point.

14. **Assertion :** If two concentric conducting sphere which are connected by a conducting wire. No charge can exist on inner sphere.
Reason : When charge on outer sphere will exist then potential of inner shell and outer shell will be same.

15. **Assertion :** Electric field E at a point P is zero if potential at that point is zero.
Reason : Potential difference between two points in space is zero if electric field at all points in space is zero.

16. **Assertion :** A hollow metallic sphere of inner radius a and outer radius b has charge q at the centre. A negatively charged particle moves from inner surface to outer surface. Then total work done will be zero.
Reason : Potential is constant inside the metallic sphere.

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Exercise # 4 PART - 1 PREVIOUS YEAR (NEET/AIPMT)

1. A charged wire is bent in the form of a semicircular arc of radius a. If charge per unit length is λ coulomb/metre, the electric field at the centre O is

(A) $\frac{\lambda}{2\pi a^2\varepsilon_0}$ **(B)** $\frac{\lambda}{4\pi^2\varepsilon_0 a}$

(C) $\frac{\lambda}{2\pi\varepsilon_0 a}$ **(D)** zero

2. A charge q is placed at the corner of a cube of side a. The electric flux through the cube is

(A) $\frac{q}{\varepsilon_0}$ **(B)** $\frac{q}{3\varepsilon_0}$

(C) $\frac{q}{6\varepsilon_0}$ **(D)** $\frac{q}{8\varepsilon_0}$

3. A charge q μC is placed at the centre of a cube of a side 0.1 m, then the electric flux diverging from each face of the cube is

(A) $\frac{q\times10^{-6}}{24\varepsilon_0}$ **(B)** $\frac{q\times10^{-4}}{\varepsilon_0}$

(C) $\frac{q\times10^{-6}}{6\varepsilon_0}$ **(D)** $\frac{q\times10^{-4}}{12\varepsilon_0}$

4. Identical charges (–q) are placed at each corners of a cube of side b, then the electrostatic potential energy of charge (+q) placed at the centre of the cube will be

(A) $-\frac{4\sqrt{2}q^2}{\pi\varepsilon_0}$ **(B)** $\frac{8\sqrt{2}q^2}{\pi\varepsilon_0 b}$

(C) $-\frac{4q^2}{\sqrt{3}\pi\varepsilon_0 b}$ **(D)** $\frac{8\sqrt{2}q^2}{4\pi\varepsilon_0 b}$

5. An electron is moving round the nucleus of a hydrogen atom in a circular orbit of radius r. The coloumb force F between the two is

(A) $k\frac{e^2}{r^3}r$ **(B)** $-k\frac{e^2}{r^3}r$

(C) $k\frac{e^2}{r^3}\hat{r}$ **(D)** $-k\frac{e^2}{r^3}\hat{r}$

(where, $k=\frac{1}{4\pi\varepsilon_0}$)

6. A charge q is located at the centre of a cube. The electric flux through any face is

(A) $\frac{\pi q}{6(4\pi\varepsilon_0)}$ **(B)** $\frac{q}{6(4\pi\varepsilon_0)}$

(C) $\frac{2\pi q}{6(4\pi\varepsilon_0)}$ **(D)** $\frac{4\pi q}{6(4\pi\varepsilon_0)}$

7. An electric dipole has the magnitude of its chatge as q and its dipole moment p. It is placed in a uniform electric field E. If its dipole moment is along the direction of the field, the force on it and its potential energy are respectively

(A) 2 qE and minimum **(B)** qE and pE

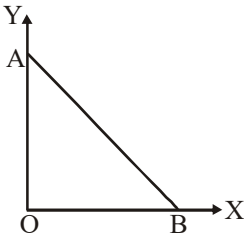
(C) Zero and minimum **(D)** qE and maximum

8. A bullet of mass 2 g is having charge of 2 μC. Through what potential difference must it be accelerated, starting from rest, to acquire a speed of 10 m/s ?

(A) 5 kV **(B)** 50 kV

(C) 5 V **(D)** 50 V

9. As per this diagram a point charge +q is place at the origin O. Work done in taking another point charge –Q from the point A [coordinates (0, a)] to another point B [coordinates (a,0)] along the straight path AB is



(A) Zero

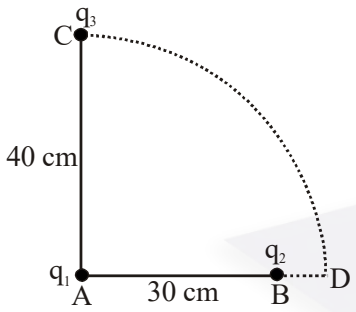
(B) $\left(\frac{-qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right)\sqrt{2}a$

(C) $\left(\frac{qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right)\cdot\frac{a}{\sqrt{2}}$

(D) $\left(\frac{qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right)\sqrt{2}a$

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10. Two charges q_1 and q_2 are placed 30 cm apart, as shown in the figure. A third charge q_3 is moved along the arc of a circle of radius 40 cm from C to D. The change in the potential energy of the system is $\frac{q_3}{4\pi\varepsilon_0}$ k, where k is



(A) $8\,q^2$ **(B)** $8\,q_1$

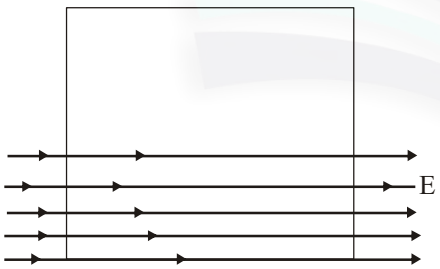
(C) $6\,q_2$ **(D)** $6\,q_1$

11. An electric dipole of moment p is lying along a uniform electric field E. The work done in rotating the dipole by 90° is

(A) $\sqrt{2}$pE **(B)** $\frac{pE}{2}$

(C) 2 pE **(D)** pE

12. A square surface of side L metre is in the plane of the paper. A uniform electric field E(V/m), also in the plane of the paper, is limited only to the lower half of the square surface, (see figure). The electric flux in SI units associated with the surface is



(A) $\frac{EL^2}{(2\varepsilon_0)}$ **(B)** $\frac{EL^2}{2}$

(C) Zero **(D)** EL^2

13. Three point charges +q, –2q and +q are placed at points (x = 0, y = a, z = 0), respectively. The magnitude and direction of the electric dipole moment vector of this charge assembly are

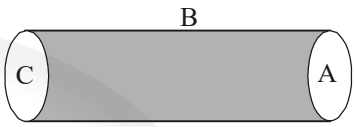
(A) $\sqrt{2}$ qa along +y direction

(B) $\sqrt{2}$ aq along the lone joining points (x = 0, y = 0, a = 0) and (x = a, y = a, z = 0)

(C) qa along the line joining points (x = 0, y = 0, a = 0) and (x = a, y = a, z = 0)

(D) $\sqrt{2}$ aq along + x direction

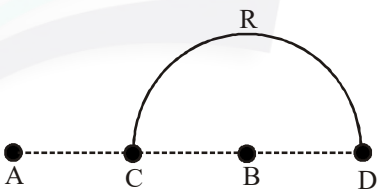
14. A hollow cylinder has a charge q coulomb within it. If ϕ is the electric flux in unit of voltmeter associated with the curved surface B, the flux linked with the plane surface A in unit of voltmeter will be



(A) $\frac{1}{2}\left(\frac{q}{\varepsilon_0}-\phi\right)$ **(B)** $\frac{q}{2\varepsilon_0}$

(C) $\frac{q}{2\varepsilon_0}$ **(D)** $\frac{q}{\varepsilon_0}-\phi$

15. Charges +q and –q are placed at points A and B respectively which are a distance 2 L apart, C is the midpoint between A and B. The work done in moving a charge +Q along the semicircle CRD is



(A) $\frac{qQ}{4\pi\varepsilon_0 L}$ **(B)** $\frac{qQ}{2\pi\varepsilon_0 L}$

(C) $\frac{qQ}{6\pi\varepsilon_0 L}$ **(D)** $-\frac{qQ}{6\pi\varepsilon_0 L}$

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16. The electric potential at a point in free space due to a charge Q coulomb is $Q \times 10^{11}$ V. The electric field at that point is

(A) $4\pi\varepsilon_0 Q \times 10^{22}$ V/m **(B)** $12\pi\varepsilon_0 Q \times 10^{20}$ V/m

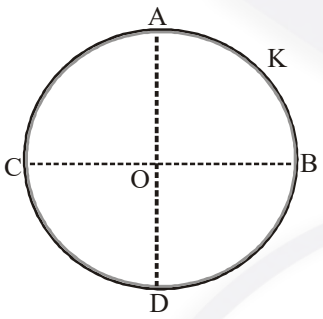
(C) $4\pi\varepsilon_0 Q \times 10^{20}$ V/m **(D)** $12\pi\varepsilon_0 Q \times 10^{22}$ V/m

17. The energy required to charge a parallel plate condensor of plate separation d and plate area of cross-section A such that the uniform electric field between the plates E, is

(A) $\frac{1}{2}\frac{\varepsilon_0 E^2}{Ad}$ **(B)** $\frac{\varepsilon_0 E^2}{Ad}$

(C) $\varepsilon_0 E^2 Ad$ **(D)** $-\frac{1}{2}\frac{\varepsilon_0 E^2}{Ad}$

18.



A thin conducting ring of radius R is given a charge +Q. The electric field at the centre O of the ring due to the charge on the part AKB of the ring is E. The electric field at the centre due to the charge on the part ACDC of the ring is

(A) 3E along KO **(B)** E along OK

(C) E along KO **(D)** 3E along OK

19. Three concentric spherical shells have radii a, b and c (a < b < c) and have surface charge densities σ, –σ and σ respectively. If V_A, V_B and V_C denote the potentials of the three shells, then for c = a+b, we have

(A) $V_C = V_A \neq V_B$ **(B)** $V_C = V_B \neq V_A$

(C) $V_C \neq V_B \neq V_A$ **(D)** $V_C = V_B = V_A$

20. The electric potential at a point (x, y, z) is given by $V = x^2y - xy^3 + 4$ The electric field E at that point is

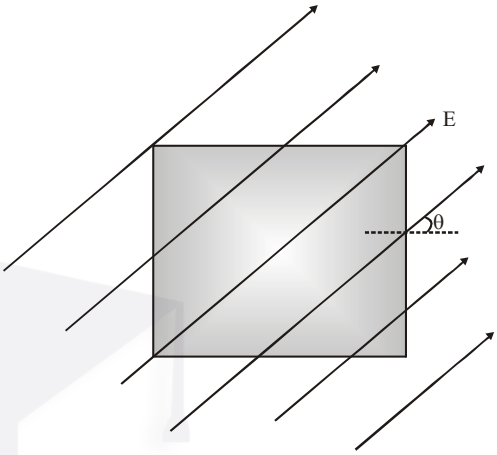
(A) $E = (2xy + z^3)\hat{j} + x^2\hat{j} + 3xz^2\hat{k}$

(B) $E = 2xy\hat{i} + (x^2 + y^2)\hat{j} + (3xz - y^2)\hat{k}$

(C) $E = z^3\hat{i} + xyz\hat{j} + z^2\hat{k}$

(D) $E = (2xy - z^3)\hat{i} + xy^2\hat{j} + 3z^2x\hat{k}$

21. A square surface of side L metre in the plane of the paper is placed in a uniform electric field E(V/m) acting along the same place at an angle q with the horizontal side of the square as shown in figure. The electric flux linked to the surface in unit of V-m, is



(A) EL^2 **(B)** $EL^2\cos\theta$

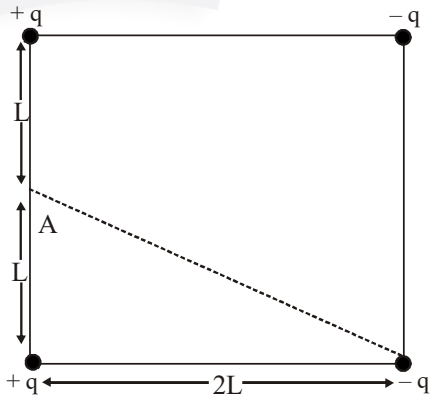
(C) $EL^2\sin\theta$ **(D)** 0

22. Two positive ions, each carrying a charge q, are separated by a distance d. If F is the force of repulsion between thye ions, the number of electrons missing from each ion will be (e being the charge on an electron)

(A) $\frac{4\pi\varepsilon_0 Fd^2}{e^2}$ **(B)** $\sqrt{\frac{4\pi\varepsilon_0 Fe^2}{d^2}}$

(C) $\sqrt{\frac{4\pi\varepsilon_0 Fd^2}{e^2}}$ **(D)** $\frac{4\pi\varepsilon_0 Fd^2}{q^2}$

23. Four electric charges +q, +q, –q, and –q are placed at the corners of a square of side 2 L (see figure). The electric potential at point A, mid-way between the two charges +q and +q is



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(A) $\frac{1}{4\pi\varepsilon_0}\frac{2q}{L}\left(1+\frac{1}{\sqrt{5}}\right)$ (B) $\frac{1}{4\pi\varepsilon_0}\frac{2q}{L}\left(1-\frac{1}{\sqrt{5}}\right)$

(C) Zero (D) $\frac{1}{4\pi\varepsilon_0}\frac{2q}{L}\left(1+\sqrt{5}\right)$

24. A charge Q is enclosed by a Gaussian spherical surface of radius R. If the radius is doubled, then the outward electric flux will

(A) Be reduced to half (B) Remain the same

(C) Be doubled (D) Increase four times

25. A parallel plate condenser has a uniform electric field E(V/m) in the space between the plates. If the distance between the plates d(m) and area of each plate is A$(m)^2$, the energy (joule) stored in the condenser is

(A) $\frac{1}{2}\varepsilon_0 E^2$ (B) $\varepsilon_0 EAd$

(C) $\frac{1}{2}\varepsilon_0 E^2 Ad$ (D) $E^2 Ad/\varepsilon_0$

26. What is the flux through a cube of side a if a point charge of q is at one of its corner ?

(A) $\frac{2q}{\varepsilon_0}$ (B) $\frac{q}{8\varepsilon_0}$

(C) $\frac{q}{\varepsilon_0}$ (D) $\frac{q}{2\varepsilon_0}6a^2$

27. Four point charges –Q, –q, 2q and 2Q are placed, one at each corner of the square. The relation between Q and q for which the potential at the centre of the square is zero, is

(A) Q = –q (B) $Q = -\frac{1}{q}$

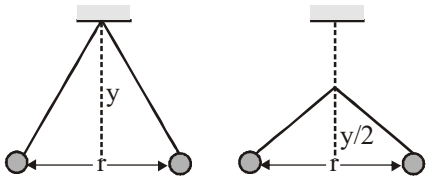
(C) Q = q (D) $Q = \frac{1}{q}$

28. An electric dipole of moment p is placed in an electric field of intensity E. The dipole acquires a position such that the axis of the dipole makes an angle θ with the direction of the field. Assuming that the potential energy of the dipole to be zero when θ = 90°, the torque and the potential energy of the dipole will respectively be (A) pE sinθ, –pE cosθ

(B) pE sinθ, –2pE cosθ

(C) pE sinθ, 2pE cosθ (D) pE cosθ, –pE sinθ

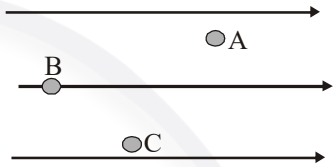
29. Two pith balls carrying equal charges are suspended from a common point by strings of equal length, the equilibrium separation between them is r. Now, the strings are rigidly clamped at half the height. The equilibrium separation between the balls now becomes



(A) $\left(\frac{1}{\sqrt{2}}\right)^2$ (B) $\left(\frac{r}{\sqrt{2}}\right)$

(C) $\left(\frac{2r}{\sqrt{3}}\right)$ (D) $\left(\frac{2r}{3}\right)$

30. A, B and C are three points in a uniform electric field. The electric potential is



(A) Maximum at A

(B) Maximum at B

(C) Maximum at C

(D) Same at all the three points A, B and C

31. In a region, the potential is represented by V(x, y, z) = 6x - 8xy - 8y + 6 yz, where V is in volts and x, y, z are in meters. The electric force experienced by a charge of 2 C situated at point (1, 1, 1) is

(A) $6\sqrt{5}$N (B) 30 N

(C) 24 N (D) $4\sqrt{35}$N

32. A conducting sphere of radius R is given a charge Q. The electric potential and the electric field at the centre of the sphere respectively are

(A) zero and $\frac{Q}{4\pi\varepsilon_0 R^2}$ (B) $\frac{Q}{4\pi\varepsilon_0 R}$ and zero

(C) $\frac{Q}{4\pi\varepsilon_0 R}$ and $\frac{Q}{4\pi\varepsilon_0 R^2}$ (D) Both are zero

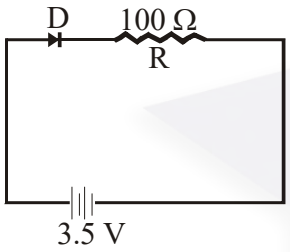
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33. If potential (in volts) in a region is expressed as V(x, y, z)= 6xy – y + 2yz, the electric field (in N/C) at point (1, 1, 0) is

(A) $-(3\hat{i}+5\hat{j}+3\hat{k})$ **(B)** $-(6\hat{i}+5\hat{j}+2\hat{k})$

(C) $-(2\hat{i}+5\hat{j}+\hat{k})$ **(D)** $-(6\hat{i}+9\hat{j}+\hat{k})$

34. In the given figure, a diode D is connected to an external resistance R = 100 Ω and an e.m.f. of 3.5 V. If the barrier potential developed across the diode is 0.5 V, the current in the circuit will be



(A) 30 mA **(B)** 40 mA

(C) 20 mA **(D)** 35 mA

35. The electric field in a certain region is acting radially outward and is given by E = Ar. A charge contained in a sphere of radius 'a' centered at the origin of the field' will be given by

(A) $4\pi\varepsilon_0 Aa^2$ **(B)** $A\varepsilon_0 a^2$

(C) $4\pi\varepsilon_0 Aa^3$ **(D)** $\varepsilon_0 Aa^3$

36. An electric dipole is placed at an angle of 30° with an electric field intensity 2×10^5 N/C. It experiences a torque equal to 4 Nm. The charge on the dipole, if the dipole length is 2 cm, is

(A) 8 mC **(B)** 2 mC

(C) 5 mC **(D)** 7 μC

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Exercise # 4 PART - 2 PREVIOUS YEAR (AIIMS)

1. Let E_a be the electric field due to a diploe in its axial plane at distant r and let E_q be the field in the equitorial plane at distant r. The relation between E_a and E_q is

(A) $E_a = E_q$ **(B)** $E_a = 2E_q$

(C) $E_q = 2E_a$ **(D)** $E_a = 3E_q$

2. A charge is placed at the centre of cube of side a then flux linked with one of its given faces will be

(A) $\frac{Q}{\varepsilon_0}$ **(B)** $\frac{Q}{6\varepsilon_0}$

(C) $\frac{Q}{\varepsilon_0 a^2}$ **(D)** $\frac{Q}{4\pi\varepsilon_0 a^2}$

3. An electron having charge e and mass m is moving in a uniform electric field E. Its acceleration will be

(A) $\frac{e^2}{m}$ **(B)** $\frac{eE}{m}$

(C) $\frac{eE^2}{m}$ **(D)** $\frac{mE}{e}$

4. An electric dipole placed in a non-uniform electric field experiences

(A) both a torque and a net force

(B) only a force but no torque

(C) only a torque but no net force

(D) no torque and no net force

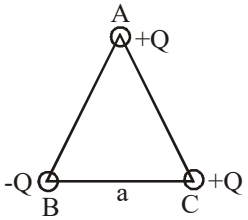
5. Three charges are placed at the vertices of an equilateral triangle of side a as shown in the given figure. The force experienced by the charge placed at the vertex A in a direction normal to BC is

(A) $\frac{Q^2}{4\pi\varepsilon_0 a^2}$

(B) $-Q2\,(4\pi\varepsilon_0 a^2)$

(C) zero

(D) $\frac{Q^2}{2\pi\varepsilon_0 a^2}$



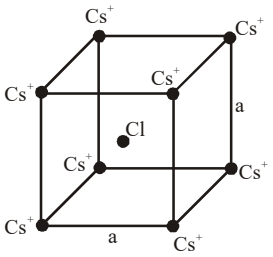
6. In the basic CsCl crystal structure, Cs^+ and Cl^- ions are arranged in a bcc configuration as shown in the figure. The net electrostatic force exerted by the eight Cs+ ions on the Cl^- ions is

(A) $\frac{1}{4\pi\varepsilon_0}\frac{4e^2}{3a^2}$

(B) $\frac{1}{4\pi\varepsilon_0}\frac{16e^2}{3a^2}$

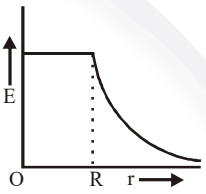
(C) $\frac{1}{4\pi\varepsilon_0}\frac{32e^2}{3a^2}$

(D) zero

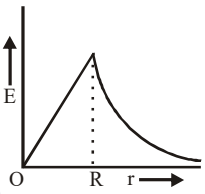


7. The electric field due to a uniformly charged nonconducting sphere of radius R as a function of the distance from its centre is represented graphically be

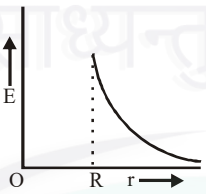
(A)



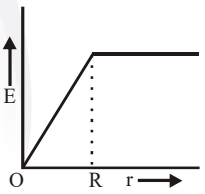
(B)



(C)

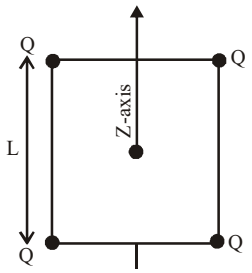


(D)



8. Four point +ve charges of same magnitude (Q) are placed at four corners of a rigid square frame as shown in figure. The plane of the frame is perpendicular to Z-axis. If –ve point charge is placed at a distance z away from the above frame ($z << L$) then

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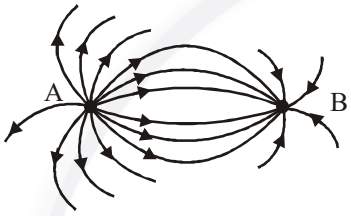


(A) –ve charge oscillates along the Z-axis
(B) it moves away from the frame
(C) it moves slowly towards the frame and stays in the plane of the frame
(D) it passes through the frame only once

9. Two parallel large thin metal sheets have equal surface charge densities ($s = 26.4 \times 10^{-12}$ C/m^2) of opposite signs. The electric field between these sheets is

(A) 1.5 N/C **(B)** 1.5×10^{-10} N/C
(C) 3 N/C **(D)** $3 \times 10–10$ N/C

10. The spatial distribution of the electric field due to two charges (A, B) is shown in figure. Which one of the following statements is correct ?



(A) A is +ve and B is –ve and |A| > |B|
(B) A is –ve and B is +ve; |A| = |B|
(C) both are +ve but A > B
(D) both are –ve but A > B

11. In case of infinite long wire electric field is proportional to

(A) $\frac{1}{r}$ **(B)** $\frac{1}{r^2}$
(C) $\frac{1}{r^3}$ **(D)** r^0

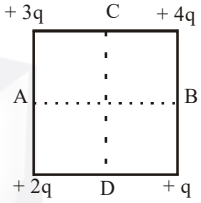
12. Electric field at the centre of a uniformly charged semicircle of radius a is

(A) $\frac{\lambda}{2\pi\varepsilon_0 a^2}$ **(B)** $\frac{\lambda}{4\pi^2\varepsilon_0 a^2}$
(C) $\frac{\lambda^2}{2\pi\varepsilon_0 a}$ **(D)** $\frac{\lambda}{2\pi\varepsilon_0 a}$

13. A charge q is uniformly distributed on a ring of radius r. A sphere of an equal radius is constructed with its centre lying on the periphery of the ring. The flux of electric field through the surface of the sphere will be

(A) $\frac{q}{\varepsilon_0}$ **(B)** $\frac{q}{2\varepsilon_0}$
(C) $\frac{q}{3\varepsilon_0}$ **(D)** $\frac{q}{4\varepsilon_0}$

14. Four charges are arranged at the corners of a square as shown in the figure. The direction of electric field at the centre of the square is along



(A) DC **(B)** BC
(C) AB **(D)** AD

15. Identify incorrect for electric charge q

(A) Quantised **(B)** Conserved
(C) Additive **(D)** Non-transferable.

16. Electric field outside a long wire carrying charge q is proportional to

(A) $\frac{1}{r}$ **(B)** $\frac{1}{r^2}$
(C) $\frac{1}{r^{3/5}}$ **(D)** $\frac{1}{r^{3/2}}$

17. An electron projected with velocity $\vec{v} = v_0\hat{i}$ in the electric field $\vec{E} = E_0\hat{j}$. Trace the path followed by the electron.

(A) Parabola
(B) Circle
(C) Straight line in + y direction.
(D) Straight line in – y direction.

18. A dipole of dipole moment 'P' is placed in non-uniform electric field along x-axis, Electric field is increasing at the rate of 1 V m^{-1} then the force on dipole is

(A) 0 **(B)** 2p
(C) p/2 **(D)** p

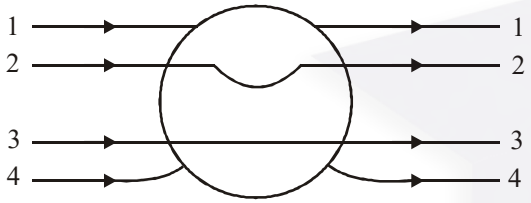
19. Electric field at a distance r from infinitely long conducting sheet is proportional to

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(A) r^{-1} (B) r^{-2}
(D) $r^{-3/2}$ (D) independent of r

20. A hemisphere is uniformly positively charged. The electric field at a point on a diameter away from the centre is directed
(A) perpendicular to the diameter
(B) parallel to the diameter
(C) at an angle tilted towards the diameter
(D) at an angle tilted away from the diameter

21. A metallic solid sphere is placed in a uniform electric field. Which path, the lines of force follow as shown in figure ?



(A) 1 (B) 2
(C) 3 (D) 4

22. Three identical charges are placed at the vertices of an equilateral triangle. The force experienced by each charge, (if $k = 1/4\pi\varepsilon_0$) is

(A) $2k\frac{q^2}{r^2}$ (B) $\frac{kq^2}{2r^2}$

(C) $\sqrt{3}k\frac{q^2}{r^2}$ (D) $\frac{kq^2}{\sqrt{2}r^2}$

23. Two charged spheres separated by a distance 'd' exert some force on each other. If they are immersed in a liquid of dielectric constant 2, then what is the force exerted, if all other conditions are same ?
(A) F/2 (B) F
(C) 2F (D) 4F

ASSERTION AND REASON

24. **Assertion :** The Coulomb force is dominating force in the universe.
Reason : The Coulomb force is weaker than the gravitational force.

25. **Assertion :** In a cavity within a conductor, the electric field is zero.
Reason : Charges in a conductor reside only at its surface.

26. **Assertion :** Gauss's law can't be used to calculate electric field near an electric dipole.
Reason : Electric dipole don't have symmetrical charge distribution.

27. **Assertion :** Gauss's law shows diversion when inverse square law is not obeyed.
Reason : Gauss's law is a consequence of conservation of charges.

28. **Assertion :** An electrostatic field line never form closed loop.
Reason : Electrostatic field is a conservative field.

29. **Assertion :** On going away from a point charge or a small electric dipole, electric field decreases at the same rate in both the cases.
Reason : Electric field is inversely proportional to square of distance from the charge or on electric dipole.

30. **Assertion :** If a conductor is given charge then no excess inner charge appears.
Reason : Electric field inside conductor is zero.

31. **Assertion :** Gaussian surface is considered carefully.
Reason : The point where electric field to be calculated should be with in the surface.

32. **Assertion :** A charged particle free to move in an electric field always moves along an electric field line.
Reason : The electric field lines diverge from a negative charge and converge at positive charge.

33. **Assertion :** If an electron and proton possessing same kinetic energy enter an electric field in a perpendicular direction, the path of the electron is more curved than that of the proton.
Reason : Electron form a larger curve due to its small mass.

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MOCK TEST

STRAIGHT OBJECTIVE TYPE

1. A point charge + Q is placed at the centroid of an equilateral triangle. When a second charge + Q is placed at a vertex of the triangle, the magnitude of the electrostatic force on the central charge is 8 N. The magnitude of the net force on the central charge when a third charge + Q is placed at another vertex of the triangle is:

(A) zero **(B)** 4 N **(C)** $4\sqrt{2}$ N **(D)** 8 N

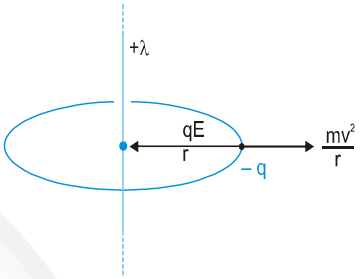
2. The electric field inside a sphere which carries a volume charge density proportional to the distance from the origin $\rho = \alpha r$ (α is a constant) is :

(A) $\frac{\alpha r^3}{4 \epsilon_0}$ **(B)** $\frac{\alpha r^2}{4 \epsilon_0}$ **(C)** $\frac{\alpha r^2}{3 \epsilon_0}$ **(D)** none of these

3. A particle of charge - q & mass *m* moves in a circle of radius *r* around an infinitely long line charge of linear charge density + λ. Then time period of revolution of charge will be :

(A) $T = 2\pi r \sqrt{\frac{m}{2k\lambda q}}$ **(B)** $T^2 = \frac{4\pi^2 m}{2k\lambda q} r^3$

(C) $T = \frac{1}{2\pi r}\sqrt{\frac{2k\lambda q}{m}}$ **(D)** $T = \frac{1}{2\pi r}\sqrt{\frac{m}{2k\lambda q}}$

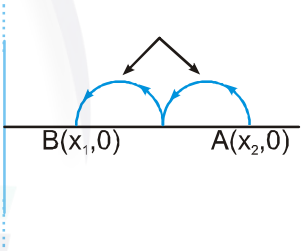


where $k = \frac{1}{4\pi\epsilon_0}$

4. An infinitely long plate has surface charge density σ. As shown in the fig, a point charge q is moved from A to B. Net work done by electric field is:

(A) $\frac{\sigma q}{2\epsilon_0}(x_1 - x_2)$ **(B)** $\frac{\sigma q}{2\epsilon_0}(x_2 - x_1)$

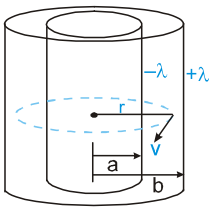
(C) $\frac{\sigma q}{\epsilon_0}(x_2 - x_1)$ **(D)** $\frac{\sigma q}{\epsilon_0}(2\pi r + r)$



5. Figure shows two large cylindrical shells having uniform linear charge densities + λ and – λ. Radius of inner cylinder is 'a' and that of outer cylinder is 'b'. A charged particle of mass m, charge q revolves in a circle of radius r (where a < r < b). Then it's speed 'v' is : (Neglect gravity and assume the radii of both the cylinders to be very small in comparison to their length.)

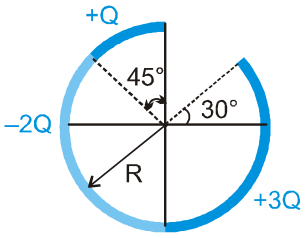
(A) $\sqrt{\frac{\lambda q}{2\pi\epsilon_0 m}}$ **(B)** $\sqrt{\frac{2\lambda q}{\pi\epsilon_0 m}}$

(C) $\sqrt{\frac{\lambda q}{\pi\epsilon_0 m}}$ **(D)** $\sqrt{\frac{\lambda q}{4\pi\varepsilon_0 m}}$



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6. Figure shows three circular arcs, each of radius R and total charge as indicated. The net electric potential at the centre of curvature is :



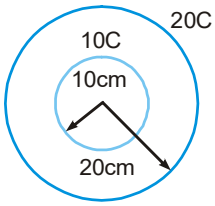
(A) $\frac{Q}{2\pi\varepsilon_0 R}$ **(B)** $\frac{Q}{4\pi\varepsilon_0 R}$

(C) $\frac{2Q}{\pi\varepsilon_0 R}$ **(D)** $\frac{Q}{\pi\varepsilon_0 R}$

7. An electric field is given by $E_x = -2x^3$ kN/C. The potential of the point (1, –2), if potential of the point (2, 4) is taken as zero, is

(A) -7.5×10^3 V **(B)** 7.5×10^3 V **(C)** -15×10^3 V **(D)** 15×10^3 V

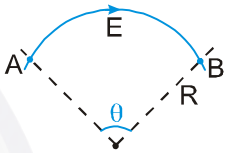
8. Two concentric uniformly charged spheres of radius 10 cm & 20 cm are arranged as shown in the figure. Potential difference between the spheres is:



(A) 4.5×10^{11} V **(B)** 2.7×10^{11} V

(C) 0 **(D)** none of these

9. Figure shows an electric line of force which curves along a circular arc. The magnitude of electric field intensity is same at all points on this curve and is equal to E. If the potential at A is V, then the potential at B is :

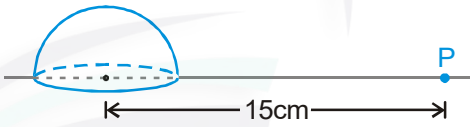


(A) $V - ER\theta$ **(B)** $V - 2ER \sin\frac{\theta}{2}$

(C) $V + ER\theta$ **(D)** $V + 2ER \sin\frac{\theta}{2}$

10. Figure shows a solid hemisphere with a charge of 5 nC distributed uniformly throughout its volume. The hemisphere lies on a plane and point P is located on the plane, along a radial line from the centre of curvature at distance 15 cm. The electric potential at point P due to the hemisphere, is :

(A) 150 V
(B) 300 V
(C) 450 V
(D) 600 V



11. A point charge Q is placed at a distance d from the centre of an uncharged conducting sphere of radius R. The potential of the sphere is (d > R) :

(A) $\frac{1}{4\pi\epsilon_0}\cdot\frac{Q}{(d-R)}$ **(B)** $\frac{1}{4\pi\epsilon_0}\cdot\frac{Q}{d}$ **(C)** $\frac{1}{4\pi\epsilon_0}\cdot\frac{Q}{R}$ **(D)** zero

12. Two point dipoles of dipole moments $p\hat{k}$ & $\frac{p}{2}\hat{k}$ are located at (0, 0, 0) & (1 m, 0, 2 m) respectively. The resultant electric field due to the two dipoles at the point (1 m, 0, 0) is :

(A) $\frac{9p}{32\pi\epsilon_0}\hat{k}$ **(B)** $\frac{-7p}{32\pi\epsilon_0}\hat{k}$ **(C)** $\frac{7p}{32\pi\epsilon_0}\hat{k}$ **(D)** none of these

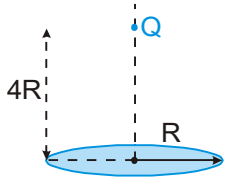
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13. A dipole of dipole moment p is kept at the centre of a ring of radius R and charge Q. The dipole moment has direction along the axis of the ring. The resultant force on the ring due to the dipole is:

(A) zero **(B)** $\frac{kPQ}{R^3}$ **(C)** $\frac{2kPQ}{R^3}$

(D) $\frac{kPQ}{R^3}$ only if the charge is uniformly distributed on the ring.

14. A charge Q is placed at a distance of 4R above the centre of a disc of radius R. The magnitude of flux through the disc is ϕ. Now a hemispherical shell of radius R is placed over the disc such that it forms a closed surface. The flux through the curved surface taking direction of area vector along outward normal as positive, is

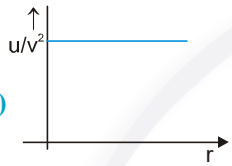


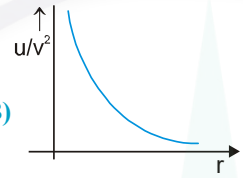
(A) zero **(B)** ϕ **(C)** $-\phi$ **(D)** 2ϕ

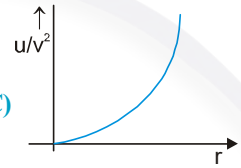
15. A conducting disc of radius R rotates about its axis with an angular velocity ω.Then the potential difference between the centre of the disc and its edge is (no magnetic field is present) :

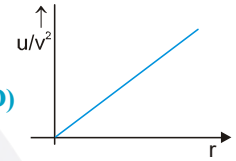
(A) zero **(B)** $\frac{m_e\omega^2R^2}{2e}$ **(C)** $\frac{m_e\omega R^3}{3e}$ **(D)** $\frac{em_e\omega R^2}{2}$

16. At distance 'r' from a point charge, the ratio $\frac{u}{v^2}$ (where 'u' is energy density and 'v' is potential) is best represented by :

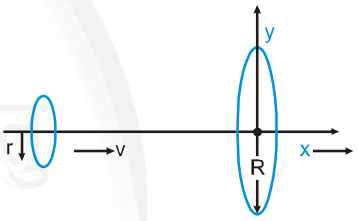
(A)


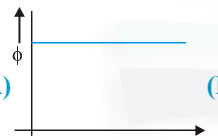
(B)


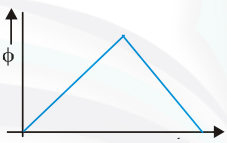
(C)


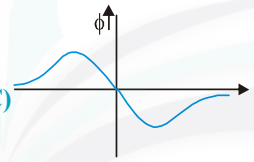
(D)


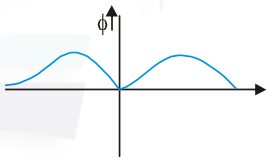
17. A ring of radius R is placed in the plane with its centre at origin and its axis along the x-axis and having uniformly distributed positive charge. A ring of radius r (<< R) and coaxial with the larger ring is moving along the axis with constant velocity then the variation of electrical flux (ϕ) passing through the smaller ring with Position will be best represented by:



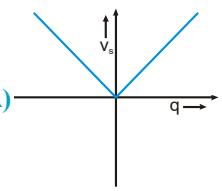
(A)


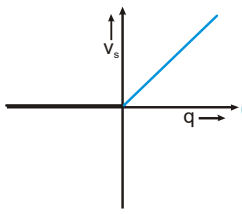
(B)


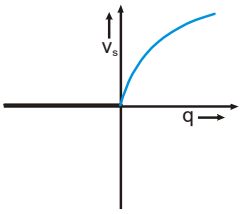
(C)


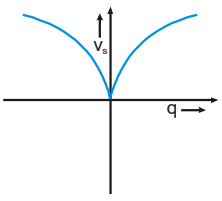
(D)


18. A negative charge Q is distributed uniformly in volume of a sphere of radius R and a point charge particle of charge q (may be negative or positive) is present on the surface of this sphere then the variation of escape velocity (v_s) of charge 'q' as a function of 'q' will be [neglect gravitational interaction]

(A)


(B)


(C)


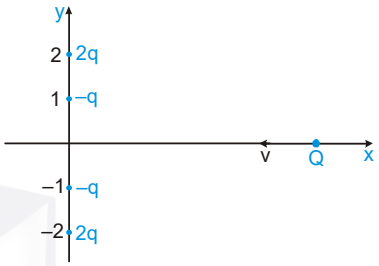
(D)


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19. Electrical potential 'v' in space as a function of co-ordinates is given by, $v = \frac{1}{x} + \frac{1}{y} + \frac{1}{z}$. Then the electric field intensity at (1, 1, 1) is given by:

(A) $-\left(\hat{i} + \hat{j} + \hat{k}\right)$ **(B)** $\hat{i} + \hat{j} + \hat{k}$ **(C)** zero **(D)** $\frac{1}{\sqrt{3}}\left(\hat{i} + \hat{j} + \hat{k}\right)$

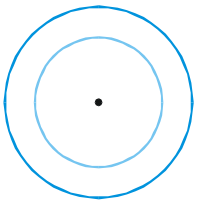
20. Four charges are rigidly fixed along the Y axis as shown. A positive charge approaches the system along the X axis with initial speed just enough to cross the origin. Then its total energy at the origin is



(A) zero **(B)** positive

(C) negative **(D)** data insufficient

21. In the figure two conducting concentric spherical shells are shown. If the electric potential at the centre is 20 V & the electric potential of the outer shell is 5 V, then the potential of the inner shell is:

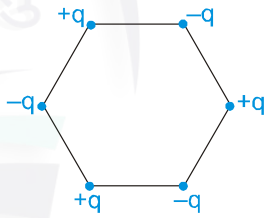


(A) 5 V **(B)** 15 V **(C)** 20 V **(D)** 25 V

22. A dipole of dipole moment $\vec{P} = 2\hat{i} - 3\hat{j} + 4\hat{k}$ is placed at point A (2, –3, 1). The electric potential due to this dipole at the point B (4, – 1, 0) is equal to (All the parameters specified here are in S.I. units.)

(A) 2×10^9 volts **(B)** -2×10^9 volts **(C)** 3×10^9 volts **(D)** -3×10^9 volts

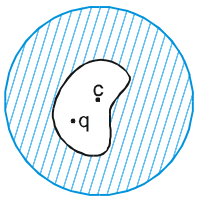
23. Six charges of magnitude + q and –q are fixed at the corners of a regular hexagon of edge length a as shown in the figure. The electrostatic interaction energy of the charged particles is :



(A) $\frac{q^2}{\pi \in_0 a}\left[\frac{\sqrt{3}}{8} - \frac{15}{4}\right]$ **(B)** $\frac{q^2}{\pi \in_0 a}\left[\frac{\sqrt{3}}{2} - \frac{9}{4}\right]$

(C) $\frac{q^2}{\pi \in_0 a}\left[\frac{\sqrt{3}}{4} - \frac{15}{2}\right]$ **(D)** $\frac{q^2}{\pi \in_0 a}\left[\frac{\sqrt{3}}{2} - \frac{15}{8}\right]$

24. The figure shows a charge q placed inside a cavity in an uncharged conductor. Now if an external electric field is switched on :



(A) only induced charge on outer surface will redistribute.

(B) only induced charge on inner surface will redistribute.

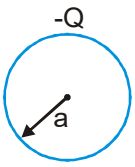
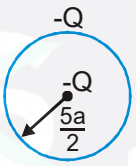
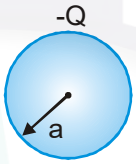
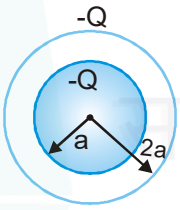
(C) both induced charge on outer and inner surface will redistribute.

(D) force on charge q placed inside the cavity will change.

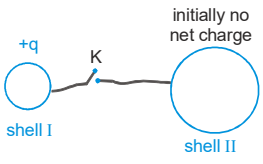
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MATRIX - MATCH TYPE

25. In each situation of column-I, some charge distributions are given with all details explained.The electrostatic potential energy and its nature is given in column -II. Then match situation in column-I with the corresponding results in column-II and indicate your answer by darkening appropriate bubbles in the 4 × 4 matrix given in the OMR.

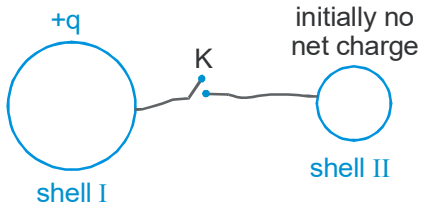
Column-I		Column-II
(A) A thin shell of radius a and having a charge – Q uniformly distributed over its surface as shown		**(P)** $\frac{1}{8\pi\epsilon_0}\frac{Q^2}{a}$ in magnitude
(B) A thin shell of radius $\frac{5a}{2}$ and having a charge – Q uniformly distributed over its surface and a point charge – Q placed at its centre as shown.		**(Q)** $\frac{3}{20\pi\epsilon_0}\frac{Q^2}{a}$ in magnitude
(C) A solid sphere of radius a and having a charge – Q uniformly distributed throughout its volume as shown.		**(R)** $\frac{2}{5\pi\epsilon_0}\frac{Q^2}{a}$ in magnitude
(D) A solid sphere of radius a and having a charge – Q uniformly distributed throughout its volume. The solid sphere is surrounded by a concentric thin uniformly charged spherical shell of radius 2a and carrying charge –Q as shown		**(S)** Positive in sign **(T)** zero

26. Column I gives certain situations involving two thin conducting shells connected by a conducting wire via a key K. In all situations one sphere has net charge +q and other sphere has no net charge. After the key K is pressed, column II gives some resulting effect. Match the figures in Column I with the statements in Column II and indicate your answer by darkening appropriate bubbles in the 4 × 4 matrix given in the ORS.

Column I		Column II
(A)		**(P)** charge flows through connecting wire

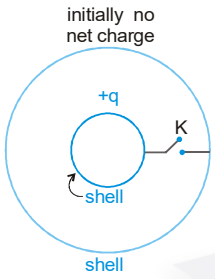
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(B)



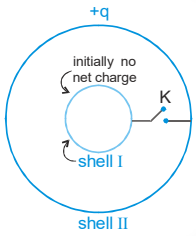
(Q) Potential energy of system of spheres decreases.

(C)



(R) No heat is produced.

(D)



(S) The sphere I has no charge after equilibrium is reached.

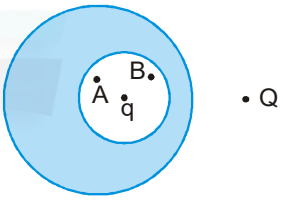
(T) charge does not flows through connecting wire

ASSERTION AND REASON TYPE

These questions contains, Statement 1 (assertion) and Statement II (reason).
(A) Statement-1 is True, Statement-2 is True; Statement-2 **is** a correct explanation for Statement-1
(B) Statement-1 is True, Statement-2 is True; Statement-2 **is NOT** a correct explanation for Statement-1
(C) Statement-1 is True, Statement-2 is False
(D) Statement-1 is False, Statement-2 is True.

27. **Assertion :** Electric field E at a point P is zero if potential at that point is zero.
Reason : Potential difference between two points in space is zero if electric field at all points in space is zero.

28. **Assertion :** A point charge q is placed at centre of spherical cavity inside a spherical conductor as shown. Another point charge Q is placed outside the conductor as shown. Now as the point charge Q is pushed away from conductor, the potential difference $(V_A - V_B)$ between two points A and B within the cavity of sphere remains constant.
Reason : The electric field due to charges on outer surface of conductor and outside the conductor is zero at all points inside the conductor.



29. **Assertion :** For a non-uniformly charged thin circular ring with net charge zero, the electric field at any point on axis of the ring is zero.
Reason : For a non-uniformly charged thin circular ring with net charge zero, the electric potential at each point on axis of the ring is zero.

30. **Assertion :** A uniformly charged disc has a pin hole at its centre. The electric field at the centre of the disc is zero.
Reason : Disc can be supposed to be made up of many rings. Also electric field at the centre of uniformly charged ring is zero.

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ANSWER KEY

EXERCISE - 1

1. D **2.** D **3.** B **4.** C **5.** D **6.** B **7.** B **8.** C **9.** C **10.** A **11.** B **12.** A **13.** D
14. C **15.** B **16.** A **17.** A **18.** B **19.** D **20.** C **21.** B **22.** B **23.** B **24.** A **25.** C **26.** C
27. B **28.** D **29.** C **30.** C **31.** C **32.** D **33.** B **34.** D **35.** A **36.** B **37.** D **38.** D **39.** B
40. B **41.** D **42.** C **43.** A **44.** B **45.** C **46.** A **47.** D **48.** A **49.** C **50.** B

EXERCISE - 2

1. B **2.** B **3.** B **4.** D **5.** A **6.** B **7.** C **8.** B **9.** C **10.** B **11.** D **12.** C **13.** B
14. B **15.** C **16.** B **17.** A **18.** D **19.** D **20.** C **21.** B **22.** A **23.** A **24.** C **25.** A **26.** A
27. C **28.** C **29.** B **30.** A **31.** C **32.** B **33.** A **34.** D **35.** B **36.** A **37.** B **38.** A **39.** A
40. D **41.** B **42.** B **43.** A **44.** A **45.** B **46.** B **47.** B **48.** C **49.** D **50.** D **51.** D **52.** B

EXERCISE - 3 : PART - 1

1. A $\rightarrow$S; B $\rightarrow$ P; C $\rightarrow$ R; D$\rightarrow$ Q
2. A $\rightarrow$ R ; B$\rightarrow$ R $\rightarrow$ C$\rightarrow$ P
3. A$\rightarrow$ P,R ; B $\rightarrow$ P,Q,S ; C$\rightarrow$ P,Q ; D $\rightarrow$ P,Q
4. A $\rightarrow$ P,Q ; B $\rightarrow$ P,Q ; C $\rightarrow$ P,Q,S; D$\rightarrow$ R,S
5. A$\rightarrow$ R; B$\rightarrow$ R ; C $\rightarrow$ P
6. A $\rightarrow$ P,S; B$\rightarrow$ Q,S ; C $\rightarrow$ Q,S ; D$\rightarrow$ S
7. A$\rightarrow$ Q ; B $\rightarrow$ P,S ; C $\rightarrow$ P,Q,R ; D $\rightarrow$ Q,R

PART - 2

1. C **2.** D **3.** C **4.** A **5.** B **6.** C **7.** B **8.** C **9.** D **10.** B **11.** B **12.** A **13.** A
14. D **15.** D **16.** D

EXERCISE - 4 : PART - 1

1. C **2.** D **3.** C **4.** C **5.** B **6.** D **7.** C **8.** B **9.** A **10.** A **11.** D **12.** C **13.** B
14. A **15.** D **16.** A **17.** C **18.** B **19.** D **20.** A **21.** D **22.** C **23.** B **24.** B **25.** C **26.** B
27. A **28.** A **29.** B **30.** B **31.** D **32.** B **33.** B **34.** A **35.** C **36.** B

PART - 2

1. B **2.** B **3.** B **4.** A **5.** C **6.** D **7.** B **8.** A **9.** C **10.** A **11.** A **12.** D **13.** C
14. A **15.** D **16.** A **17.** A **18.** D **19.** D **20.** A **21.** D **22.** C **23.** A **24.** D **25.** A **26.** A
27. B **28.** B **29.** D **30.** B **31.** A **32.** D **33.** D

MOCK TEST

1. D **2.** B **3.** A **4.** A **5.** A **6.** A **7.** B **8.** A **9.** A **10.** B **11.** B **12.** B **13.** B
14. C **15.** B **16.** B **17.** C **18.** C **19.** B **20** B **21.** C **22.** B **23.** D **24.** A
25. A $\rightarrow$ P,S; B $\rightarrow$ Q,S ; C $\rightarrow$ Q,S; D$\rightarrow$ S **26.** A $\rightarrow$P,Q ; B $\rightarrow$ P,Q ; C $\rightarrow$ P,Q,S; D $\rightarrow$ R,S,T
27. D **28.** A **29.** D **30.** A

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HINTS & SOLUTIONS

EXERCISE - 1
NEET LEVEL

1. **(D)** Coulomb's law is used to calculate the force between charges.

2. **(D)** $F \propto \frac{1}{r^2}$; so when r is halved the force becomes four times.

3. **(B)** The same force will act on both bodies although their directions will be different.

4. **(C)** The force will still remain $\frac{q_1 q_2}{4\pi\varepsilon_0 r^2}$

5. **(D)** Gravitational force between electrons

$$F_G = \frac{G(m_e)^2}{r^2}$$

Electrostatics force between electrons $F_e = k.\frac{e^2}{r^2}$

$$\frac{F_G}{F_e} = \frac{G(m_e)^2}{k.e^2} = \frac{6.67\times10^{-11}\times(9.1\times10^{-31})^2}{9\times10^9\times(1.6\times10^{-19})^2} = 2.39\times10^{-43}$$

6. **(B)** $F_a = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}, F_b = \frac{q_1 q_2}{K4\pi\varepsilon_0 r^2} \Rightarrow F_a : F_b = K : 1$

7. **(B)** Due to mutual repulsion of charges distributed on the surface of bubble.

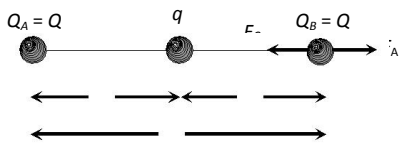
8. **(C)** We put a unit positive charge at O. Resultant force due to the charge placed at A and C is zero and resultant charge due to B and D is towards D along the diagonal BD.

9. **(C)** Surface charge density $\sigma = \frac{q}{A}$

10. **(A)** Excess of electron gives the negative charge on body.

11. **(B)** Suppose in the following figure, equilibrium of charge B is considered. Hence for it's equilibrium $|F_A| = |F_C|$

$$\Rightarrow \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{4x^2} = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{x^2} \Rightarrow q = \frac{-Q}{4}$$



Short Trick : For such type of problem the magnitude of middle charge can be determined if either of the extreme charge is in equilibrium by using the following formula.

If charge A is in equilibrium then $q = -Q_B\left(\frac{x_1}{x}\right)^2$

If charge B is in equilibrium then $q = -Q_A\left(\frac{x_2}{x}\right)^2$

If the whole system is in equilibrium then use either of the above formula.

12. **(A)** Inside the hollow sphere, at any point the potential is constant.

13. **(D)** The force is perpendicular to the displacement.

14. **(C)** A movable charge produces electric field and magnetic field both.

15. **(B)** Because current flows from higher potential to lower potential.

16. **(A)** All charge resides on the outer surface so that according to Gauss law, electric field inside a shell is zero.

17. **(A)** The electric potential $V(x, y, z) = 4x^2$ *volt*

Now $\vec{E} = -\left(\hat{i}\frac{\partial V}{\partial x} + \hat{j}\frac{\partial V}{\partial y} + \hat{k}\frac{\partial V}{\partial z}\right)$

Now $\frac{\partial V}{\partial x} = 8x, \frac{\partial V}{\partial y} = 0$ and $\frac{\partial V}{\partial z} = 0$

Hence $\vec{E} = -8x\hat{i}$, so at point $(1m, 0, 2m)$

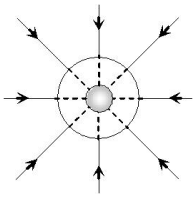
$\vec{E} = -8\hat{i}$ *volt/metre* or 8 along negative X-axis.

18. **(B)** Since potential inside the hollow sphere is same as that on the surface.

19. **(D)** On the equipotential surface, electric field is normal to the charged surface (where potential exists) so that no work will be done.

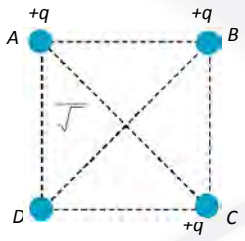
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20. **(C)** Electric lines force due to negative charge are radially inward.



21. **(B)** Potential at the centre O, $V = 4 \times \frac{1}{4\pi\varepsilon_0} \cdot \frac{Q}{a/\sqrt{2}}$

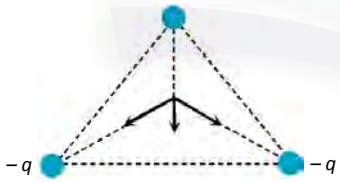
where $Q = \frac{10}{3} \times 10^{-9} C$ and $a = 8\,cm = 8 \times 10^{-2} m$



So $V = 5 \times 9 \times 10^9 \times \frac{\frac{10}{3} \times 10^{-9}}{\frac{8 \times 10^{-2}}{\sqrt{2}}} = 1500\sqrt{2}\ volt$

22. **(B)** $\because E = -\frac{dV}{dX} \Rightarrow V_x = -xE_0$

23. **(B)** Obviously, from charge configuration, at the centre electric field is non-zero. Potential at the centre due to $2q$ charge $V_{2q} = \frac{2q}{r}$



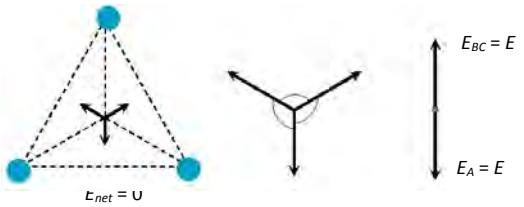
and potential due to $-q$ charge

$V_{-q} = -\frac{q}{r}$ (r = distance of centre point)

$\therefore$ Total potential $V = V_{2q} + V_{-q} + V_{-q} = 0$

24. **(A)** In non-uniform electric field. Intensity is more, where the lines are more denser.

25. **(C)**



26. **(C)** ABCDE is an equipotential surface, on equipotential surface no work is done in shifting a charge from one place to another.

27. **(B)** According to the question, $eE = mg \Rightarrow E = \frac{mg}{e}$

28. **(D)** May be at positive, zero or negative potential, it is according to the way one defines the zero potential.

29. **(C)** $a = \frac{qE}{m} \Rightarrow \frac{a_e}{a_p} = \frac{m_p}{m_e}$

30. **(C)** $K = \frac{E_{\text{without dielectric}}}{E_{\text{with dielectric}}} = \frac{2 \times 10^5}{1 \times 10^5} = 2$

31. **(C)** Potential energy $= -\ pE\cos\theta$

When $\theta = 0$. Potential energy $= -pE$ (minimum)

32. **(D)** Force on charge $F = q(E_a) = q \times \frac{k.2p}{r^3} \Rightarrow F \propto \frac{1}{r^3}$

When $r \rightarrow$ doubled; $F \rightarrow \frac{1}{8}$ times

33. **(B)** Electric potential due to dipole in it's general position is given by $V = \frac{k.p\cos\theta}{r^2} \Rightarrow V \propto \frac{1}{r^2}$

34. **(D)** Potential energy of dipole in electric field $U = -PE\cos\theta$; where θ is the angle between electric field and dipole.

35. **(A)** As the dipole will feel two forces which are although opposite but not equal.

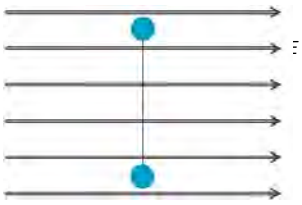
$\therefore$ A net force will be there and as these forces act at different points of a body. A torque is also there.

36. **(B)** Maximum torque $= pE$

$= 2 \times 10^{-6} \times 3 \times 10^{-2} \times 2 \times 10^5 = 12 \times 10^{-3}\ N\text{-}m.$

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37. (D) Work done $= \int_{90}^{270} pE\sin\theta\, d\theta = [-pE\cos\theta]_{90}^{270} = 0$



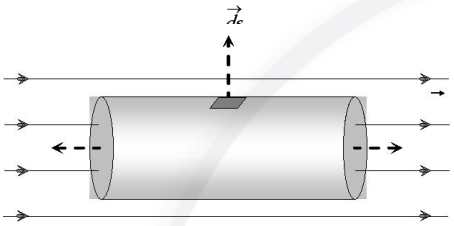
38. (D) Field along the axis of the dipole

$$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2p}{d^3} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2(q\times r)}{d^3};\ \therefore\ E \propto \frac{qr}{d^3}$$

39. (B) $p = q\times(2l) = 1.6\times10^{-19}\times10^{-10} = 1.6\times10^{-29}\ C\text{-}m$

40. (B)

41. (D) Flux through surface A $\phi_A = E\times\pi R^2$ and $\phi_B = -E\times\pi R^2$



Flux through curved surface $C = \int\vec{E}.\vec{ds} = \int E ds\cos90^o = 0$

$\therefore$ Total flux through cylinder $= \phi_A + \phi_B + \phi_C = 0$

42. (C) $E = \sigma/(2\varepsilon_0)$

43. (A) By Gauss's theorem.

44. (B) Total flux coming out from unit charge $= \vec{E}.\vec{ds} = \frac{1}{\varepsilon_0}\times1 = \varepsilon_0^{-1}$

45. (C)

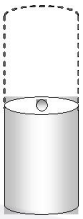
46. (A) As there is no charge residing inside the cube, hence net flux is zero.

47. (D) $\phi = \frac{\Sigma q}{\varepsilon_0} = 0$ *i.e.* net charge on dipole is zero.

48. (A) Electric flux coming out through a closed surface is q/ε_0.

49. (C) To apply Gauss's theorem it is essential that charge should be placed inside a closed surface. So imagine another similar cylindrical vessel above it as shown in figure (dotted).

50. (B)

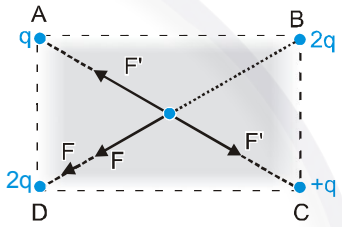


EXERCISE - 2
AIIMS LEVEL

1. (B) $\frac{K(9e)q}{r^2} = \frac{Keq}{(16-r)^2} \Rightarrow \frac{3}{r} = \frac{1}{16-r} \Rightarrow r = 12\ cm$

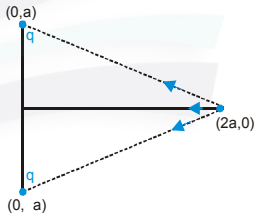
2. (B) $[\in_0] = \frac{[Q^2]}{[F][4\pi][\sigma^2]} = \frac{A^2T^2}{MLT^{-2}\times L^2} = M^{-1}L^{-3}T^4A^2$

3. (B)



Hence net force is along BD

4. (D) $F = QE = \frac{QKQx}{(R+x^2)^{3/2}}$



$F \propto (-x)$

(required equation for SHM)

5. (A) Same charges repels each other.

6. (B) $t = \sqrt{\frac{2x}{a}} = \sqrt{\frac{2x\times m}{qE}}$ $\therefore\ t \propto \sqrt{\frac{m}{q}} \propto \sqrt{m}$

[when x, q & E are same] $\therefore\ \frac{t_2}{t_1} = \sqrt{\frac{m_p}{m_e}}$

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7. **(C)** Force between two line charges On a unit length

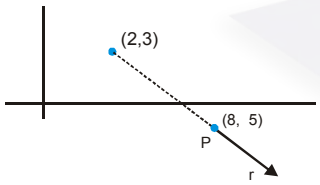
$$= \frac{2K\lambda}{r} \times \lambda = \frac{2 \times 9 \times 10^9 \times (5 \times 10^{-6})^2}{0.1} = 4.5 \text{ N/m}$$

8. **(B)**

9. **(C)** If particle will loose KE (in that direction) against work done by electric field $\frac{K}{2} = qEd \Rightarrow E = \frac{K}{2qd}$

10. **(B)** Charge moves $\perp^r$ to the field lines. So the work done will be zero.

11. **(D)**



$$E = \frac{KQ}{r^2}\tilde{r} = \frac{9 \times 10^9 \times 50 \times 10^{-6}}{100} \times \left(\frac{6\tilde{i} - 8\tilde{j}}{10}\right)$$

$= 4500$ V/m.

12. **(C)** Work done by external force = ΔU
[It is state function]

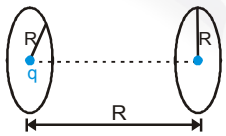
13. **(B)** By mechanical energy conservation
$(PE + KE)_i = (PE + KE)_f$

$$0 + \frac{1}{2}mv^2 + 0 = \frac{KQ^2}{d} + \frac{1}{2}m\left(\frac{v}{2}\right)^2 \text{ x2}$$

($\because$ from momentum conservation at closet approach, both particle will move with a common speed v/2)

$$\therefore d = \frac{4KQ^2}{mv^2}$$

14. **(B)** $U_i = \frac{KQ_1q}{R} + \frac{KQ_2q}{\sqrt{R^2+R^2}}$



$$U_f = \frac{KQ_1q}{\sqrt{R^2+R^2}} + \frac{KQ_2q}{R}$$

Work done by external force : $\Delta U = U_f - U_i$

15. **(C)** Let distance of closest approach be 'd' then

$$\frac{1}{2}mv^2 = \frac{K(2e)(9)(2e)}{d^2} \Rightarrow d = 10^{-12} \text{ cm}$$

16. **(B)** $V = (n-1)\frac{KQ}{r}$, $E = \frac{KQ}{r^2} \Rightarrow \frac{V}{E} = (n-1)r$

17. **(A)** $F = QE \Rightarrow 300 = 3 \times E \Rightarrow E = 100$ N/C

$$E = \frac{dV}{dx} \Rightarrow \Delta V = 100 \times \frac{1}{10} = 10 \text{ V}$$

18. **(D)** Equipotential lines are always $\perp^r$ to the electric field strength lines .

$\because$ slope of equipotential lines =2

$\therefore$ Slope of electric field must be = – 1/2

$\Rightarrow$ Electric field strength vector $= -8\tilde{i} + 4\tilde{j}$

19. **(D)** Slope from x axis

$y = 3 + x$; $\tan\theta = 1 \Rightarrow \theta = 45°$

$\therefore$ Electric field in vector from $\vec{E} = 100\left(\frac{\tilde{i} + \tilde{j}}{\sqrt{2}}\right)$

$$\therefore V = -\int_{(3,1)}^{(1,3)} \vec{E} \cdot d\vec{r}$$

$$V = \frac{-100}{\sqrt{2}}\left[\int_3^1 dx + \int_1^3 dy\right] = 50\sqrt{2}\,[-2+2] = 0$$

Alternate solution : The direction of electric field and the slope of line A (3,1) & (1,3) is $\perp$ to each others so the dot product $\vec{E}.d\vec{r}$ becomes zero.

20. **(C)** Slope of equipotential lines will be = 1/2

$\therefore$ Slope of electric lines must be = – 2

OR

$$E_x = -\left(\frac{\Delta V}{\Delta x}\right)_{y=\text{constant}} = -\frac{(4-2)\text{V}}{(4-2)\text{cm}} = -100 \text{ V/m}$$

$$E_y = -\left(\frac{\Delta V}{\Delta y}\right)_{x=\text{constant}} = -\frac{(2-4)\text{V}}{(1-0)\text{cm}} = 200 \text{ V/m}$$

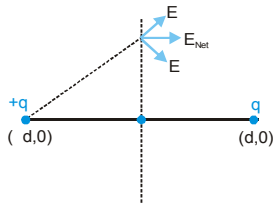
21. **(B)** $E = -\left(\frac{\partial V}{\partial x}\tilde{i} + \frac{\partial V}{\partial y}\tilde{j} + \frac{\partial V}{\partial z}\tilde{k}\right) = -k$

$\left[4x\tilde{i} - 2y\tilde{j} + 2z\tilde{k}\right]$

$= -k\left[\sqrt{16+4+4}\right] = 2k\sqrt{6}$

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22. (A) In figure (–d,0) to (d,0) on x–axis the direction of $\vec{E}$ in +ve x–axis and left side of (–d,0) the direction in –ve x–axis, but on y–axis, at any point the net electric field along the x–axis.



23. (A) $-\int_{\infty}^{\ell=0} \vec{E}.\vec{d\ell}$ is the potential at the centre of the ring which is

$$V=\int dV=\int \frac{Kdq}{0.5}=\frac{Kq}{0.5}$$

$$V=\frac{9\times10^{9}\times1.11\times10^{-10}\times2}{1}=2 \text{ volt}$$

24. (C) Electric field lines can't be closed

25. (A) W=(–pEcosθ) – (– pE)=PE(1–cosθ)

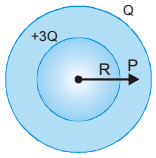
26. (A) From flux $=\int \vec{E}.\vec{ds}=\frac{Eq_{enclosed}}{\epsilon_0}$ $\therefore$ flux $=\frac{Q}{\epsilon_0}$

27. (C) Area(100 m^2) in xy plane so area vector in $\hat{k}$

$$=\int \vec{E}_z\cdot d\vec{S}=\sqrt{3}\hat{k}.100\hat{k}=173.2$$

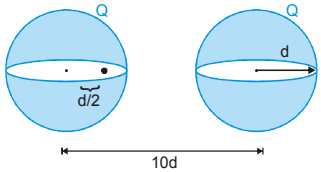
28. (C) $q=\epsilon_0\int \vec{E}_x.d\vec{x}=\epsilon_0\times600\int_{0.1}^{0.2}\frac{dx}{\sqrt{x}}=7\times10^{-12}C$

29. (B)



$$E_P=\frac{3Q}{4\pi\epsilon_0 R^2}$$

30. (A)



$$F=\frac{1}{4\pi\epsilon_0}\times\frac{Qq}{\left(\frac{19}{2}d\right)^2}+0=\frac{qQ}{361\pi\epsilon_0 d^2}$$

31. (C) For any metallic surface, electric field lines are $\perp^r$ to the surface.

32. (B) In hollow sphere potential remains constant inside the shell.

33. (A) The potential difference (work done against field) between the shell & sphere is due to the field present inside that region which is only due to the sphere.

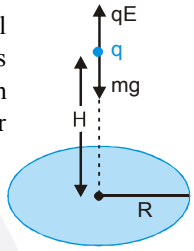
34. (D) 1, 2, & 3 are wrong because in metallic solid sphere, there is no field inside the sphere. Option (4) is correct from given reason and also it has field lines perpendicular to the surface (as required in metallic surface)

35. (B) $mg=q\times\frac{KQH}{(R^2+H^2)^{3/2}}$

The field due to ring on its axis will be maximum at

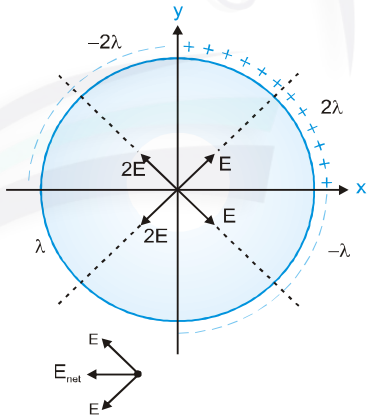
$$H=\pm\frac{R}{\sqrt{2}}$$

i.e. above that point qE force will decrease and resultant force becomes in downward direction (equilibrium position) and also in same way for below point.



$$mg=q\times\frac{KQH}{(R^2+H^2)^{3/2}}$$

36. (A) $E_{net}=\sqrt{2}E=\sqrt{2}\left[\frac{\lambda\sqrt{2}}{4\pi\epsilon_0 R}\right]\Rightarrow\vec{E}=\frac{\lambda(-\hat{i})}{2\pi\epsilon_0 R}$



37. (B) $E=\frac{KQr}{(R^2+r^2)^{3/2}}$.

It is maximum at $r=\pm\frac{R}{\sqrt{2}}$ and also E is not a linear function of r.

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38. (A) Potential at any point is a scalar quantity.

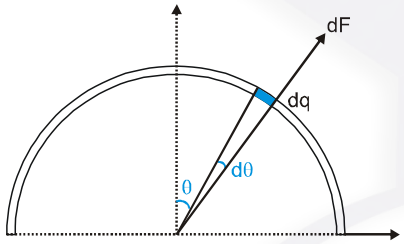
∵ Positive charge = negative charge i.e. the net charge is equal to zero. Hence potential is zero. Electric field is a vector quantity so it depends not only distance but also the way of distribution of charge.

39. (A) $V=\frac{KQ}{r}=\frac{9\times10^{9}\times10^{-8}}{\sqrt{(1-4)^2+(3-7)^2+(2-2)^2}}=18V$

and electric field lines will be in all three direction.

$$V=\frac{KQ}{r}=\frac{9\times10^{9}\times10^{-8}}{\sqrt{(1-4)^2+(3-7)^2+(2-2)^2}}=18V$$

40. (D)



$$dF=(dq)\left(\frac{\lambda}{2\pi\in_0 R}\right)=\left(\frac{qd\theta}{\pi}\right)\left(\frac{\lambda}{2\pi\in_0 R}\right)$$

$$F_{net}=\int_0^{\pi/2}2dF\cos\theta=\frac{q\lambda}{\pi^2\in_0 R}$$

$$\Rightarrow\int_0^{\pi/2}\cos\theta d\theta=\frac{q\lambda}{\pi^2\in_0 R}$$

41. (B) Here potential decreases 2V as we moves unit distance. Hence for point (1, 1, 1) from (0, 0, 0). The total potential decrease is 2 +2 +2 = 6V. Hence the potential at point will (10 – 6) = 4V.

42. (B) If Y is fixed i.e. another force is exist on Y additional to the mutual interaction between X & Y. So the net force on system (X &Y) is not zero so p is changed but total energy always remain conserved.

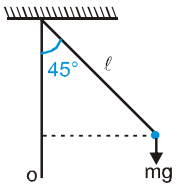
43. (A) Equal electrostatic force (mutual interaction) acts on X and Y but in opposite direction which accelerate Y but retards X. After long time the velocity of X becomes zero while Y becomes u.

44. (A) Velocity due to acceleration $=\frac{10^{-6}\times300}{10^{-3}}\times10$

= 3 m/s

Then the resultant velocity may be between 1 m/s and 7 m/s

45. (B) By work energy theorem $W_g+W_{elec}=\Delta KE$



$$mg\ell\left(1-\frac{1}{\sqrt{2}}\right)+qE\times\frac{\ell}{\sqrt{2}}=\frac{1}{2}mv^2-0$$

$$\left(\because E=\frac{mg}{q}\right)\ u=\sqrt{2g\ell}\ ;\ W=\frac{u}{\ell}=\sqrt{\frac{2g}{\ell}}$$

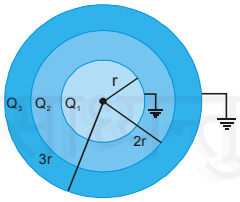
46. (B) Energy at surface = Energy at centre

$$\frac{1}{2}mu^2+\frac{Kq\times q}{R}=\frac{3}{2}\frac{Kq}{R}\times q+0$$

$$\therefore\quad U=\frac{q}{\sqrt{4\pi\in_0 mR}}$$

47. (B) Due to the induction, the opposite nature of charge is induced at near by surface.

48. (C)



Potential at outermost shell

$$=\frac{KQ_1}{3r}+\frac{KQ_2}{3r}+\frac{KQ_3}{3r}=0$$

$$\Rightarrow Q_1+Q_2+Q_3=0\quad\text{....(i)}$$

and potential at innermost surface

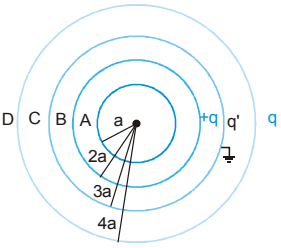
$$\frac{KQ_1}{r}+\frac{KQ_2}{2r}+\frac{KQ_3}{3r}=0$$

$$\Rightarrow\frac{K\left[6Q_1+3Q_2+2Q_3\right]}{6r}=0\ \text{....(ii)}$$

From eq. (i) & (ii) $Q_1=-\frac{Q_2}{4}$ and also $\frac{Q_3}{Q_1}=3$.

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49. (D)

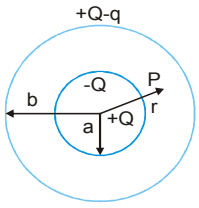


$$\text{Potential at C} = \frac{Kq}{3a} - \frac{Kq}{4a} + \frac{Kq'}{3a} = 0 \Rightarrow q' = -\frac{q}{4}$$

$$\text{Potential at A} = \frac{Kq}{2a} - \frac{Kq}{4a} - \frac{K\frac{q}{4}}{3a} = \frac{Kq}{6a}.$$

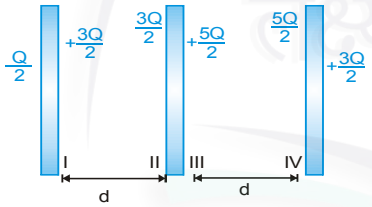
Hence $V_A - V_C = \frac{Kq}{6a}$

50. (D)

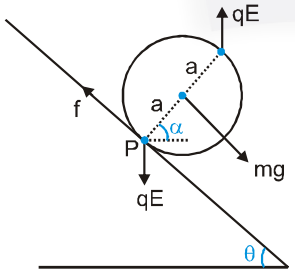


from figure $V_P = \frac{K(Q-q)}{b}$

51. (D) Final charge distribution on plate



52. (B)



For rotational equilibrium, $\sum \tau_P = 0$

$\Rightarrow mga\cos\alpha - qE(2a\cos\alpha) = 0 \Rightarrow E = \frac{mg}{2q}$

EXERCISE - 3

P-1 (Matrix Match)

1. A → s; B → p; C → r; D → q

Electric field $\vec{E} = -\frac{\partial V}{\partial x}\tilde{i} - \frac{\partial V}{\partial y}\tilde{j}$

For (A) : $\vec{E} = -\tilde{i} + \frac{1}{\sqrt{3}}\tilde{j}$

For (B) : $\vec{E} = +\tilde{i}$

For (C) : $\vec{E} = -\tilde{i} + \sqrt{3}\tilde{j}$

For (D) : $\vec{E} = +\frac{1}{\sqrt{3}}\tilde{i} + \sqrt{3}\tilde{j}$

2. A → r ; B → r → C → p

Electric field due to metallic plates remains same and constant at near by points.

[A] For $\sigma_1 + \sigma_2 = 0 \Rightarrow \sigma_1 = -\sigma_2$

$\therefore$ Electric field at a point is equal & opposite in direction.

$\sigma_1 + \sigma_2 = 0 \Rightarrow \sigma_1 = -\sigma_2$

[B] $\sigma_1 + \sigma_2 > 0 \Rightarrow \sigma_1 \& \sigma_2$ [densities]

either both positive or opposite but positive has a greater magnitude. So the net electric field will be away from the plates in region I & III.

[C] Same explanation according to [B]

3. A → p,r ; B → p,q,s ; C → p,q ; D → p,q

$\because$ Electric field due to an electric dipole at a point on equatorial line of dipole makes either 0° or 180° with the dipole moment of another dipole.

$\therefore$ Torque on dipole $\vec{\tau} = \vec{P} \times \vec{E}$ becomes zero

($\because \theta = 0$ or $\theta = 180°$) Hence in column II,

[P] option is suit for every queries for column I.

Electrostatic potential energy (U) =– PE cosθ

θ = Angle between moment & electric field.

[A] Here $\theta = 180°$ $\therefore U = -PE\cos 180° = PE$ (+ve)

[B] Here $\theta = 0°$ $\therefore U = -PE\cos\theta = -PE$ (–ve)

[C] & [D] : $\theta < 90°$ $\therefore U =$ –ve

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4. **A → p,q ; B → p,q ; C → p,q,s; D→ r,s**

(A) Initially, the potential difference exist between both shells, so positive charge is flow from high to low potential.

Every system wants to acquire minimum potential energy if possible for stability. So charge flown to achieve it.

(B) As explained in [A], charge flow does not depend on the size of sphere.

(C) Charge flow through wire until the potential becomes same for both shells.

(D) Potential is same everywhere inside a conducting shell. So no charge is flow through connecting wire, so no heat is produced.

5. **A→ r; B→ r ; C → p**

(A) Electric field at a point is the vector sum of all individual fields at that point

(B) Electric flux $\oint \vec{E}\cdot d\vec{S} = \frac{q_{enc}}{\epsilon_0}$

(C) Electric flux $\oint \vec{E}\cdot d\vec{S} = \frac{q_{enclosed}}{\epsilon_0}$

6. **A → p,s; B→ q,s ; C → q,s ; D→ s**

Electrostatic potential energy

= self energy + interaction energy

(A) Self energy of uniformly charged thin shell

$= \frac{KQ^2}{2a}$ (radius a)

(B) Self energy $= \frac{KQ^2}{2\times\frac{5a}{2}}$ &

Interaction energy $= \frac{KQ^2}{\frac{5a}{2}}$

(C) Self energy of solid sphere of radius 'a'= $\frac{3KQ^2}{5a}$

7. **A→ q ; B → p,s ; C → p,q,r ; D → q,r**

EXERCISE - 3

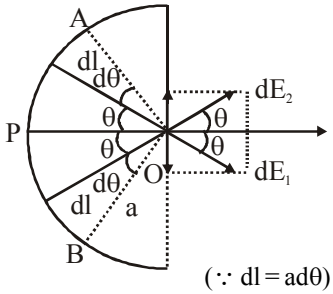
P-2 (Assertion & Reason)

1.	C	**2.**	D	**3.**	C	**4.**	A	**5.**	B	**6.**	C
7.	B	**8.**	C	**9.**	D	**10.**	B	**11.**	B	**12.**	A
13.	A	**14.**	D	**15.**	D	**16.**	D				

EXERCISE - 4

P-1 (NEET/AIPMT)

1. **(C)** Considering symmetric elements each of length dl at Aand B, we know that electric fields perpendicular to PO are cancelled and those along PO are added. The electric field due to an element of length dl(=adθ) along PO.



$$dE = \frac{1}{4\pi\varepsilon_0}\frac{d\theta}{a^2}\cos\theta$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{\lambda dl}{a^2\cos\theta}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{\lambda(a\,d\theta)}{a^2}\cos\theta \qquad (\because dl = ad\theta)$$

Net electric field at O

$$E = \int_{-\pi/2}^{\pi/2} dE = 2\int_0^{\pi/2}\frac{1}{4\pi\varepsilon_0}\frac{\lambda\, a\cos\theta\, d\theta}{a^2}$$

$$= 2.\frac{1}{4\pi\varepsilon_0}\frac{\lambda}{a}[\sin\theta]_0^{\pi/2}$$

$$= 2.\frac{1}{4\pi\varepsilon_0}.\frac{\lambda}{a}.1 = \frac{\lambda}{2\pi\varepsilon_0 a}$$

2. **(D)** According to Gauss's law, the electric flux through a closed surface is equal to $\frac{1}{\varepsilon_0}$ times the net charge enclosed by the surface.

Since, q is the charge enclosed by the surface, then electric flux, $\phi = \frac{q}{\varepsilon_0}$

If charge q is placed at a corner of cube, it will be divided into 8 such cubes. Therefore, electric flux through the cube is

$$\phi' = \frac{1}{8}\left(\frac{q}{\varepsilon_0}\right)$$

3. **(C)** The electric flux emerging from the cube is

$$\phi = \frac{1}{\varepsilon_0}\times \text{ charge enclosed} \qquad (q_{inside})$$

$$= \frac{1}{\varepsilon_0}\times q_{inside}\times 10^{-6}$$

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$$= \frac{1}{\varepsilon_0} \times q_{inside} \times 10^{-6} \qquad [q_{inside} = q \times 10^{-6})$$

Since, a cube has six faces, so electric flux through each face is

$$\phi' = \frac{\phi}{6} = \frac{1}{6\varepsilon_0} \times q \times 10^{-6} = \frac{q \times 10^{-6}}{6\varepsilon_0}$$

4. **(C)** Electrostatic potential energy of charge +q placed at the centre of cube is

$$U = 8 \times \frac{1}{4\pi\varepsilon_0} \times \frac{q(-q)}{\text{half} - \text{diagonal distance}}$$

$$= 8 \times \frac{1}{4\pi\varepsilon_0} \frac{-q^2}{b\frac{\sqrt{3}}{2}} \left[\begin{matrix}\text{diagonal of cube } = \sqrt{3}b \\ \text{where, b = side of cube}\end{matrix}\right]$$

$$= \frac{-4q^2}{\sqrt{3}\pi\varepsilon_0 b}$$

5. **(B)** Let charges on an electron and hydrogen nucleus be q_1 and q_2. Then, Coulomb's force between them at a distance r is

$$F = -\frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}\hat{r}$$

Putting, $\frac{1}{4\pi\varepsilon_0} = k$ (given)

$$F = -k\frac{q_1q_2}{r^2}\hat{r}$$

Since, the nucleus of hydrogen atom has one proton, so charge on nucleus is e i.e. $q_2 = +e$

also $q_1 = e$ for electron

So, $F = -k\frac{e.e}{r^2}\hat{r} = -k\frac{e^2}{r^2}\hat{r}$

but $\hat{r} = \frac{r}{|r|} = \frac{r}{r}$

Hence, $F = -k\frac{e^2}{r^2}.\frac{r}{r} = -k\frac{e^2}{r^3}.r$

6. **(D)** As we know expression of Gauss's law is

$$\oint E.ds = \frac{q_{inside}}{\varepsilon_0}$$

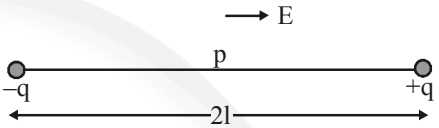
So, $\phi = \frac{q}{\varepsilon_0} \qquad \left[\phi = \oint E.ds\right]$

This is the net flux coming out from cube.

Since, a cube has 6 sides so electric flux through any face is

$$\phi' = \frac{\phi}{6} = \frac{q}{6\varepsilon_0}$$

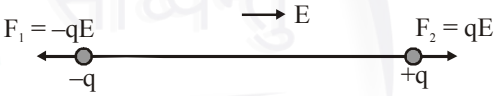
7. **(C)** An electric dipole is an arrangement of two equal ans opposite charges placed at a distance 2l. The dipole is placed in electric field as such its dipole moment is in direction of electric field as shown in figure. Direction of dipole moment is from negative to positive charg.



Now, force on the charge q is $F_2 = qE$ along the direction of E and force on charge –q is

$F_1 = -qE$ in the direction opposite to E.

Since, forces on the dipole are equal and opposite. so net force on the electric dipole is zero.



Now, potential energy of the dipole

$U = -pE\cos\theta$

where, θ is the angle between direction of electric field and direction of dipole moment.

$\therefore \quad \theta = 0°$

Hence, $U = -pE\cos 0° = pE$ (minimum)

8. **(B)** Kinetic energy of bullet = qV

$$\left[\begin{matrix}\text{q= charge on bullet} \\ \text{V = potential difference}\end{matrix}\right]$$

From energy conservation,

$$\frac{1}{2}mv^2 = qV \Rightarrow V = \frac{mv^2}{2q}$$

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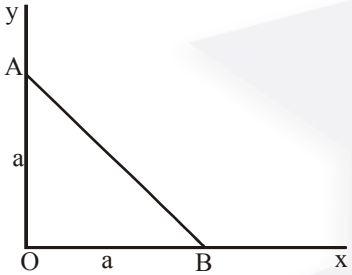
Given, $m = 2g = 2 \times 10^{-3}$ kg, $v = 10$ m/s,
$q = 2\mu C = 2 \times 10^{-6}$ C
Substituting the values in relation for V, we obtain

$$V = \frac{2\times10^{-3}\times(10)^2}{2\times2\times10^{-6}}$$

$$= 50 \times 10^3 \text{ V}$$

$$= 50 \text{ kV}$$

9. **(A)** Potential at A, $V_A = \frac{1}{4\pi\varepsilon_0}\frac{q}{a}$



Thus, work done in carrying a test charge $-Q$ from A to B

$$W = (V_A - V_B)(-Q) = 0$$

10. **(A)** When charge q_3 is at C, then its potential energy is

$$U_C = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1q_3}{0.4} + \frac{q_2q_3}{0.5}\right)$$

When charge q_3 is at D, then potential energy is

$$U_D = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1q_3}{0.4} + \frac{q_2q_3}{0.1}\right)$$

Hence, change in potential energy

$$\Delta U = U_D - U_C = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_2q_3}{0.1} - \frac{q_2q_3}{0.5}\right)$$

but $\Delta U = \frac{q_3}{4\pi\varepsilon_0}k$

$$\frac{q_3}{4\pi\varepsilon_0}k = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_2q_3}{0.1} - \frac{q_2q_3}{0.5}\right)$$

$$k = q_2(10-2) = 8q_2$$

11. **(D)** When an electric dipole is placed in an electric field E, a torque $\tau = p \times E$ acts on it. This torque tries to rotate the dipole.
If the dipole is rotated from an angle θ_1 to θ_2, then work done by external force is given by

$$W = pE(\cos\theta_1 - \cos\theta_2) \quad \text{.....(i)}$$

Putting $\theta_1 = 0°$, $\theta_2 = 90°$ in the Eq. (i), we get

$$W = pE(\cos 0° - \cos 90°)$$

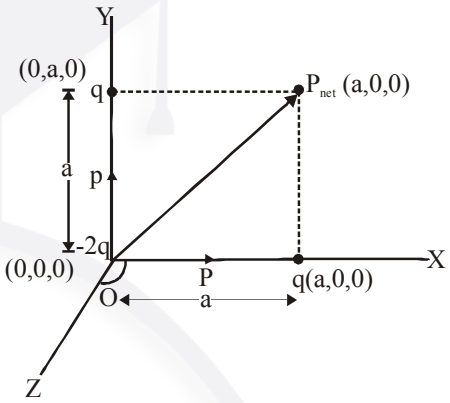
$$= pE(1-0) = pE$$

12. **(C)** As we know, the electric flux (ϕ) through any surface area id given by

$$\phi = E.ds = |E|\,|ds|\cos\theta$$

As according to question, surface area is in plane of paper and E is also in plane of paper. So, angle between area vector and E is 90°
So, $\phi = E.ds = |E|\,|ds|\cos 90° = 0°$

13. **(B)** Choose the three coordinate axes are X, Y and Z and plot the charges with the given coordinates as shown O is the origin at which –2q charge is placed. The system is equivalent to two dipoles along x and y-directionsw respectively. The dipole moments of two dipoles are shown in figure.



The resultant dipole moment will be directed along OP where coordinate ofg P_{net} is given by (a, a, 0). The magnitude of resultant dipole moment is

$$P_{net} = \sqrt{p^2 + q^2}$$

$$= \sqrt{(qa)^2 + (qa)^2} = \sqrt{2}qa$$

14. **(A)** Gauss's law states that the net electric flux through any closed surface is equal to the net charge inside the surface divided by ε_0.

i.e. $\phi_{total} = \frac{q_{inside}}{\varepsilon_0}$

Let electric flux linked with surfaces A, B and C are ϕ_A, ϕ_B and ϕ_C respectively, i.e.

$$\phi_{total} = \phi_A + \phi_B + \phi_C$$

Since, $\phi_C = \phi_A$

$$\therefore \quad 2\phi_A + \phi_B = \phi_{total} = \frac{q}{\varepsilon_0}$$

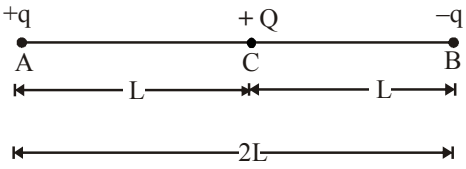
or $$\phi_A = \frac{1}{2}\left(\frac{q}{\varepsilon_0} - \phi_B\right)$$

But $\phi_B = \phi$ (given)

Hence, $$\phi_A = \frac{1}{2}\left(\frac{q}{\varepsilon_0} - \phi\right)$$

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15. **(D)** In case I, when charge +Q is situated at C.



Electric potential energy of system,

$$U_1 = \frac{1}{4\pi\varepsilon_0}\frac{(q)(-q)}{2L} + \frac{1}{4\pi\varepsilon_0}\frac{(-q)Q}{L} + \frac{1}{4\pi\varepsilon_0}\frac{qQ}{L}$$

In case II, when charge +Q is moved from C to D



Electric potential energy of system in that case,

$$U_2 = \frac{1}{4\pi\varepsilon_0}.\frac{(q)(-q)}{2L} + \frac{1}{4\pi\varepsilon_0}\frac{qQ}{3L} + \frac{1}{4\pi\varepsilon_0}\frac{(-q)(Q)}{L}$$

As we know thjat work done in moving a charge is equal to change in potential energy between the points it has been moved.

Work done, $\Delta U = U_2 - U_1$

$$= \left(\frac{1}{4\pi\varepsilon_0}\frac{q^2}{2L} + \frac{1}{4\pi\varepsilon_0}.\frac{qQ}{3L} - \frac{1}{4\pi\varepsilon_0}\frac{qQ}{L}\right)$$

$$-\left(-\frac{1}{4\pi\varepsilon_0}\frac{q^2}{2L} - \frac{1}{4\pi\varepsilon_0}.\frac{qQ}{L} + \frac{1}{4\pi\varepsilon_0}\frac{qQ}{L}\right)$$

$$= \frac{qQ}{4\pi\varepsilon_0}.\left(\frac{1}{3L} - \frac{1}{L}\right) = \frac{qQ}{4\pi\varepsilon_0}\frac{(1-3)}{3L}$$

$$= \frac{-2qQ}{12\pi\varepsilon_0 L} = -\frac{qQ}{6\pi\varepsilon_0 L}$$

16. **(A)** As potential at any point due to a point charge is given by,

$$V = \frac{kQ}{r} \qquad \left[k = \frac{1}{4\pi\varepsilon_0}\right]$$

$$V = \frac{1}{4\pi\varepsilon_0}\times\frac{Q}{r}$$

$$E = \frac{1}{4\pi\varepsilon_0}\times\frac{Q}{r^2}$$

$$E = \frac{4\pi\varepsilon_0 V^2}{Q} = 4\pi\varepsilon_0 \times \frac{Q^2\times 10^{22}}{Q}$$

$$E = 4\pi\varepsilon_0 Q \times 10^{22}\ \text{V/m}$$

17. **(C)** Energy of charge capacitor $= \frac{1}{2}CV^2$

Energy given by cell $= CV^2 = \frac{A\varepsilon_0}{d}\times(Ed)^2$

As, $V = Ed = A\varepsilon_0 E^2 d$

18. **(B)** **Concept** Net electric field at the centre of thin conducting ring is zero.

$$E_{\text{total}=0}$$
$$E_{AKB} + E_{ACDB} = 0$$
$$E_{ACDB} = -E_{AKB}$$
$$E_{ACDB} = E \text{ along OK}$$

19. **(D)** $V_A = \frac{1}{4\pi\varepsilon_0}\frac{\sigma 4\pi a^2}{a} - \frac{1}{4\pi\varepsilon_0}\frac{\sigma 4\pi b^2}{b} + \frac{1}{4\pi\varepsilon_0}.\frac{\sigma 4\pi c^2}{c}$

$$= \frac{\sigma}{\varepsilon_0}(a-b+c) = \frac{\sigma}{\varepsilon_0}(2a) \qquad [\because c = a+b]$$

$$V_B = \frac{1}{4\pi\varepsilon_0}.\frac{\sigma 4\pi a^2}{c} - \frac{1}{4\pi\varepsilon_0}\frac{\sigma 4\pi b^2}{b} + \frac{1}{4\pi\varepsilon_0}.\frac{\sigma 4\pi c^2}{c}$$

$$= \frac{\sigma}{\varepsilon_0}\left(\frac{a^2}{c} - b + c\right) = \frac{\sigma}{\varepsilon_0}(2a) \qquad [\because c = a+b]$$

$$V_C = \frac{1}{4\pi\varepsilon_0}.\frac{\sigma 4\pi a^2}{c} - \frac{1}{4\pi\varepsilon_0}\frac{\sigma 4\pi b^2}{c} + \frac{1}{4\pi\varepsilon_0}.\frac{\sigma 4\pi c^2}{c}$$

$$= \frac{\sigma}{\varepsilon_0}\left(\frac{a^2}{c} - \frac{b^2}{c} + c\right) = \frac{\sigma}{\varepsilon_0}(2a) \qquad [\because c = a+b]$$

Hence, $V_A = V_C = V_B$

20. **(A)** Potential gradient relates with electric field according to the following relation, $E = \frac{-dV}{dr}$

$$E = \frac{-dV}{dr}$$

As $V = -x^2y - xz^2 + 4$

So, $E = -\frac{dV}{dx}\hat{i} - \frac{dV}{dy}\hat{j} - \frac{dV}{dz}\hat{k}$

$$E = (2xy + z^3)\hat{i} + x^2\hat{j} + 3xz^2\hat{k}$$

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21. **(D)** Flux of electric field E through any area A is defined $\phi = E.A\cos\theta$ or $\phi = E.A = 0$, the lines are parallel to the surface.

22. **(C)** Two positive ions each carrying a charge q are kept at a distance d, then it is found that force of repulsion between them is

$$F = \frac{kqq}{d^2} = \frac{1}{4\pi\varepsilon_0}\frac{qq}{d^2}$$

where, $q = ne$

$$\therefore \quad F = \frac{1}{4\pi\varepsilon_0}\frac{n^2e^2}{d^2}$$

$$\Rightarrow \quad n = \sqrt{\frac{4\pi\varepsilon_0 Fd^2}{e^2}}$$

23. **(B)** Potential at any distance r due to a point charge is given by

$$V = V = \frac{kq}{r} \qquad \left[k = \frac{1}{4\pi\varepsilon_0}\right]$$

Given, $V = 2V_{positive} + 2V_{negative}$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{2q}{L} - \frac{2q}{L\sqrt{5}}\right]$$

$$V = \frac{2q}{4\pi\varepsilon_0 L}\left(1 - \frac{1}{\sqrt{5}}\right)$$

24. **(B)** Total flux through any enclosed surface is given by,

$$\phi_{net} = \frac{\text{net charge enclosed}}{\varepsilon_0}$$

hence, we can say that the electric flux depends only on net enclosed charge by surface.

25. **(C)** As we know that the energy stored in the capacitor is given by

$$U = \frac{1}{2}CV^2 \qquad \begin{bmatrix} C = \text{capacitance of capacitor} \\ V = \text{voltage across the plate} \end{bmatrix}$$

$$U = \frac{1}{2}\left(\frac{A\varepsilon_0}{d}\right)(Ed^2) \qquad \left(\because C = \frac{\varepsilon_0 A}{d} \text{ and } V = Ed\right)$$

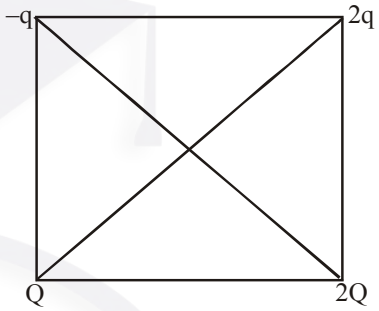
$$U = \frac{1}{2}\frac{\varepsilon_0 A}{d}(Ed)^2, \qquad U = \frac{1}{2}\varepsilon_0 E^2 Ad$$

26. **(B) Concept :** According to Gause's law, the electric flux through a closed surface is equal to $\frac{1}{\varepsilon_0}$ times the net charge enclosed by the surface.

As the charge enclosed = q/8

So, electric flux $= \frac{q_{enclosed}}{\varepsilon_0} \Rightarrow \phi = \frac{q}{8\varepsilon_0}$

27. **(A)** As, shown in figure



If potential at centre is zero, then

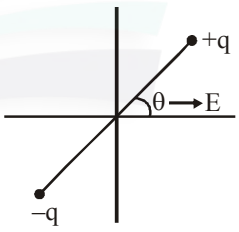
$$V_1 + V_2 + V_3 + V_4 = 0$$

$$\Rightarrow \quad -\frac{kQ}{r} - \frac{kq}{r} + \frac{k2Q}{r} + \frac{k2q}{r} = 0$$

$$\Rightarrow \quad -Q - q + 2q + 2Q = 0$$

$$\therefore \quad Q = -q$$

28. **(A)** Here, torque, $t = pE\sin\theta$



Potential energy of the dipole,

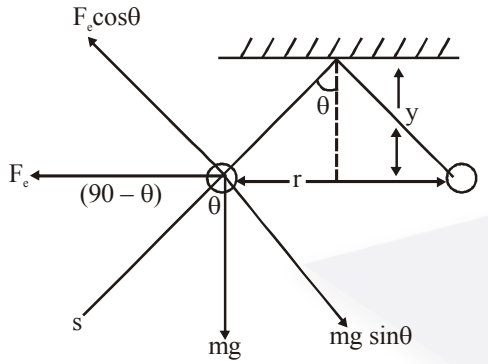
$$U = \int \tau d\theta = \int_{\pi/2}^{0} pE\sin\theta d\theta = -pE[\cos\theta]_{\pi/2}^{\theta}$$

$$= -pE\cos\theta$$

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29. (B) Case I $F_e \cos\theta = mg\sin\theta$

$$\Rightarrow \frac{F_e}{mg} = \tan\theta$$



$$\Rightarrow mg = \frac{F_e}{\tan\theta} \quad \text{..... (i)}$$

Case II $Fe' \cos\theta_1 = mg\sin\theta_1$

$$\Rightarrow \frac{Fe'}{mg} = \tan\theta_1$$

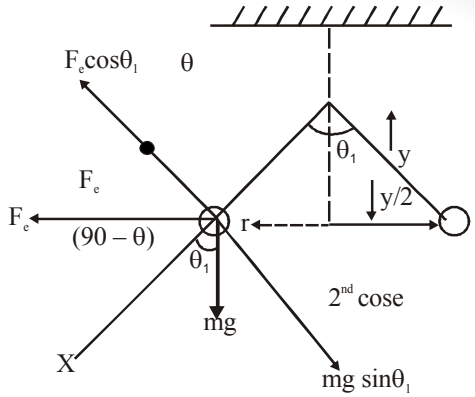
$$\Rightarrow mg = \frac{Fe'}{\tan\theta_1} \quad \text{..... (ii)}$$

From Eqs. (i) and (ii), we get

$$\frac{Fe}{\tan\theta} = \frac{Fe'}{\tan\theta_1} \Rightarrow \frac{Fe}{Fe'} = \frac{\tan\theta}{\tan\theta_1}$$

$$\text{As, } \tan\theta = \frac{P(\text{perpendicular})}{b(\text{base})} = \frac{r}{2y}$$

$$\tan\theta_1 = P/b = \frac{r}{2\times y}\times 2 = \frac{r}{y}$$



$$\frac{Fe}{Fe'} = \frac{r}{2y\times r}\times y \Rightarrow Fe' = 2Fe$$

$$\text{So, } \frac{kq^2}{r'^2} = \frac{2kq^2}{r^2}$$

$$\frac{1}{r'} = \frac{\sqrt{2}}{r}$$

$$\therefore \quad r' = \frac{r}{\sqrt{2}}$$

30. (B) The electric field is maximum at B, because field is directed along decreasing potential $V_B > V_C > V_A$.

31. (D) As we know that relation between potential difference and electric field E in a particular region is given by

$$E = -\frac{dV}{dt}$$

$$\text{As } V = 6x - 8xy - 8y + 6yz$$

$$\text{So, } E = -\frac{dV}{dt}$$

$$= [6 - 8y)\hat{i}+) - (8x - 8 + 6z)\hat{j} + 6y\hat{k}j$$

The value of E at coordinate (1, 1, 1)

$$E = -[-2\hat{i} - 10\hat{j} + 6\hat{k}]$$

$$\text{So, } E_{net} = \sqrt{(-2)^2 + (-10)^2 + 6^2} = 2\sqrt{35}\,N/C$$

and force on charge q due to E_{net} is given by

$$F = q\,E_{net} = 2\times 2\sqrt{35} = 4\sqrt{35}N$$

32. (B) In a conducting sphere charge id present on the surface of the sphere. So, electric field inside will be zero and potential remains constant from centre to surface of sphere and is equal to $\frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$

33. (B) Given, potential in a region, $V = 6xy - y + 2yz$

Electric field in a region

$$E = -\frac{\partial V}{\partial x}\hat{i} - \frac{\partial V}{\partial y}\hat{j} - \frac{\partial V}{\partial z}\hat{k}$$

$$\Rightarrow E = -6y\hat{i} - (6x - 1)\hat{j} - 2y\hat{k}$$

At (1, 1, 0), electric field can be expressed,

$$E = -(6\times 1\hat{i}) - (6\times 1 - 1)\hat{j} - 2\times 1.\hat{k}$$

$$= -(6\hat{i} + 5\hat{j} + 2\hat{k})\,N/C$$

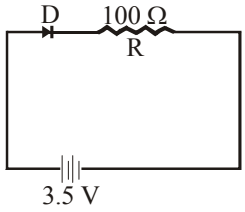
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34. **(A)** Given, external resistance R = 100 Ω and an emf is 3.5 V. Potential barrier across the diode is 0.5 V, Potential difference on R = 3.5 V – 0.5 V = 3.0 V

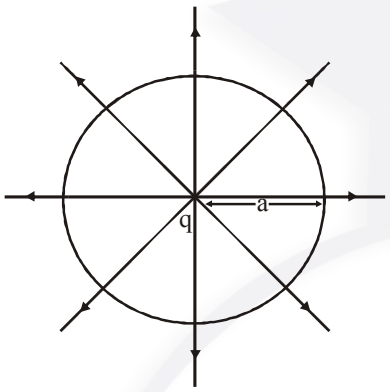
Current in circuit

$$I = \frac{V}{R} = \frac{3}{100}$$

$$= 0.03A = 30mA$$



35. **(C)** Given $E = Ar$ ..... (i)



Here $r = a \Rightarrow E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{a^2}$

From Eq. (i)

$$\frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{a^2} = Aa \Rightarrow q = 4\pi\varepsilon_0 Aa^3$$

36. **(B)** ∵ Torque on an electric dipole in an electric field,

$\tau = p \times E \Rightarrow |\tau| = pE\sin\theta$

where, θ is angle between E and p

$\Rightarrow \quad 4 = p \times 2 \times 10^5 \times \sin 30$

$\Rightarrow \quad p = 4 \times 10^{-5}$ cm

$\Rightarrow \quad p = q2l$

$\therefore \quad q2l = 4 \times 10^{-5}$

where, $2l = 2\text{ cm} = 2 \times 10^{-4}$ m

$$\therefore \quad q = \frac{4\times10^{-5}}{2\times10^{-2}} \Rightarrow 2 \times 10^{-3}\,C = 2mC$$

EXERCISE - 4

P-2 (AIIMS)

1. **(B) :** $E_{axial} = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}$; $E_{equatorial} = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$.

2. **(B) :** Gauss's law tells that the total flux through an area enclosing a charge Q is $\frac{Q}{\varepsilon_0}$. Now as the cube is having six faces and as we can assume a symmetrical distribution of fluxes among its faces, the flux associated with one of its faces is $\frac{Q}{6\varepsilon_0}$.

3. **(B) :** Charge on electron = e

Mass of electron = m and intensity of uniform electric field = E.

Acceleration of the electron,

$$a = \frac{\text{Force on the electron}}{\text{Mass of electron}}$$

$$= \frac{\text{Electric charge} \times \text{electric field}}{\text{Mass of electron}} = \frac{eE}{m}.$$

4. **(A) :** If an electric dipole is placed in a non-uniform electric field, then the positive and the negative charges of the dipole will experience a net force. And as one end of the dipole is experiencing a force in one direction and the other end in the opposite direction, so the dipole will have a net torque also.

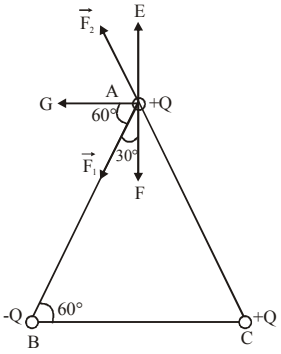
5. **(C) :** The force experienced by A due to B is

$$F_1 = \frac{1}{4\pi\varepsilon_0}\frac{QQ}{a^2} \text{ along } \overrightarrow{AB} \text{ (attractive)}$$

The force experienced by A due to C is

$$F_2 = \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{a^2} \text{ along } \overrightarrow{CA} \text{ produced (repulsive)}$$

Now the force $\vec{F}_1$ is having a component $F_1\cos30°$ along $\overrightarrow{AF}$ and the force $\vec{F}_2$ is having a component $F_2\cos30°$ along $\overrightarrow{AE}$. $\overrightarrow{AE}$ and $\overrightarrow{AF}$ are both normal to $\overrightarrow{BC}$ but they are mutually opposite to each other. And



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as $|\vec{F}_1| = |\vec{F}_2|$, so the forces

along $\overrightarrow{AE}$ and $\overrightarrow{AF}$ will both cancel each other. And so the force experienced by the charge at A in the direction normal to $\overrightarrow{BC}$ is zero.

6. **(D) :** The electrostatic force due to one Cs^+ ion is balanced by diagonally opposite other Cs^+. Thus the net electrostatic force on Cl^- ion due to eight Cs^+ ion is zero.

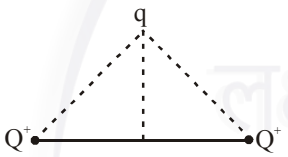
7. **(B) :** The magnitude of the electric field at a point exterior to the sphere is $\frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$.

The magnitude of electric field inside the sphere is given by $\frac{1}{4\pi\varepsilon_0}\frac{Qr}{R^3}$.

The field is directly proportional to r.

8. **(A) :** The negative charge oscillates, the resultant force acts as a restoring force and is cosθ component, proportional to displacement. When it reaches the plane XY, the resultant force is zero and the mass moves down due to inertia. Thus oscillation is set.

[This problem is similar to]



9. **(C) :** Electric field between the sheets is

$$E = \frac{\sigma}{\varepsilon_0} = \frac{26.4\times10^{-12}}{8.85\times10^{-12}} = 3N/C.$$

10. **(A) :** The lines proceed from the positive and lines will reach B, if B is negative.

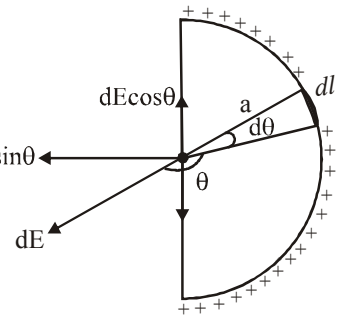
The number of lines/unit area i.e. the density of lines is greater for the greater charge.

A is +ve, B is –ve and |A| > |B|.

11. **(A) :** Electric field due to a infinite long wire of linear charge density λ is given by

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

12. **(D) :**



Electric field intensity at O due to small elemental length dl of charged ring.

$$dE = \frac{1}{4\pi\varepsilon_0}.\frac{\lambda dl}{a^2} = \frac{1}{4\pi\varepsilon_0}.\frac{\lambda a d\theta}{a^2}$$

$$dE = \frac{1}{4\pi\varepsilon_0}.\frac{\lambda}{a}d\theta$$

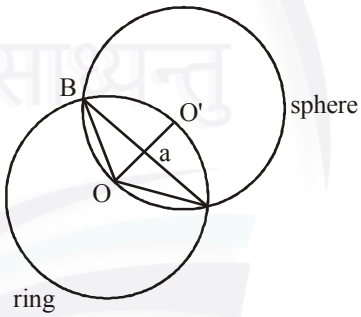
∴ Net electric field at centre O is

$$E = \int dE\sin\theta = \int_0^{\pi}\frac{1}{4\pi\varepsilon_0}\frac{\lambda}{a}\sin\theta d\theta$$

$$= \frac{\lambda}{4\pi\varepsilon_0 a}[-\cos\theta]_0^{\pi}$$

$$\therefore \quad E = \frac{\lambda}{2\pi\varepsilon_0 a}.$$

13. **(C) :**



Charge on ring q, centre of ring = O
Centre of sphere = O'

Linear charge density of ring, $\lambda = \frac{q}{2\pi a}$

Charge on arc AB of ring,

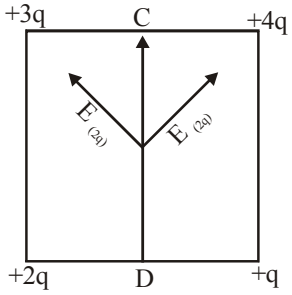
$$q_{AB} = \lambda(\text{arc AB}) = \frac{1}{2\pi a}.a.\frac{2\pi}{3}$$

$$q_{AB} = q/3$$

i.e., charged enclosed by sphere = q/3
∴ Flux coming out of sphere = $q/3\varepsilon_0$.

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14. (A) : The resultant electric fields due to diagonally opposite charges will act as shown below.



Hence the resultant field is along DC.

15. (D)

16. (A) : Electric field due to a long charged wire is given as

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

where, λ = linear charge density.
r = distance from the wire.

$$\therefore \quad E \propto \frac{1}{r}$$

17. (A) : Since, $\vec{v} = v_0\hat{i}$

$$\vec{E} = E_0\hat{j}$$

The electron is moving in x-direction perpendicular to the electric field which is in y-direction.
Thus, the path of electron moving perpendicular to field will be a parabola.

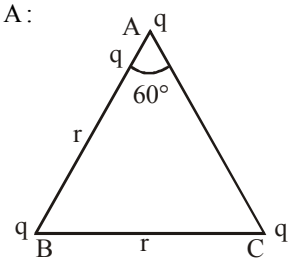
18. (D)

19. (D) : From Gauss's law, E is independent of r.

20. (A) : When the point is on the diameter and away from the centre of hemisphere which is charged uniformly and positively, the component of electric field intensity parallel to the diameter cancel out.
So the electric field is perpendicular to the diameter.

21. (D) : When metallic solid sphere is placed in a uniform electric field, the electrons of the sphere will move against the direction of the electric field. Consequently, the left face of the sphere acquires negative charge while the right face attains positive charge. The field lines will terminate at the left face of sphere and restart from its right face. The electric field inside the sphere is zero. On the surface of the sphere, the field lines are normal at every point i.e., directed towards the centre. Therefore, the correct field line is represented by line 4.

22. (C) : Force on charge q at A :



(i) Due to B, $f = kq \times \frac{q}{r^2}$

or $f = \frac{kq^2}{r^2}$ along BA

(ii) Due to C,

$f = \frac{kq^2}{r^2}$ along CA

$\therefore$ Resultant force = F

$F^2 = f^2 + f^2 + 2f \times f \times \cos 60°$

$$F^2 = 2f^2 + \frac{2f^2 \times 1}{2} = 3f^2 \quad \text{or} \quad F = \sqrt{3}f$$

or Resultant force $= \sqrt{3}\frac{kq^2}{r^2}$

23. (A) : Given : distance between two charges = d and dielectric constant (k) = 2. Force between tow charged spheres (F) $= \frac{1}{4\pi\varepsilon_0} \times \frac{q_1q_2}{r^2}$, where ε_0 is permitivity of free space. Force for a medium with dielectric constant k,

$$F' = \frac{1}{k} \times \frac{1}{4\pi\varepsilon_0} \times \frac{q_1q_2}{r^2},$$

where $F' = \frac{1}{k} \times \frac{1}{4\pi\varepsilon_0} \times \frac{q_1q_2}{r^2} = \frac{F}{k} = \frac{F}{2}$

24. (D) : The dominating force in the universe is the gravitational force. Because the gravitational force of attraction exists between any two bodies in the universe. Moreover it is the weakest of all the four fundamental forces in nature.

25. (A) : Both the assertion and reason are true and the reason is the correct explanation. It is because the charges are only at the surface of a conductor, the charge enclosed in the Gaussian surface in the cavity is zero. The field is therefore zero.

26. (A) : Gauss's law is applicable for any closed surface. Gauss's law is most useful in situation where the charge distribution has spherical or cylindrical symmetry or is distributed uniformly over the plane. Whereas electric dipole is a system of two equal and opposite point charges separated by a very small and finite distance.

27. (B) : Gauss's theorem is based on inverse square dependence of electric field on distance.

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28. (B) : Electrostatic field is a conservative field which means work done by an electrostatic field in moving a charge from one point to another depends only on the initial and the final positions and is independent at the path taken to go from one point to the another.

29. (D)

30. (B) : When a conductor is charged the excess charge can reside only on the surface. The electric field inside conductor is zero.

31. (A)

32. (D) : Only a charged particle initially at rest moves along the electric field line. In case, the charged particle is in motion and its initial velocity is at an angle with the electric field line, the particle may follow a parabolic path.

33. (D) $qE = \frac{mv^2}{r}, r = \frac{mv^2}{qE} = \frac{2K}{qE}$ $\left(\text{where } K = \frac{1}{2}mv^2\right)$

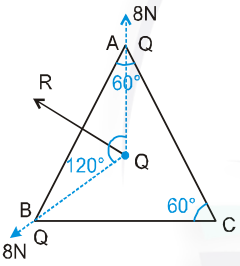
i.e., $r \propto \frac{1}{q}$.

Since electron and proton have equal charge, r is the same for both of them.

Here, r depends on K(which is given to be the same for both the particles) and as such not on their masses.

MOCK TEST

1. (D)



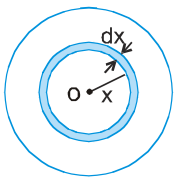
$R = \sqrt{8^2 + 8^2 + 2.8.8\cos 120°} = 8\,N$

2. (B) We can consider all the charge inside the sphere to be concentrated on the center of sphere

Consider an elementry shell of radius x and thickness dx.

$$E = \frac{K\int dq}{r^2} = \frac{K\int_0^r 4\pi x^2 dx\,(\alpha x)}{r^2}$$

$$= \frac{k4\pi\alpha}{r^2}\int_0^r x^3 dx = \frac{\alpha r^2}{4\varepsilon_0}$$



3. (A) From the F.B.D. of charge, we have :

$$q\left(\frac{2k\lambda}{r}\right) = \frac{mv^2}{r}$$

so $v = \sqrt{\frac{2kq\lambda}{m}}$ Now, $T = \frac{2\pi r}{v} = 2\pi r\sqrt{\frac{m}{2k\lambda q}}$

where, $k = \frac{1}{4\pi\varepsilon_0}$

4. (A) $W_{net} = q\vec{E}.\vec{d}$ where $\left(\vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{i}\ \&\right.$

$\left.\vec{d} = (x_1 - x_2)\hat{i}\right)$ $\therefore$ $W_{net} = q\frac{\sigma}{2\varepsilon_0}.(x_1 - x_2)$

5. (A) Electric field between the two cylinders $= \frac{2k\lambda}{r}$

$\therefore$ Force on charge $q = \frac{2k\lambda q}{r}$

This force is centripetal force

$\therefore$ $\frac{2k\lambda q}{r} = \frac{mv^2}{r}$

$\therefore$ $v = \sqrt{2\frac{1}{4\pi\epsilon_0}\frac{\lambda q}{m}} = \sqrt{\frac{\lambda q}{2\pi\epsilon_0 m}}$

6. (A) $V = V_1 + V_2 + V_3$

(where V_1, V_2 & V_3 are potentials due to the three parts of ring)

$$= \frac{1}{4\pi\varepsilon_0}\cdot\frac{Q}{R} + \frac{1}{4\pi\varepsilon_0}\left(\frac{-2Q}{R}\right) + \frac{1}{4\pi\varepsilon_0}\left(\frac{3Q}{R}\right)$$

$$= \frac{1}{4\pi\varepsilon_0}\cdot\left(\frac{2Q}{R}\right) = \frac{Q}{2\pi\varepsilon_0 R}$$

7. (B) $dV = -\vec{E}.d\vec{r} = -(-2x^3\times10^3\hat{i}).(dx\,\hat{i} + dy\,\hat{j} + dz\,\hat{k})$

$= 2x^3\times10^3\,dx$

$\Rightarrow \int_0^v dV = -\int_2^1 (2x^3)\times10^3\,dx$

$\Rightarrow V = 7.5\times10^3\,V$

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8. **(A)** Potential difference due to inner 10C charge

$= K\,10\left(\frac{1}{\cdot 1}-\frac{1}{\cdot 2}\right)=9\times10^{10}(5)$

$=45\times10^{10}=4.5\times10^{11}V$

Potential difference due to outer charge

$=\left(\frac{K\times20}{0.2}-\frac{K\times20}{0.2}\right)=0\ V$

$\therefore$ P.d. $=4.5\times10^{11}V$

9. **(A)** $V_A - V_B$ = work done by electric field on + 1 coul. charge from A to B = E Rθ

$\therefore \quad V_B = V_A - ER\theta = V - ER\theta$

10. **(B)** By argument of symmetry, it will be half of the potential produced by the full sphere

$\because$ Charge on hemisphere = Q,

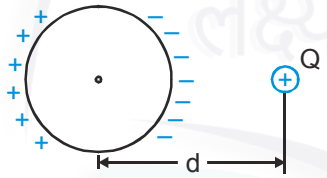
so charge on sphere = 2Q

$\Rightarrow \frac{1}{2}\cdot\frac{K(2Q)}{R}=\frac{KQ}{R}$

$V=\frac{KQ}{R}=\frac{9\times10^9\times5\times10^{-9}}{15\times10^{-2}}=300\ V$

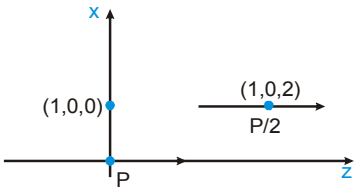
11. **(B)** Net potential of the sphere due to the induced charge is zero. Therefore potential is due to the point charge only, equal to

potential at the centre of the sphere.



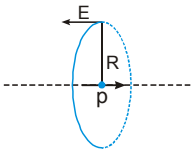
12. **(B)** The given point is at axis of $\frac{\vec{P}}{2}$ dipole and at equatorial line of $\vec{P}$ dipole so

total field at given point is.



$\vec{E}=-\frac{k\vec{P}}{(1)^3}+\frac{2k(\vec{P}/2)}{(2)^3}=k\vec{P}\left(-1+\frac{1}{8}\right)=\frac{-7\vec{P}}{32\pi\varepsilon_0}$

13. **(B)** Electric field at each point on the surface of ring due to dipole is $E=\frac{k\,p}{R^3}$ in direction opposite to the dipole moment. (figure below)



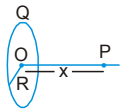
Hence net force on ring is $F = QE = \frac{kpQ}{R^3}$

Alternate solution

Electric field due to ring at point P on its axis at a distance x from centre O of ring is

$E = k\,.\,\frac{Qx}{(x^2+R^2)^{3/2}}\,;\left.\frac{dE}{dx}\right]_{at\ x=0}=\frac{kQ}{R^3}$

$\therefore$ Force on dipole $=\frac{dE}{dx}=\frac{k\,Qp}{R^3}$



14. **(C)** After covering with a hemispherical shell ; $\phi_{shell}+\phi_{disc}=0$ (from Gauss law)

$\therefore \quad \phi_{shell}=-\phi_{disc}=-\phi$

15. **(B)** $eE = m_e\omega^2 r$ (Balancing of forces on e^-)

Also, $V_O - V_R = -\int_R^0 E.dr = \int_0^R E.dr = \frac{m_e\omega^2}{e}\int_0^R r\,dr$

So, $V=\frac{m_e\omega^2R^2}{2e}$



16. **(B)** $u=\frac{1}{2}\varepsilon_0E^2=\frac{1}{2}\frac{\varepsilon_0K^2Q^2}{2r^4}\Rightarrow \quad v=\frac{KQ}{r}$

$\frac{u}{v^2}=\frac{\frac{1}{2}\varepsilon_0K^2\frac{Q^2}{r^4}}{\frac{K^2Q^2}{r^2}}=\frac{1}{2}\frac{\varepsilon_0}{r^2}$

because $\frac{u}{v^2}\propto\frac{1}{r^2}$ so the correct option is B.

17. **(C)** $\phi=\vec{E}\cdot\vec{ds}$

since r<< R so we can consider electric field is constant throughout the surface of smaller ring, hence

$\phi\propto E\propto\frac{x}{(R^2+x^2)^{3/2}}$

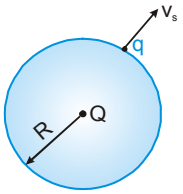
So, the best represnted graph is C.

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18. (C) Let q be positive.

If it escapes then from energy conservation principle,

$$\frac{1}{2}mv_s^2 + \frac{KQq}{R} = 0$$

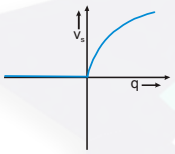


$$v = \sqrt{\frac{-2KQq}{Rm}}$$

{Note that Q is negative, therefore the quantity within the root is positive.}

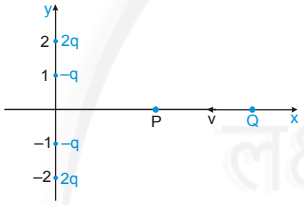
$$\therefore\ v \propto \sqrt{q}$$

When q is negative, escape velocity will be zero due to electrostatic repulsion from negative Q.



19. (B) $\vec{E} = -\nabla v = +\frac{1}{x^2}\hat{i} + \frac{1}{y^2}\hat{j} + \frac{1}{z^2}\hat{k} = \hat{i} + \hat{j} + \hat{k}$

20. (B) There exists a point P on the x-axis (other than the origin), where net electric field is zero.Once the charge Q reaches point P, attractive forces of the two –ve charge will dominate and automatically cause the charge Q to cross the origin.



Now if Q is projected with just enough velocity to reach P,

its K.E. at P is zero.

But while being attracted towards origin it acquires K.E. & hence its net energy at the origin is positive. (P.E. at origin = zero).

21. (C) The electric field inside the inner shell is zero

So, the potential on inner shell and all the points inside it will be constant.

22. (B) $V = \frac{K\,\vec{p}.\vec{r}}{r^3} = \frac{9\times10^9\times(2\hat{i}-3\hat{j}+4\hat{k}).(2\hat{i}+2\hat{j}-\hat{k})}{[2^2+2^2+1^2]^{3/2}}$

$$= \frac{9\times10^9\times(4-6-4)}{27}$$

$V = -2\times109$ volts **Ans.**

23. (D) Interaction energy of system of charges is

$$= \frac{1}{2}[U_1 + ... + U_6] = \frac{1}{2}[6U_1] = 3U_1$$

$$= 3kq^2\left(-\frac{2}{a} + \frac{2}{a\sqrt{3}} - \frac{1}{2a}\right) = \frac{q^2}{\pi\epsilon_0 a}\left(\frac{\sqrt{3}}{2} - \frac{15}{8}\right)$$

24. (A) The distribution of charge on the outer surface, depends only on the charges outside, and it distributes itself such that the net, electric field inside the outer surface due to the charge on outer surface and all the outer charges is zero. Similarly the distribution of charge on the inner surface, depends only on the charges inside the inner surface, and it distributes itself such that the net, electric field outside the inner surface due to the charge on inner surface and all the inner charges is zero.

Also the force on charge inside the cavity is due to the charge on the inner surface. Hence answer is option

25. A → p,s; B → q,s ; C → q,s; D→ s

(A) Electrostatic potential energy

$$= \frac{1}{4\pi\epsilon_0}\frac{(-Q)^2}{2a} = \frac{Q^2}{8\pi\epsilon_0 a}$$

(B) Electrostatic potential energy

$$= \frac{1}{4\pi\epsilon_0}\left[\frac{(-Q)\times(-Q)}{5a/2} + \frac{(-Q)^2}{2(5a/2)}\right] = \frac{3}{20}\frac{Q^2}{\pi\epsilon_0 a}$$

(C) Electrostatic potential energy

$$= \frac{1}{4\pi\epsilon_0}\frac{3Q^2}{5a} = \frac{3}{20}\frac{Q^2}{\pi\epsilon_0 a}$$

(D) Electrostatic potential energy

$$= \frac{1}{4\pi\epsilon_0}\left[\frac{3Q^2}{5a} + \frac{(-Q)^2}{2(2a)} + \frac{(-Q)\times(-Q)}{2a}\right] = \frac{27Q^2}{80\pi\epsilon_0 a}$$

26. A→p,q ; B→p,q ; C→p,q,s; D→r,s,t

In situation A, B and C, shells I and II are not at same potential. Hence charge shall flow from sphere I to sphere II till both acquire same potential.

If charge flows, the potential energy of system decreases and heat is produced.

In situations A and B charges shall divide in some fixed ratio , but in situation C complete charge shall be transferred to shell II for potential of shell I and II to be same.

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In situation D both the shells are at same potential, hence no charge flows through connecting wire.

$\therefore$ **(D)** $\rightarrow$ r, s

$$V_A'' = \frac{1}{4\pi \epsilon_0} \frac{\frac{4}{3}\pi\left(\frac{R}{2}\right)^3(-\rho)}{\frac{R}{2}} = \frac{-\rho R^2}{12\epsilon_0}$$

$$\vec{E}_C'' = \frac{-\rho}{3\epsilon_0}\overrightarrow{BC}$$

Now net values for the solid sphere with the cavity can be given by superposition of the above two cases

Hence, $V_A = V_A' + V_A'' = \frac{\rho R^2}{\epsilon_0}\left(\frac{1}{2} - \frac{1}{12}\right) = \frac{5\rho R^2}{12\epsilon_0}$

$$\vec{E}_C = \vec{E}_C' + \vec{E}_C'' = \frac{\rho}{3\epsilon_0}(\overrightarrow{AC} - \overrightarrow{BC}) = \frac{\rho}{3\epsilon_0}\overrightarrow{AB}$$

$$\therefore E_C = \frac{\rho}{3\epsilon_0}\left(\frac{R}{2}\right) = \frac{\rho R}{6\epsilon_0}$$

Ans. $V_A = \frac{5\rho R^2}{12\epsilon_0}$, $E_C = \frac{\rho R}{6\epsilon_0}$

27. (D) Potential at a point is zero does not imply that electric field at same point should be zero. For instance in the equatorial plane of a dipole, potential at any point is zero but electric field is not zero. Hence statement 1 is false.

No electric field in space means , potential at all points in space is same. Hence potential difference between any two points is zero. Hence statement 2 is true.

Statement–1 is False, Statement–2 is True.

28. (A) The electric field inside the cavity depends only on point charge q. Hence $V_A - V_B$ remains constant even if point charge Q is shifted. Here statement 2 is correct explanation of statement 1.

29. (D) For a non-uniformly charged thin circular ring with net zero charge, electric potential at each point on its axis is zero. Hence electric field at each point on its axis must be perpendicular to the axis. Therefore statement 1 is false and statement 2 is true.

30. (A) The electric field due to disc is superposition of electric field due to its constituent ring as given in statement-2. Statement-1 is True, Statement-2 is True; Statement-2 is a correct explanation for Statement-1

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CHAPTER 02

CAPACITANCE

A natural law regulates the advance of science. Where only observation can be made, the growth of knowledge creeps; where laboratory experiments can be carried on, knowledge leaps forward.

"MICHAEL FARADAY"

INTRODUCTION

Capacitor is an arrangement of two conductors generally carrying charges of equal magnitudes and opposite sign and separated by an insulating medium. A capacitor is a device which stores electric charge. Capacitors vary in shape and size, but the basic configuration is two conductors carrying equal but opposite chagres (Figure). Capacitors have many important applications in electronics. Some examples include storing electric potential energy, delaying voltage changes when coupled with resistors, filtering out unwanted frequency signals, forming resonant circuits and making frequency- dependent and independent voltage divides when combined with resistors, Some of these applications will be discussed in latter chapters.

When charges are pulled apart, energy is associated with the pulling apart of charges, just like energy is involved in stretching a spring. Thus, some energy is stored in capacitors.

In the uncharged staste, the charge on eitherone of the conductors in the capacitor is zero. During the charging process, a charge Q is moved from one conductor to the other one, giving one conductor a charge +Q, and the other one a charge – Q. A potential difference ΔV is created, with the positively charged conductor at a higher potential than the negatively charged conductor. Note that whether charged or uncharged, the net charge on the capacitor as a whole is zero.

Limitations on Charging a Conductor

How much electric charge can be placed on a conductor ?

As more air is pumped into the tank, the pressure opposing the flowadditional air becomes greater so it becomes further diffifult to pump more air. Similarly, as more charge Q is transferred to the conductor, the potential V of the conductor becomes higher, making it increasingly difficult to transfer more charge. Suppose we try to place an indefinite quantify of charge Q on a spherical conductor of radius r. the air surrounding the conductor is an insulator, sometimes called a dielectric, which contains few charges free to move. The electric field intensity E and the potential V at the surface of the sphere are given by

$$E = \frac{kQ}{r^2} \quad \text{and} \quad V = \frac{kQ}{r}$$

Since the radius r is constant, bothe the field intensity and the potential at the surface of the sphere increase in direct proportion to the charge Q. There is a limit, however, to the field intensity that can exist on a conductor without ionizing the surrounding air. When this occurs, the air essentially becomes a conductor, and any additional charge placed onthe sphere will "leak off" to the air. This limiting value of electric field intensity for which a material loses its insulation properties is called the dielectric strength of that material.

The dielectric strength for a given material is that electric field intensity for which the material ceases to bhe an insulator and becomes a conductor.

The dielectric strength for dry air at 1 atm pressure is around 3MC/C. Since the dielectric strength of a material varies considerably with environmental conditions, such as pressure and humidity, it is diffifult to compute accurate values.

Note that the amount of charge that can be placed on a spherical conductor decreases with the radius of the sphere. thus, smaller conductors can usually hold less charge. But the shape of a conductor also influences its ability to retain charge. Consider the charged conductros. If these conductor are tested with an electroscope, it will be discovered that the charge on the surface of conductor is concentrated at points of greatest curvature. Because of the greater charge density in these regions, the electric field intensity is also greater in regions of higher curvature. If the surface is reshaped to a sharp point, the field intensity may become great enough to ionize the surrounding air. A show leakage of charge sometimes occurs at these locations, producing a corona discharge, which is often observed as a faint violet glow in the vicinity of the sharply pointed conductor. It is important to remove all sharp edges from electrical equipment to minimize this leakage of charge.

Ex. What is the maximum charge that may be placed on a spherical conductor 1m in diameter? Assume it is surrounded by air. Assume the dielectric strength for dry air at 1 atm pressure is around 3MN/C.

Sol. $= \frac{1}{12} \times 10^{-3} C$

Concept of Capacitance

Capacitance of a conductor is a measure of ability of the conductor to store charge on it. When a conductor is charged then its potential rises. The increase in potential is directly proportional to the charge given to the conductor. $Q \propto V \Rightarrow Q = CV$

The constant C is known as the capacity of the conductor.

Capacitance is a scalar quantity with dimension $C = \frac{Q}{V} = \frac{Q^2}{W} = \frac{A^2T^2}{M^1L^2T^{-2}} = M^{-1}L^{-2}T^4A^2$

Unit :- farad, coulomb/volt

The capacity of a conductor is independent of the charge given or its potential raised. It is also independent of nature of material and thickness of the conductor. Theoretically infinite amount of charge can be given to a conductor. But practically the electric field becomes so large that it causes ionisation of medium surrounding it. The charge on conductor leaks reducing its potential.

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Capacitance of an Isolated Conductor

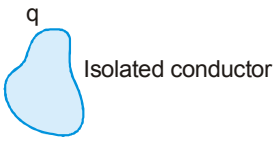
When a conductor is charged its potential increases. It is found that for an isolated conductor (conductor should be of finite dimension, so that potential of infinity can be assumed to be zero) potential of the conductor is proportional to charge given to it.

q = charge on conductor

V = potential of conductor

$q \propto V$

$\Rightarrow \quad q = CV$



Where C is proportionality constant called capacitance of the conductor.

(1) Definition of Capacitance

Capacitance of conductor is defined as charge required to increase the potential of conductor by one unit.

(2) Important points about the capacitance of an isolated conductor

(i) It is a scalar quantity.

(ii) Unit of capacitance is farad in SI units and its dimensional formula is $M^{-1} L^{-2} I^2 T^4$

(iii) **1 Farad :** 1 Farad is the capacitance of a conductor for which 1 coulomb charge increases potential by 1 volt.

$$1 \text{ Farad} = \frac{1 \text{ Coulomb}}{1 \text{ Volt}}$$

$1\ \mu F = 10^{-6}$ F, $1nF = 10^{-9}$ F or $1\ pF = 10^{-12}$ F

(iv) **Capacitance of an isolated conductor depends on following factors :**

(a) Shape and size of the conductor :

On increasing the size, capacitance increases.

(b) On surrounding medium :

With increase in dielectric constant K, capacitance increases.

(c) Presence of other conductors :

When a neutral conductor is placed near a charged conductor, capacitance of conductors increases.

(v) Capacitance of a conductor do not depend on

(a) Charge on the conductor

(b) Potential of the conductor

(c) Potential energy of the conductor.

Potential Energy or Self Energy of an isolated Conductor

Work done in charging the conductor to the charge on it against its own electric field or total energy stored in electric field of conductor is called self energy or self potential energy of conductor.

Electric Potential Energy (Self Energy)

Work done in charging the conductor

$$W = \int_0^q \frac{q}{C} dq = \frac{q^2}{2C}$$

$$W = U = \frac{q^2}{2C} = \frac{1}{2} CV^2 = \frac{qV}{2}.$$

q = Charge on the conductor

V = Potential of the conductor

C = Capacitance of the conductor.

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Self energy is stored in the electric field of the conductor with energy density (Energy per unit volume)

$$\frac{dU}{dV} = \frac{1}{2}\epsilon_0 E^2 \text{ [The energy density in a medium is } \frac{1}{2}\epsilon_0\epsilon_r E^2 \text{]}$$

where E is the electric field at that point.

In case of charged conductor energy stored is only out side the conductor but in case of charged insulating material it is outside as well as inside the insulator.

Capacitance of an Isolated Spherical Conductor

The capacitance of an isolated spherical conductor of radius R.

Let there is charge Q on sphere.

$\because$ Potential $V = \frac{KQ}{R}$

Hence by formula : $Q = CV$

$$Q = \frac{CKQ}{R}$$

$$C = 4\pi\epsilon_0 R$$

Capacitance of an isolated spherical conductor

$$C = 4\pi\epsilon_0 R$$

(i) If the medium around the conductor is vacuum or air.

$C_{Vacuum} = 4\pi\epsilon_0 R$

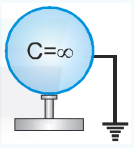
R = Radius of spherical conductor. (may be solid or hollow.)

(ii) If the medium around the conductor is a dielectric of constant K from surface of sphere to infinity.

$C_{medium} = 4\pi\epsilon_0 KR$

(iii) $\frac{C_{medium}}{C_{air/vaccum}} = K$ = dielectric constant.

(i) As the potential of the Earth is assumed to be zero, capacity of earth or a conductor connected to earth will be infinite $C = \frac{q}{V} = \frac{q}{0} = \infty$



(ii) Actual capacity of the Earth $C = 4\pi\varepsilon_0 R = \frac{1}{9\times10^9}\times 64\times10^5 = 711\ \mu F$

(iii) Work done by battery W_b = (charge given by battery) × (emf) = QV but Energy stored in conductor $= \frac{1}{2}QV$ so 50% energy supplied by the battery is lost in form of heat.

Ex. Find out the capacitance of the earth ? (Radius of the earth = 6400 km)

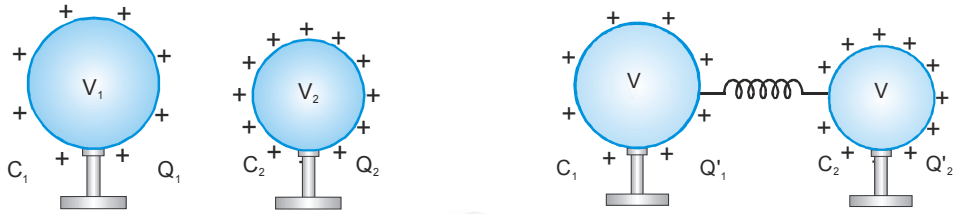
Sol. $C = 4\pi\epsilon_0 R = \frac{6400\times10^3}{9\times10^9} = 711\ \mu F$

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Redistribution of Charges and Loss of Energy

When two charged conductors are connected by a conducting wire then charge flows from a conductor at higher potential to that at lower potential. This flow of charge stops when the potential of two conductors became equal.

Let the amounts of charges after the conductors are connected are Q_1' and Q_2' respectively and potential is V then



(Before connection) (After connection)

Common Potential

According to law of Conservation of charge $Q_{\text{before connection}} = Q_{\text{after connection}} \Rightarrow C_1V_1 + C_2V_2 = C_1V + C_2V$

Common potential after connection $V = \dfrac{C_1V_1 + C_2V_2}{C_1 + C_2}$

Charges After Connection

$Q_1' = C_1V = C_1\left(\dfrac{Q_1 + Q_2}{C_1 + C_2}\right) = \left(\dfrac{C_1}{C_1 + C_2}\right)Q$ (Q : Total charge on system)

$Q_2' = C_2V = C_2\left(\dfrac{Q_1 + Q_2}{C_1 + C_2}\right) = \left(\dfrac{C_2}{C_1 + C_2}\right)Q$

Ratio of the charges after redistribution $\dfrac{Q_1'}{Q_2'} = \dfrac{C_1V}{C_2V} = \dfrac{R_1}{R_2}$ (in case of spherical conductors)

Loss of Energy in Redistribution

When charge flows through the conducting wire then **energy is lost mainly on account of Joule effect**, electrical energy is converted into heat energy, so change in energy of this system,

$$\Delta U = U_f - U_i \Rightarrow \left(\frac{1}{2}C_1V^2 + \frac{1}{2}C_2V^2\right) - \left(\frac{1}{2}C_1V_1^2 + \frac{1}{2}C_2V_2^2\right) \Rightarrow \Delta U = -\frac{1}{2}\left(\frac{C_1C_2}{C_1 + C_2}\right)(V_1 - V_2)^2$$

Here negative sign indicates that energy of the system decreases in the process.

Ex. A conductor gets a charge of 50 μC when it is connected to a battery of e.m.f. 5 V. Calculate capacity of the conductor.

Sol. Capacity of the conductor $C = \dfrac{Q}{V} = \dfrac{50 \times 10^{-6}}{5} = 10\mu F$

Ex. The capacity of a spherical capacitor in air is 50 μF and on immersing it into oil it becomes 110 μF. Calculate the dielectric constant of oil.

Sol. Dielectric constant of oil $\varepsilon_r = \dfrac{C_{\text{medium}}}{C_{\text{air}}} = \dfrac{110}{50} = 2.2$

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Ex. A radio active source in the form of a metal sphere of diameter 10^{-3}m emits β particles at a constant rate of 6.25×10^{10} particles per second. If the source is electrically insulated, how long will it take for its potential to rise by 1.0 volt, assuming that 80% of emitted β particles escape from the surface.

Sol. Capacitance of sphere $C = 4\pi\varepsilon_0 R = \frac{0.5\times10^{-3}}{9\ \ 10^{9}} = \frac{1}{18}\times10^{-12}\,F$

Rate to escape of charge from surface $= \frac{80}{100}\times6.25\times10^{10}\times1.6\times10^{-19} = 8\times10^{-9}$ C/s

therefore $q = (8\times10^{-9})t$ and $q = CV \Rightarrow 8\times10^{-9}\times t = \frac{1}{18}\times10^{-12}\times1 \Rightarrow t = \frac{10^{-12}}{8\times10^{-9}\times18} = \frac{10^{-3}}{144} = 6.95\ \mu s$

Ex. The plates of a capacitor are charged to a potential difference of 100 V and then connected across a resister. The potential difference across the capacitor decays exponentially with respect to time. After one second the potential difference between the plates of the capacitor is 80 V. What is the fraction of the stored energy which has been dissipated ?

Sol. Energy losses $\Delta U = \frac{1}{2}CV_0^2 - \frac{1}{2}CV^2$

Fractional energy loss $\frac{\Delta U}{U_0} = \frac{\frac{1}{2}CV_0^2 - \frac{1}{2}CV^2}{\frac{1}{2}CV_0^2} = \frac{V_0^2 - V^2}{V_0^2} = \frac{(100)^2 - (80)^2}{(100)^2} = \frac{20\times180}{(100)^2} = \frac{9}{25}$

Ex. Two uniformly charged spherical drops at potential V coalesce to form a larger drop. If capacity of each smaller drop is C then find capacity and potential of larger drop.

Sol. When drops coalesce to form a larger drop then total charge and volume remains conserved. If r is radius and q is charge on smaller drop then $C = 4\pi\varepsilon_0 r$ and $q = CV$

Equating volume we get $\frac{4}{3}\pi R^3 = 2\times\frac{4}{3}\pi r^3 \Rightarrow R = 2^{1/3} r$

Capacitance of larger drop $C' = 4\pi\varepsilon_0 R = 2^{1/3} C$

Charge on larger drop $Q = 2q = 2CV$

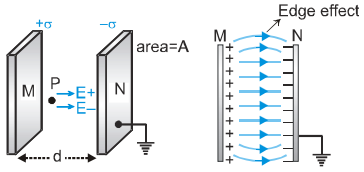
Potential of larger drop $V' = \frac{Q}{C'} = \frac{2CV}{2^{1/3}C} = 2^{2/3} V$

Parallel Plate Capacitor

(i) Capacitance

It consists of two metallic plates M and N each of area A at separation d.

Plate M is positively charged and plate N is earthed. If ε_r is the dielectric constant of the material medium and E is the field at a point P that exists between the two plates, then



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I Step : Finding electric field $E = E_+ + E_- = \frac{\sigma}{2\varepsilon} + \frac{\sigma}{2\varepsilon} = \frac{\sigma}{\varepsilon} = \frac{\sigma}{\varepsilon_0 \varepsilon_r}$ $[\varepsilon = \varepsilon_0 \varepsilon_r]$

II Step : Finding potential difference $V = Ed = \frac{\sigma}{\varepsilon_0 \varepsilon_r} d = \frac{qd}{A\varepsilon_0 \varepsilon_r}$ $(\because E = \frac{V}{d}$ and $\sigma = \frac{q}{A})$

III Step : Finding capacitance $C = \frac{q}{V} = \frac{\varepsilon_r \varepsilon_0 A}{d}$

If medium between the plates is air or vacuum, then $\varepsilon_r = 1 \Rightarrow C_0 = \frac{\varepsilon_0 A}{d}$

So $C = \varepsilon_r C_0 = KC_0$ (where $\varepsilon_r = K$ = dielectric constant)

(ii) Force Between The Plates

The two plates of capacitor attract each other because they are oppositely charged.

Electric field due to positive plate $E = \frac{\sigma}{2\varepsilon_0} = \frac{Q}{2\varepsilon_0 A}$

Force on negative charge –Q is $F = -Q\,E = -\frac{Q^2}{2\varepsilon_0 A}$

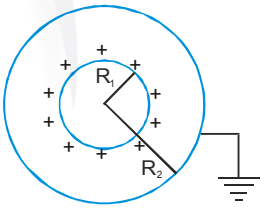
Magnitude of force $F = \frac{Q^2}{2\varepsilon_0 A} = \frac{1}{2}\varepsilon_0 A E^2$

Force per unit area or energy density or electrostatic pressure $= \frac{F}{A} = u = p = \frac{1}{2}\epsilon_0 E^2$

Spherical Capacitor

(i) Outer sphere is earthed

When a charge Q is given to inner sphere it is uniformly distributed on its surface A charge –Q is induced on inner surface of outer sphere. The charge +Q induced on outer surface of outer sphere flows to earth as it is grounded.



$E = 0$ for $r < R_1$ and $E = 0$ for $r > R_2$

Potential of inner sphere $V_1 = \frac{Q}{4\pi\varepsilon_0 R_1} + \frac{-Q}{4\pi\varepsilon_0 R_2} \Rightarrow \frac{Q}{4\pi\varepsilon_0}\left(\frac{R_2 - R_1}{R_1 R_2}\right)$

As outer surface is earthed so potential $V_2 = 0$

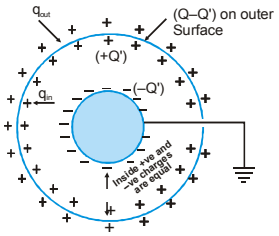
Potential difference between plates $V = V_1 - V_2 = \frac{Q}{4\pi\varepsilon_0}\frac{(R_2 - R_1)}{R_1 R_2}$

So $C = \frac{Q}{V} = 4\pi\varepsilon_0 \frac{R_1 R_2}{R_2 - R_1}$ (in air or vacuum)

In presence of medium between plate $C = 4\pi\varepsilon_r\varepsilon_0 \frac{R_1 R_2}{R_2 - R_1}$

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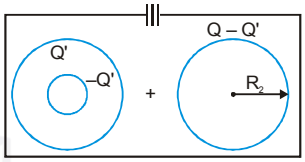
(ii) Inner sphere is earthed



Here the system is equivalent to a spherical capacitor of inner and outer radii R_1 and R_2 respectively and a spherical conductor of radius R_2 in parallel. This is because charge Q given to outer sphere distributes in such a way that for the outer sphere.

Charge on the inner side is $Q' = \frac{R_1}{R_2} Q$ and

Charge on the outer side is $Q - \frac{R_1}{R_2} Q = \frac{(R_2 - R_1)}{R_2} Q$



So total capacity of the system. $C = 4\pi\varepsilon_0 \frac{R_1 R_2}{R_2 - R_1} + 4\pi\varepsilon_0 R_2 = \frac{4\pi\varepsilon_0 R_2^2}{R_2 - R_1}$

CYLINDRICAL CAPACITOR

When a charge Q is given to inner cylinder it is uniformly distributed on its surface.

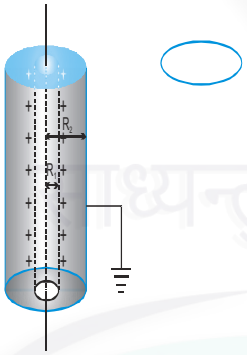
A charge –Q is induced on inner surface of outer cylinder. The charge +Q induced on outer surface of outer cylinder flows to earth as it is grounded

Electrical field between cylinders

$$E = \frac{\lambda}{2\pi\varepsilon_0 r} = \frac{Q/\ell}{2\pi\varepsilon_0 r}$$

Potential difference between plates

$$V = \int_{R_1}^{R_2} \frac{Q}{2\pi\varepsilon_0 r \ell} dr = \frac{Q}{2\pi\varepsilon_0 \ell} \ell n\left(\frac{R_2}{R_1}\right)$$



Capacitance $C = \frac{Q}{V} = \frac{2\pi\varepsilon_0 \ell}{\log_e (R_2/R_1)}$

In presence of medium $C = \frac{2\pi\varepsilon_0 \varepsilon_r \ell}{\log_e (R_2/R_1)}$

Ex. The stratosphere acts as a conducting layer for the earth. If the stratosphere extends beyond 50 km from the surface of earth, then calculate the capacitance of the spherical capacitor formed between stratosphere and earth's surface. Take radius of earth as 6400 km.

Sol. The capacitance of a spherical capacitor is $C = 4\pi\varepsilon_0 \left(\frac{ab}{b-a}\right)$

b = radius of the top of stratosphere layer = 6400 km + 50 km = 6450 km = 6.45×10^6 m

a = radius of earth = 6400 km = 6.4×10^6 m

$$\therefore C = \frac{1}{9\times10^9} \times \frac{6.45\times10^6 \times 6.4\times10^6}{6.45\times10^6 - 6.4\times10^6} = 0.092 \text{ F}$$

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Ex. A cylindrical capacitor has two co-axial cylinders of length 15 cm and radii 1.5 cm and 1.4 cm. The outer cylinder is earthed and the inner cylinder is given a charge of 3.5 μC. Determine the capacitance of the system and the potential of the inner cylinder.

Sol. $\ell = 15\text{ cm} = 15\times10^{-2}\text{ m};\ a = 1.4\text{cm} = 1.4\times10^{-2}\text{ m};\ b = 1.5\text{ cm} = 1.5\times10^{-2}\text{m};\ q = 3.5\ \mu\text{C} = 3.5\times10^{-6}\text{C}$

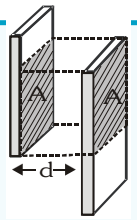
$$\text{Capacitance } C = \frac{2\pi\varepsilon_0\ell}{2.303\log_{10}\left(\frac{b}{a}\right)} = \frac{2\pi\times8.854\times10^{-12}\times15\times10^{-2}}{2.303\log_{10}\frac{1.5\times10^{-2}}{1.4\times10^{-2}}} = 1.21\times10^{-8}\text{ F}$$

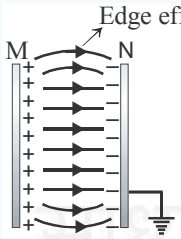
Since the outer cylinder is earthed, the potential of the inner cylinder will be equal to the potential difference between them. Potential of inner cylinder, is $V = \frac{q}{C} = \frac{3.5\times10^{-6}}{1.2\times10^{-10}} = 2.89\times10^{4}\text{ V}$

(i) If one of the plates of parallel plate capacitor slides relatively than C decrease (As overlapping area decreases).

(ii) If both the plates of parallel plate capacitor are touched each other resultant charge and potential became zero.

(iii) Electric field between the plates of a capacitor is shown in figure. Non-uniformity of electric field at the boundaries of the plates is negligible if the distance between the plates is very small as compared to the length of the plates.





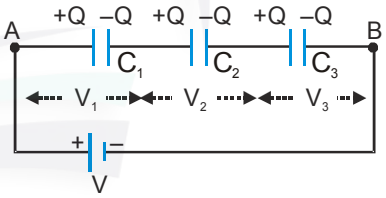
$\vec{E}$ = uniform in the centre

$\vec{E}$ = non-uniform at the edges

COMBINATION OF CAPACITOR

Capacitor in series

In this arrangement of capacitors the charge has no alternative path(s) to flow.



(i) The charges on each capacitor are equal
i.e. $Q = C_1V_1 = C_2V_2 = C_3V_3$

(ii) The total potential difference across AB is shared by the capacitors in the inverse ratio of the capacitances $V = V_1 + V_2 + V_3$

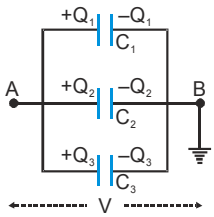
If C_S is the net capacitance of the series combination, then

$$\frac{Q}{C_S} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} \Rightarrow \frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Capacitors in parallel

In such in arrangement of capacitors the charge has an alternative path(s) to flow.

(i) The potential difference across each capacitor is same and equal the total potential applied. i.e. $V = V_1 = V_2 = V_3 \Rightarrow V = \frac{Q_1}{C_1} = \frac{Q_2}{C_2} = \frac{Q_3}{C_3}$



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(ii) The total charge Q is shared by each capacitor in the direct ratio of the capacitances. $Q = Q_1 + Q_2 + Q_3$

If C_P is the net capacitance for the parallel combination of capacitors :

$C_P V = C_1 V + C_2 V + C_3 V \Rightarrow C_P = C_1 + C_2 + C_3$

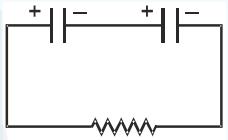
(i) For a given voltage to store maximum energy capacitors should be connected in parallel.

(ii) If N identical capacitors each having breakdown voltage V are joined in

(a) series then the break down voltage of the combination is equal to NV

(b) parallel then the breakdown voltage of the combination is equal to V.

(iii) Two capacitors are connected in series with a battery. Now battery is removed and loose wires connected together then final charge on each capacitor is zero.



(iv) If N identical capacitors are connected then $C_{series} = \frac{C}{N}$, $C_{parallel} = NC$

(v) In DC capacitor's offers infinite resistance in steady state, so there will be no current flows through capacitor branch.

Ex. Capacitor C, 2C, 4C, ... ∞ are connected in parallel, then what will be their effective capacitance ?

Sol. Let the resultant capacitance be $C_{resultant} = C + 2C + 4C + ... \infty = C[1 + 2 + 4 + ... \infty] = C \times \infty = \infty$

Ex. An infinite number of capacitors of capacitance C, 4C, 16C ... ∞ are connected in series then what will be their resultant capacitance ?

Sol. Let the equivalent capacitance of the combination = C_{eq}

$$\frac{1}{C_{eq}} = \frac{1}{C} + \frac{1}{4C} + \frac{1}{16C} + ... \infty = \left[1 + \frac{1}{4} + \frac{1}{16} + ... \infty\right]\frac{1}{C}$$ (this is G. P.series)

$\Rightarrow S_\infty = \frac{a}{1-r}$ first term a = 1, common ratio $r = \frac{1}{4} \Rightarrow \frac{1}{C_{eq}} = \frac{1}{1 - \frac{1}{4}} \times \frac{1}{C} \Rightarrow C_{eq} = \frac{3}{4}C$

Effect of Dielectric

(i) The insulators in which microscopic local displacement of charges takes place in presence of electric field are known as **dielectrics**.

(ii) Dielectrics are non conductors upto certain value of field depending on its nature. If the field exceeds this limiting value called **dielectric strength** they lose their insulating property and begin to conduct.

(iii) **Dielectric strength** is defined as the maximum value of electric field that a dielectric can tolerate without breakdown. Unit is volt/metre. Dimensions $M^1L^1T^{-3}A^{-1}$

Polar Dielectrics

(i) In absence of external field the centres of positive and negative charge do not coincide-due to asymmetric shape of molecules.

(ii) Each molecule has permanent dipole moment.

(iii) The dipole are randomly oriented so average dipole moment per unit volume of polar dielectric in absence of external field is nearly zero.

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(iv) In presence of external field dipoles tends to align in direction of field.

Ex. Water, Alcohol, CO_2, $HC\ell$, NH_3

Non Polar Dielectrics

(i) In absence of external field the centre of positive and negative charge coincides in these atoms or molecules because they are symmetric.

(ii) The dipole moment is zero in normal state.

(iii) In presence of external field they acquire induced dipole moment.

Ex. Nitrogen, Oxygen, Benzene, Methane

Polarisation

The alignment of dipole moments of permanent or induced dipoles in the direction applied electric field is called polarisation.

Polarisation Vector $\vec{P}$

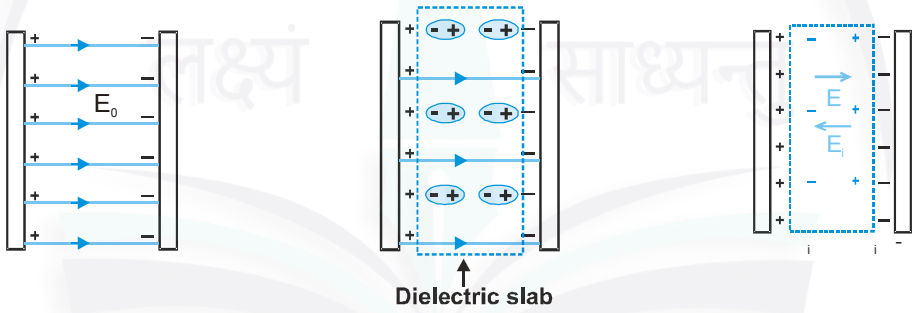
This is a vector quantity which describes the extent to which molecules of dielectric become polarized by an electric field or oriented in direction of field.

$\vec{P}$ = the dipole moment per unit volume of dielectric = $n\,\vec{p}$

where n is number of atoms per unit volume of dielectric and $\vec{p}$ is dipole moment of an atom or molecule.

$\vec{P} = n\,\vec{p} = \frac{q_i d}{Ad} = \left(\frac{q_i}{A}\right) = \sigma_i$ = induced surface charge density.

Unit of $\vec{P}$ is C/m^2 Dimension is $L^{-2}T^1A^1$



Let E_0, V_0, C_0 be electric field, potential difference and capacitance in absence of dielectric. Let E, V, C are electric field, potential difference and capacitance in presence of dielectric respectively.

Electric field in absence of dielectric $E_0 = \frac{V_0}{d} = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A}$

Electric field in presence of dielectric $E = E_0 - E_i = \frac{\sigma - \sigma_i}{\varepsilon_0} = \frac{Q - Q_i}{\varepsilon_0} = \frac{V}{d}$

Capacitance in absence of dielectric $C_0 = \frac{Q}{V_0}$

Capacitance in presence of dielectric $C = \frac{Q - Q_i}{V}$

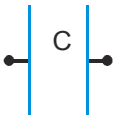
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The dielectric constant or relative permittivity K or $\varepsilon_r = \frac{E_0}{E} = \frac{V_0}{V} = \frac{C}{C_0} = \frac{Q}{Q-Q_i} = \frac{\sigma}{\sigma-\sigma_i} = \frac{\varepsilon}{\varepsilon_0}$

From $K = \frac{Q}{Q-Q_i} \Rightarrow Q_i = Q\left(1-\frac{1}{K}\right)$ and $K = \frac{\sigma}{\sigma-\sigma_i} \Rightarrow \sigma_i = \sigma\left(1-\frac{1}{K}\right)$

Capacity of Different Configuration

In case of parallel plate capacitor $C = \frac{\varepsilon_0 A}{d}$



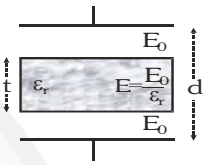
If capacitor is partially filled with dielectric

When the dielectric is filed partially between plates, the thickness of dielatric slab is t(t < d).

If no slab is introduced between the plates of the capacitor, then a field E_0 given by $E_0 = \frac{\sigma}{\varepsilon_0}$, exists in a space d.

On inserting the slab of thickness t, a field $E = \frac{E_0}{\varepsilon_r}$ exists inside the slab of thickness t and

a field E_0 exists in remaining space (d – t). If V is total potential then $V = E_0(d-t) + Et$



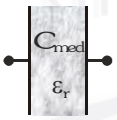
$\Rightarrow V = E_0\left[d - t + \left(\frac{E}{E_0}\right)t\right]$ $\because$ $\frac{E_0}{E} = \varepsilon_r$ = Dielectric constant

$$V = \frac{\sigma}{\varepsilon_0}\left[d - t + \frac{t}{\varepsilon_r}\right] = \frac{q}{A\varepsilon_0}\left[d - t + \frac{t}{\varepsilon_r}\right] \Rightarrow C = \frac{q}{V} = \frac{\varepsilon_0 A}{d - t\left(1-\frac{1}{\varepsilon_r}\right)} = \frac{\varepsilon_0 A}{d - t\left(1-\frac{1}{\varepsilon_r}\right)} \quad \text{...(i)}$$

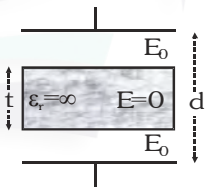
If medium is fully present between the space.

$\because$ t = d

Now from equation (i) $C_{medium} = \frac{\varepsilon_0 \varepsilon_r A}{d}$



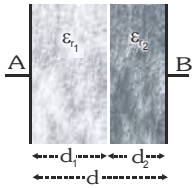
If capacitor is partialy filled by a conducting slab of thickness (t < d).



$\because \varepsilon_r = \infty$ for conductor $C = \frac{\varepsilon_0 A}{d - t\left(1-\frac{1}{\infty}\right)} = \frac{\varepsilon_0 A}{(d-t)}$

DISTANCE AND AREA DIVISION BY DIELECTRIC

Distance Division



(i) Distance is divided and area remains same.

(ii) Capacitors are in series.

(iii) Individual capacitances are $C_1 = \frac{\varepsilon_0 \varepsilon_{r_1} A}{d_1}$, $C_2 = \frac{\varepsilon_0 \varepsilon_{r_2} A}{d_2}$

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These two in series $\frac{1}{C}=\frac{1}{C_1}+\frac{1}{C_2}\Rightarrow\frac{1}{C}=\frac{d_1}{\varepsilon_0\varepsilon_{r_1}A}+\frac{d_2}{\varepsilon_0\varepsilon_{r_2}A}\Rightarrow\frac{1}{C}=\frac{1}{\varepsilon_0 A}\left[\frac{d_1\varepsilon_{r_2}+d_2\varepsilon_{r_1}}{\varepsilon_{r_1}\varepsilon_{r_2}}\right]$

$\Rightarrow C=\varepsilon_0 A\left[\frac{\varepsilon_{r_1}\varepsilon_{r_2}}{d_1\varepsilon_{r_2}+d_2\varepsilon_{r_1}}\right]$

Special case : If $d_1=d_2=\frac{d}{2}\Rightarrow C=\frac{\varepsilon_0 A}{d}\left[\frac{2\varepsilon_{r_1}\varepsilon_{r_2}}{\varepsilon_{r_1}+\varepsilon_{r_2}}\right]$

Area Division

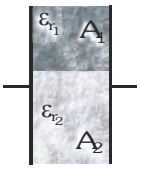
(i) Area is divided and distance remains same.

(ii) Capacitors are in parallel.

(iii) Individual capacitances are $C_1=\frac{\varepsilon_0\varepsilon_{r_1}A_1}{d}$ $C_2=\frac{\varepsilon_0\varepsilon_{r_2}A_2}{d}$

These two in parallel

So $C=C_1+C_2=\frac{\varepsilon_0\varepsilon_{r_1}A_1}{d}+\frac{\varepsilon_0\varepsilon_{r_2}A_2}{d}=\frac{\varepsilon_0}{d}(\varepsilon_{r_1}A_1+\varepsilon_{r2}A_2)$



Variable Dielectric Constant

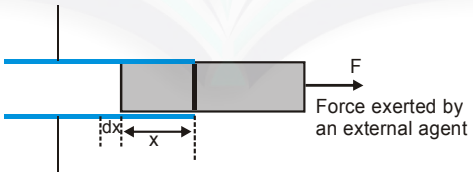
If the dielectric constant is variable, then equivalent capacitance can be obtained by selecting an element as per the given condition and then integrating.

(i) If different elements are in parallel, then $C=\int dC$, where dC = capacitance of selected differential element.

(ii) If different element are in series, then $\frac{1}{C}=\int d\left(\frac{1}{C}\right)$ is solved to get equivalent capacitance C.

Force on a Dielectric in a Capacitor

Consider a differential displacement dx of the dielectric as shown in figure always keeping the net force on it zero so that the dielectric moves slowly without acceleration. Then, $W_{Electrostatic}+W_F=0$, where W_F denotes the work done by external agent in displacement dx

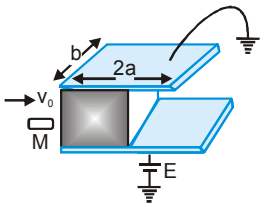


$W_F=-W_{Electrostatic}$ $W_F=\Delta U\Rightarrow -F.dx=\frac{Q^2}{2}d\left[\frac{1}{C}\right]$ $\left[W=\frac{Q^2}{2C}\right]\Rightarrow -F.dx=\frac{-Q^2}{2C^2}dC\Rightarrow F=\frac{Q^2}{2C^2}\left(\frac{dC}{dx}\right)$

This is also true for the force between the plates of the capacitor. If the capacitor has battery connected to it, then as the p.d. across the plates is maintained constant. $V=\frac{Q}{C}\Rightarrow F=\frac{1}{2}V^2\frac{dC}{dx}$.

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Ex. A parallel plate capacitor is half filled with a dielectric (K) of mass M. Capacitor is attached with a cell of emf E. Plates are held fixed on smooth insulating horizontal surface. A bullet of mass M hits the dielectric elastically and its found that dielectric just leaves out the capacitor. Find speed of bullet.



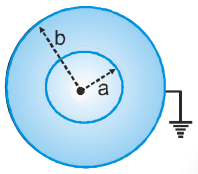
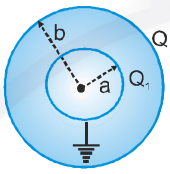
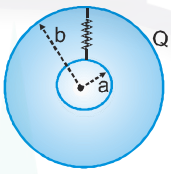
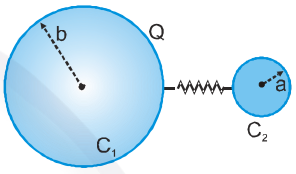
Sol. Since collision is elastic $\therefore$ Velocity of dielectric after collision is v_0.

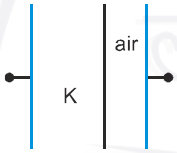
Dielectric will move and when it is coming out of capacitor a force is applied on

it by the capacitor $F = \frac{-dU}{dx} = \frac{-E^2\varepsilon_0 b(K-1)}{2d}$

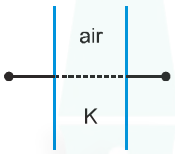
Which decreases its speed to zero, till it comes out it travels a distance a.

$$\frac{1}{2}Mv_0^2 = \frac{E^2\varepsilon_0 b(K-1)a}{2d} \Rightarrow v_0 = E\left[\frac{\varepsilon_0 ab(K-1)}{Md}\right]^{1/2}$$

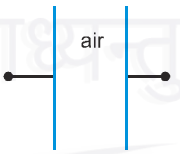
Spherical capacitor outer is earthed	Inner is earthed and outer is given a charge	Connected and outer is given a charge	Connected spheres
			
$C = \frac{4\pi\varepsilon_0 ab}{b-a}$ (b > a)	$C = \frac{4\pi\varepsilon_0 b^2}{b-a}$ (b > a)	$C = 4\pi\varepsilon_0 b$	$C = C_1 + C_2$ $C = 4\pi\varepsilon_0(a+b)$



$C_1 = \left[\frac{2K}{K+1}\right]C$



$C_2 = \left[\frac{K+1}{2}\right]C$



$C_3 = C$ when no dielectric is used

$C_2 > C_1 > C_3$

Ex. A capacitor has two circular plates whose radius are 8cm and distance between them is 1mm. When mica (dielectric constant = 6) is placed between the plates, calculate the capacitance of this capacitor and the energy stored when it is given potential of 150 volt.

Sol. Area of plate $\pi r^2 = \pi \times (8 \times 10^{-2})^2 = 0.0201\ m^2$ and $d = 1mm = 1 \times 10^{-3}\ m$

Capacity of capacitor $C = \frac{\varepsilon_0\varepsilon_r A}{d} = \frac{8.85 \times 10^{-12} \times 6 \times 0.0201}{1 \times 10^{-3}} = 1.068 \times 10^{-9}\ F$

Potential difference V = 150 volt

Energy stored $U = \frac{1}{2}CV^2 = \frac{1}{2} \times (1.068 \times 10^{-9}) \times (150)^2 = 1.2 \times 10^{-5}\ J$

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Ex. A parallel-plate capacitor is formed by two plates, each of area 100 cm^2, separated by a distance of 1mm. A dielectric of dielectric constant 5.0 and dielectric strength 1.9×10^7 V/m is filled between the plates. Find the maximum charge that can be stored on the capacitor without causing any dielectric breakdown.

Sol. If the charge on the capacitor = Q

the surface charge density $\sigma = \frac{Q}{A}$ and the electric field = $\frac{Q}{KA\varepsilon_0}$.

This electric field should not exceed the dielectric strength 1.9×10^7 V/m.

$\therefore$ if the maximum charge which can be given is Q then $\frac{Q}{KA\varepsilon_0} = 1.9 \times 10^7$ V/m

$\because A = 100\ cm^2 = 10^{-2}\ m^2 \Rightarrow Q = (5.0) \times (10^{-2}) \times (8.85 \times 10^{-12}) \times (1.9 \times 10^7) = 8.4 \times 10^{-6}$ C.

Ex. The distance between the plates of a parallel-plate capacitor is 0.05 m. A field of 3×10^4 V/m is established between the plates. It is disconnected from the battery and an uncharged metal plate of thickness 0.01 m is inserted into the **(i)** before the introduction of the metal plate and **(ii)** after its introduction. What would be the potential difference if a plate of dielectric constant K = 2 is introduced in place of metal plate ?

Sol. **(i)** In case of a capacitor as E = (V/d), the potential difference between the plates before the introduction of metal plate

$$V = E \times d = 3 \times 10^4 \times 0.05 = 1.5\ kV$$

(ii) Now as after charging battery is removed , capacitor is isolated so q = constant. If C' and V' are the capacity and potential after the introduction of plate $q = CV = C'V'$ i.e., $V' = \frac{C}{C'}V$

And as $C = \frac{\varepsilon_0 A}{d}$ and $C' = \frac{\varepsilon_0 A}{(d-t)+(t/K)}$, $V' = \frac{(d-t)+(t/K)}{d} \times V$

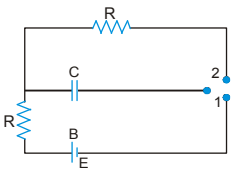
So in case of metal plate as $K = \infty$, $V_M = \left[\frac{d-t}{d}\right] \times V = \left[\frac{0.05-0.01}{0.05}\right] \times 1.5 = 1.2$ kV

And if instead of metal plate, dielectric with K = 2 is introduced $V_D = \left[\frac{(0.05-0.01)+(0001/2)}{0.05}\right] \times 1.5 = 1.35$ kV

CHARGING AND DISCHARGING OF A CAPACITOR

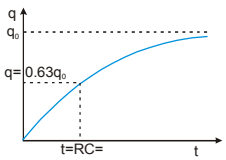
Charging of a Condenser

(i) In the following circuit. If key 1 is closed then the condenser gets charged. Finite time is taken in the charging process. The quantity of charge at any instant of time t is given by $q = q_0[1 - e^{-(t/RC)}]$



Where q_0 = maximum final value of charge at $t = \infty$.

According to this equations the quantity of charge on the condenser increases exponentially with increase of time.



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(ii) If $t = RC = \tau$ then

$$q = q_0 [1 - e^{-(RC/RC)}] = q_0 \left[1 - \frac{1}{e}\right]$$

or $q = q_0 (1 - 0.37) = 0.63\, q_0 = 63\%$ of q_0

(iii) Time $t = RC$ is known as time constant.

i.e. the time constant is that time during which the charge rises on the condenser plates to 63% of its maximum value.

(iv) The potential difference across the condenser plates at any instant of time is given by

$V = V_0[1 - e^{-(t/RC)}]$ volt

(v) The potential curve is also similar to that of charge. During charging process an electric current flows in the circuit for a small interval of time which is known as the transient current. The value of this current at any instant of time is given by

$I = I_0[e^{-(t/RC)}]$ ampere

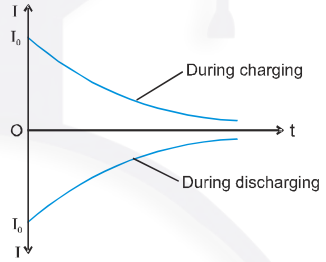
According to this equation the current falls in the circuit exponentially (Fig.).

(vi) If $t = RC = \tau$ = Time constant

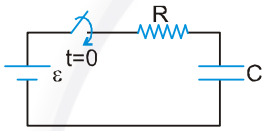
$$I = I_0 e^{(-RC/RC)} = \frac{I_0}{e} = 0.37\, I_0$$

$= 37\%$ of I_0

i.e. time constant is that time during which current in the circuit falls to 37% of its maximum value.



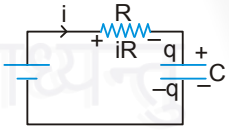
Derivation of Formulae for Charging of Capacitor



it is given that initially capacitor is uncharged.

let at any time charge on capacitor is q

Applying kirchoff voltage law



$$\varepsilon - iR - \frac{q}{C} = 0 \Rightarrow iR = \frac{\varepsilon C - q}{C}$$

$$i = \frac{\varepsilon C - q}{CR} \Rightarrow \frac{dq}{dt} = \frac{\varepsilon C - q}{CR}$$

$$\frac{dq}{dt} = \frac{\varepsilon C - q}{CR} \Rightarrow \frac{CR}{\varepsilon C - q} . dq = dt.$$

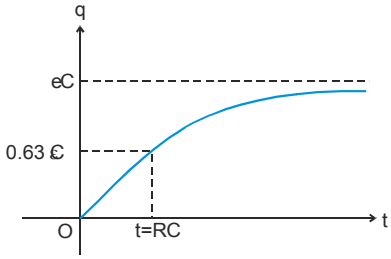
$$\int_0^q \frac{dq}{\varepsilon C - q} = \int_0^t \frac{dt}{RC} \Rightarrow -\ln(\varepsilon C - q) + \ln \varepsilon C = \frac{t}{RC}$$

$$\ln \frac{\varepsilon C}{\varepsilon C - q} = \frac{t}{RC}$$

$\varepsilon C - q = \varepsilon C . e^{-t/RC}$

$q = \varepsilon C(1 - e^{-t/RC})$

RC = time constant of the RC series circuit.

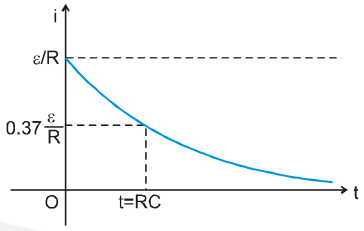


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After one time constant

$$q = \varepsilon C\left(1-\frac{1}{e}\right)$$

$$= \varepsilon C\,(1-0.37) = 0.63\,\varepsilon C.$$



Current at any time t

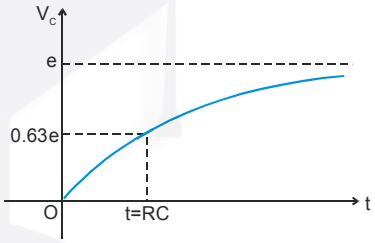
$$i = \frac{dq}{dt} = \varepsilon C\left(-e^{-t/RC}\left(-\frac{1}{RC}\right)\right)$$

$$= \frac{\varepsilon}{R}e^{-t/RC}$$

Voltage across capacitor after one time constant V = 0.63 ε

$$Q = CV$$

$$V_C = \varepsilon(1-e^{-t/RC})$$



Voltage across the resistor

$$V_R = iR = \varepsilon e^{-t/RC}$$

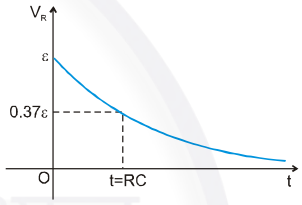
By energy conservation,

Heat dissipated = work done by battery – ΔUcapacitor

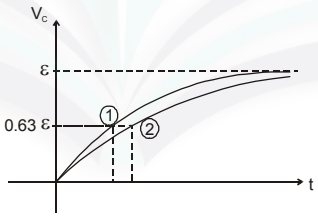
$$= C\varepsilon(\varepsilon) - \left(\frac{1}{2}C\varepsilon^2 - 0\right) = \frac{1}{2}C\varepsilon^2$$

Alternatively :

$$\text{Heat} = H = \int_0^\infty i^2R\,dt = \int_0^\infty \frac{\varepsilon^2}{R^2}\,e^{-\frac{2t}{RC}}\,R\,dt = \frac{\varepsilon^2}{R}\int_0^\infty e^{-2t/RC}\,dt$$

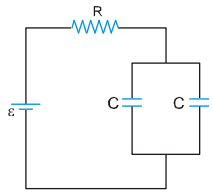


$$= \frac{\varepsilon^2}{R}\left[\frac{e^{-\frac{2t}{RC}}}{-2/RC}\right]_0^\infty = -\frac{\varepsilon^2RC}{2R}\left[e^{-\frac{2t}{RC}}\right]_0^\infty = \frac{\varepsilon^2C}{2}$$



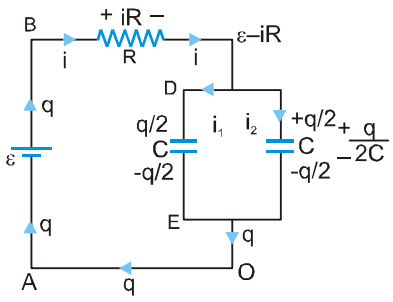
In the figure time constant of (2) is more than (1)

Ex. Without using the formula of equivalent. Find out charge on capacitor and current in all the branches as a function of time.



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Sol. Applying KVL in ABDEA



$$\varepsilon - iR = \frac{q}{2C}$$

$$i = \frac{\varepsilon}{R} - \frac{q}{2CR}$$

$$= \frac{2C\varepsilon - q}{2CR}$$

$$\frac{dq}{2\varepsilon C - q} = \frac{dt}{2CR} \quad \Rightarrow \quad \frac{dq}{2\varepsilon C - q} = \frac{dt}{2CR}$$

$$\int_0^q \frac{dq}{(2\varepsilon C - q)} = \frac{t}{2CR} \quad \Rightarrow \quad \frac{2\varepsilon C - q}{2\varepsilon C} = e^{-t/2RC}$$

$$q = 2\varepsilon C\,(1 - e^{-t/2RC})$$

$$q_1 = \frac{q}{2} = \varepsilon C\,(1 - e^{-t/2RC}) \quad \Rightarrow \quad i_1 = \frac{\varepsilon}{2R}\, e^{-t/2RC}$$

$$q_2 = \frac{q}{2} = \varepsilon C\,(1 - e^{-t/2RC}) \quad \Rightarrow \quad i_2 = \frac{\varepsilon}{2R}\, e^{-t/2RC}$$

Alternate Solution

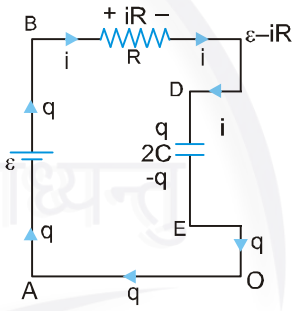
by equivalent

Time constant of circuit = $2C \times R = 2RC$

maximum charge on capacitor = $2C \times \varepsilon = 2C\varepsilon$

Hence equations of charge and current are as given below

$$q = 2\varepsilon C\,(1 - e^{-t/2RC})$$



$$q_1 = \frac{q}{2} = \varepsilon C\,(1 - e^{-t/2RC}) \quad \Rightarrow \quad i_1 = \frac{\varepsilon}{2R}\, e^{-t/2RC}$$

$$q_2 = \frac{q}{2} = \varepsilon C\,(1 - e^{-t/2RC}) \quad \Rightarrow \quad i_2 = \frac{\varepsilon}{2R}\, e^{-t/2RC}$$

Ex. A capacitor is connected to a 36 V battery through a resistance of 20Ω. It is found that the potential difference across the capacitor rises to 12.0 V in 2μs. Find the capacitance of the capacitor.

Sol. The charge on the capacitor during charging is given by $Q = Q_0(1 - e^{-t/RC})$.

Hence, the potential difference across the capacitor is $V = Q/C = Q_0/C\,(1 - e^{-t/RC})$.

Here, at t = 2 μs, the potential difference is 12V whereas the steady potential difference is

$Q_0/C = 36V$. So, $\Rightarrow$ $12V = 36V(1 - e^{-t/RC})$

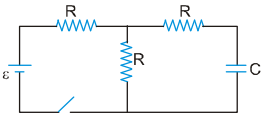
or, $1 - e^{-t/RC} = \frac{1}{3}$ or, $e^{-t/RC} = \frac{2}{3}$

or, $\frac{t}{RC} = \ell n\left(\frac{3}{2}\right) = 0.405$ or, $RC = \frac{t}{0.405} = \frac{2\ \mu s}{0.45} = 4.936\ \mu s$

or, $C = \frac{4.936\mu s}{20\Omega} = 0.25\ \mu F.$

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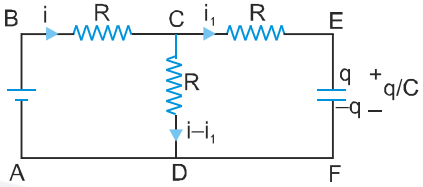
Ex. Initially the capacitor is uncharged find the charge on capacitor as a function of time, if switch is closed at t = 0.



Sol. Applying KVL in loop ABCDA

$$\varepsilon - iR - (i - i_1)R = 0$$

$$\varepsilon - 2iR + i_1R = 0 \qquad ...(i)$$



Applying KVL in loop ABCEFDA

$$\varepsilon - iR - i_1R - \frac{q}{C} = 0$$

$$\text{by eq (i)} \quad \frac{2\varepsilon - \varepsilon - i_1R - 2i_1R}{2} = \frac{q}{C} \Rightarrow \varepsilon C - 3i_1RC = 2q$$

$$\varepsilon C - 2q = 3\frac{dq}{dt}.RC \Rightarrow \int_0^q \frac{dq}{\varepsilon C - 2q} = \int_0^t \frac{dt}{3RC}$$

$$-\frac{1}{2}\ln\frac{\varepsilon C - 2q}{\varepsilon C} = \frac{t}{3RC} \Rightarrow q = \frac{\varepsilon C}{2}\left(1 - e^{-2t/3RC}\right)$$

Method for Objective

In any circuit when there is only one capacitor then

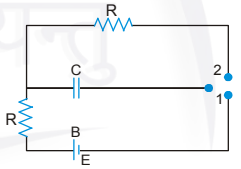
$q = Q_{st}\left(1 - e^{-t/\tau}\right)$; Q_{st} = steady state charge on capacitor (has been found in article 6 in this sheet)

$\tau = R_{eff}.C$

$R_{effective}$ is the resistance between the capacitor when battery is replaced by its internal resistance.

Discharging of a Condenser

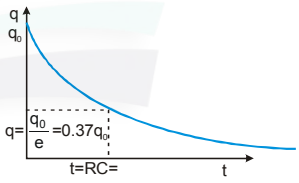
(i) In the above circuit (in article 10.1) if key 1 is opened and key 2 is closed then the condenser gets discharged.



(ii) The quantity of charge on the condenser at any instant of time t is given by $q = q_0 e^{-(t/RC)}$

i.e. the charge falls exponentially.

here q_0 = initial charge of capacitor



(iii) If t = RC = τ = time constant, then

$$q = \frac{q_0}{e} = 0.37q_0 = 37\% \text{ of } q_0$$

i.e. the time constant is that time during which the charge on condenser plates in discharge process, falls to 37%

(iv) The dimensions of RC are those of time i.e. $M^oL^oT^1$ and the dimensions of $\frac{1}{RC}$ are those of frequency i.e. $M^0L^0T^{-1}$.

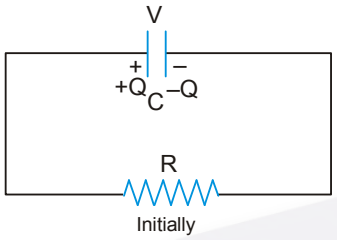
(v) The potential difference across the condenser plates at any instant of time t is given by $V = V_0e^{-(t/RC)}$ Volt.

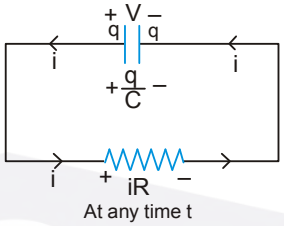
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(vi) The transient current at any instant of time is given by $I = -I_0 e^{-(t/RC)}$ ampere.

i.e. the current in the circuit decreases exponentially but its direction is opposite to that of charging current. (– ive only means that direction of current is opposite to that at charging current)

Derivation of Equation of Discharging Circuit





Applying K.V.L.

$$+\frac{q}{C} - iR = 0$$

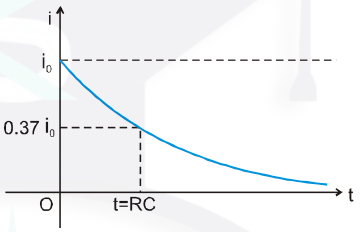
$$i = \frac{q}{CR}$$

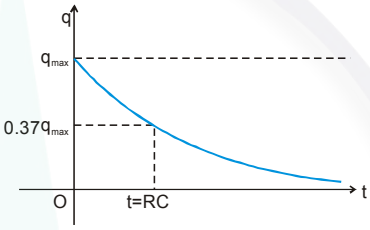
$$\int_{Q}^{q} \frac{-dq}{q} = \int_{0}^{t} \frac{dt}{CR}$$

$$-\ln \frac{q}{Q} = +\frac{t}{RC}$$

$$q = Q \cdot e^{-t/RC}$$

$$i = -\frac{dq}{dt} = \frac{Q}{RC} e^{-t/RC} = i_0 e^{-t/RC}$$





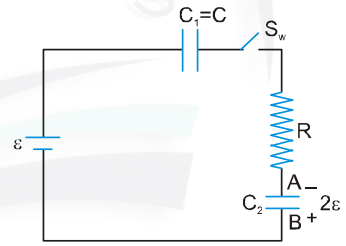
Ex. At t = 0, switch is closed, if initially C_1 is uncharged and C_2 is charged to a potential difference 2ε then find out following

(Given $C_1 = C_2 = C$)

(a) Charge on C_1 and C_2 as a function of time.

(b) Find out current in the circuit as a function of time.

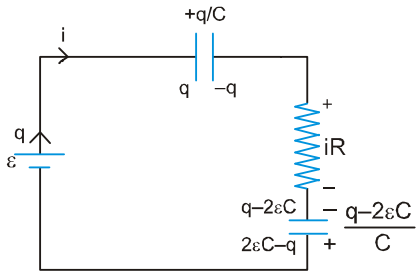
(c) Also plot the graphs for the relations derived in part (a).



Sol. Let q charge flow in time 't' from the battery as shown.

The charge on various plates of the capacitor is as shown in the figure.

Now applying KVL



$$\varepsilon - \frac{q}{C} - iR - \frac{q - 2\varepsilon C}{C} = 0 \Rightarrow \varepsilon - \frac{q}{C} - \frac{q}{C} + 2\varepsilon - iR = 0$$

$$3\varepsilon = \frac{2q}{C} + iR \qquad \Rightarrow \qquad 3\varepsilon - iR = \frac{2q}{C}$$

$$3\varepsilon C - iRC = 2q \qquad \Rightarrow \qquad \frac{dq}{dt} RC = 3\varepsilon C - 2q$$

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$$\int_0^q \frac{dq}{3\varepsilon C - 2q} = \int_0^t \frac{dt}{RC} \Rightarrow -\frac{1}{2}\ell n\left(\frac{3C\varepsilon - 2q}{3C\varepsilon}\right) = \frac{t}{RC}$$

$$\ln\left(\frac{3\varepsilon C - 2q}{3\varepsilon C}\right) = -\frac{2t}{RC} \Rightarrow 3\varepsilon C - 2q = 3\varepsilon C$$

$e^{-2t/RC}$

$$3\varepsilon C(1 - e^{-2t/RC}) = 2q \Rightarrow q = \frac{3}{2}\varepsilon C\ (1 - e^{-2t/RC})$$

(charge on C, as function of time) **Ans.**

$$i = \frac{dq}{dt} = \frac{3\varepsilon}{R} e^{-2t/RC}$$ **Ans.**

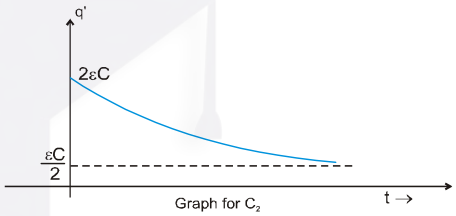
Charge on C_2 as function of time :

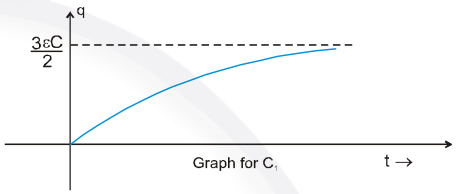
$q' = 2\varepsilon C - q$

$$= 2\varepsilon C - \frac{3}{2}\varepsilon C + \frac{3}{2}\varepsilon C\, e^{-2t/RC}$$

$$= \frac{\varepsilon C}{2} + \frac{3}{2}\varepsilon C e^{-2t/RC}$$

$$= \frac{\varepsilon C}{2}\left[1 + 3e^{-2t/RC}\right]$$



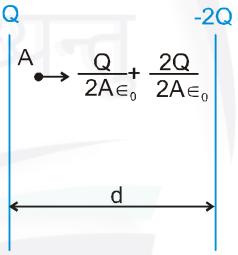


Ex. Two parallel conducting plates of a capacitor of capacitance C containing charges Q and –2Q at a distance d apart. Find out potential difference between the plates of capacitors.

Sol. Capacitance = C

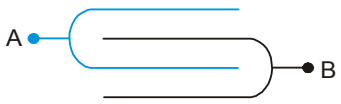
$$\text{Electric field} = \frac{3Q}{2A\in_0}$$

$$V = \frac{3Qd}{2A\in_0} \Rightarrow V = \frac{3Q}{2C}$$



Combination of Parallel Plates

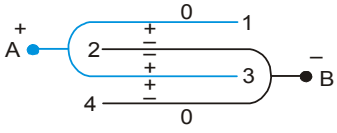
Ex. Find out equivalent capacitance between A and B. (take each plate Area = A and distance between two conjugative plates is d)



Sol. Let numbers on the plates The charges will be as shown in the figure.

$V_{12} = V_{32} = V_{34}$

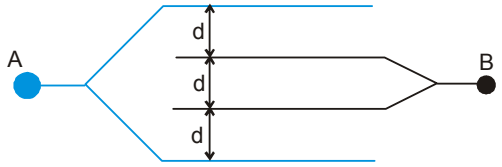
so all the capacitors are in parallel combination.



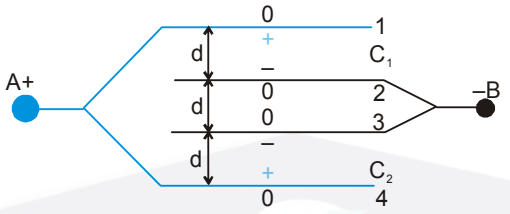
$$C_{eq} = C_1 + C_2 + C_3 = \frac{3A\in_0}{d}$$

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Ex. Find out equivalent capacitance between A and B. (take each plate Area = A)



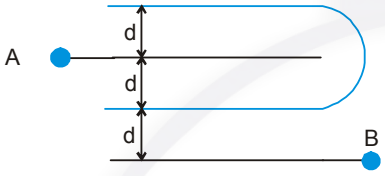
Sol.



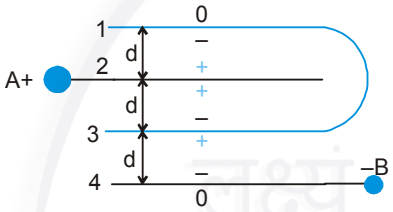
These are only two capacitors.

$$C_{eq} = C_1 + C_2 = \frac{2A\epsilon_0}{d}$$

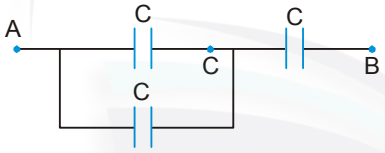
Ex. Find out equivalent capacitance between A and B. (take each plate Area = A)



Sol.

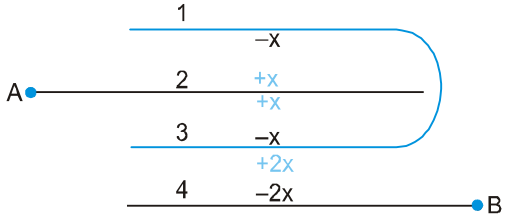


The modified circuit is



$$C_{eq} = \frac{2C}{3} = \frac{2A\epsilon_0}{3d}$$

Other method Let charge density as shown



$$C_{eq} = \frac{Q}{V} = \frac{2xA}{V}$$

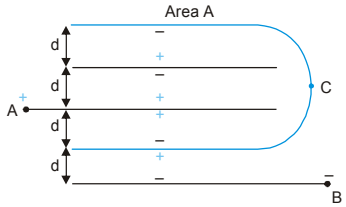
$$V = V_2 - V_4 = (V_2 - V_3) + (V_3 - V_4)$$

$$= \frac{xd}{\epsilon_0} + \frac{2xd}{\epsilon_0} = \frac{3xd}{\epsilon_0}$$

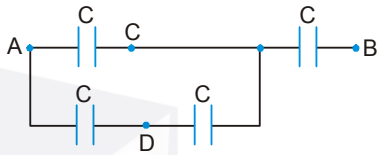
$$\therefore \quad C_{eq} = \frac{2Ax\epsilon_0}{3xd} = \frac{2A\epsilon_0}{3d} = \frac{2C}{3}.$$

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Ex. Find out equivalent capacitance between A and B.

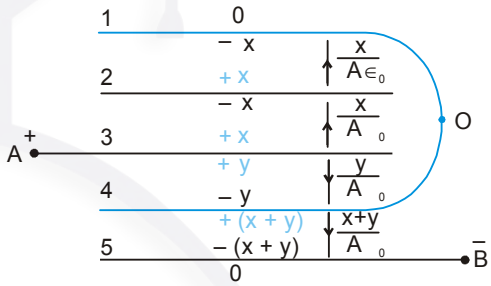


Sol. Let $C = \frac{A\epsilon_0}{d}$ Equivalent circuit : -



$$\frac{1}{C_{eq}} = \frac{1}{C} + \frac{2}{3C} = \frac{5}{3C} \Rightarrow C_{eq} = \frac{3C}{5} = \frac{3A\epsilon_0}{5d}$$

Alternative Method : Let charge distribution on plates as shown :



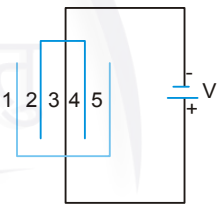
$$C = \frac{Q}{V} = \frac{x+y}{V_{AB}}$$

Potential of 1 and 4 is same

$$\frac{y}{A\epsilon_0} = \frac{2x}{A\epsilon_0} \qquad y = 2x$$

$$V = \left(\frac{2y+x}{A\varepsilon_0}\right)d \Rightarrow C = \frac{(x+2x)A\epsilon_0}{(5x)d} = \frac{3A\epsilon_0}{5d}.$$

Ex. Five similar condenser plates, each of area A, are placed at equal distance d apart and are connected to a source of e.m.f. V as shown in the following diagram. The charge on the plates 1 and 4 will be-



(A) $\frac{\epsilon_0 A}{d}, \frac{-2\epsilon_0 A}{d}$ **(B)** $\frac{\epsilon_0 AV}{d}, \frac{-2\epsilon_0 AV}{d}$

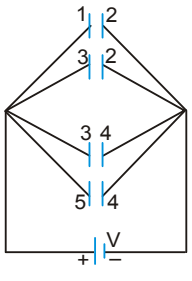
(C) $\frac{-\epsilon_0 AV}{d}, \frac{-3\epsilon_0 AV}{d}$ **(D)** $\frac{\epsilon_0 AV}{d}, \frac{-4\epsilon_0 AV}{d}$

Sol. by equivalent circuit diagram Charge on first plate

$Q = CV$

$$Q = \frac{\epsilon_0 AV}{d}$$

Charge on fourth plate



$Q' = C(-V)$ $\qquad Q' = \frac{-\epsilon_0 AV}{d}$

As plate 4 is repeated twice, hence charge on 4 will be $Q'' = 2Q'$

$$Q'' = -\frac{2\epsilon_0 AV}{d}$$

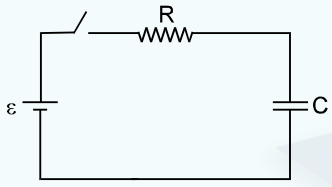
Hence the correct answer will be **(B)**.

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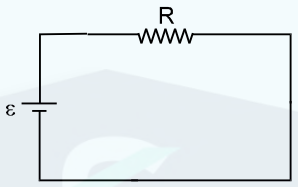
Circuit solution for R–C circuit at t = 0 (initial state) and at t = ∞ (final state)

(i) Charge on the capacitor does not change instantaneously or suddenly if there is a resistance in the path (series) of the capacitor.

(ii) When an uncharged capacitor is connected with battery then its charge is zero initially hence potential difference across it is zero initially. At this time the capacitor can be treated as a conducting wire

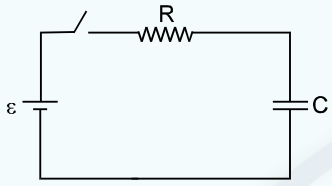


Before connection

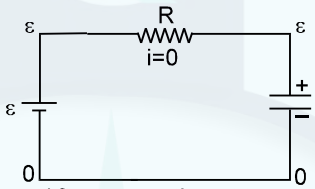


Just after connection at t = 0

(iii) The current will become zero finally (that means in steady state) in the branch which contains capacitor.



Before connection

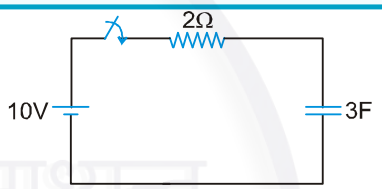


After connection at t = ∞

Ex. Find out current in the circuit and charge on capacitor which is initially uncharged in the following situations.

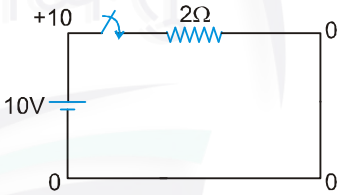
(a) Just after the switch is closed.

(b) After a long time when switch was closed.



Sol. **(a) For just after closing the switch:**

potential difference across capacitor = 0



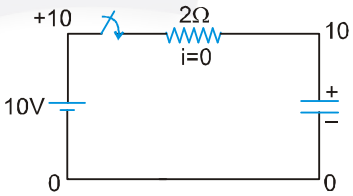
$\therefore Q_C = 0$ $\quad\quad$ $\therefore i = \frac{10}{2} = 5A$

(b) After a long time

at steady state current i = 0

and potential difference across capacitor = 10 V

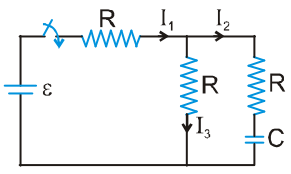
$\therefore Q_C = 3 \times 10 = 30\,C$



Ex. Find out current I_1, I_2, I_3, charge on capacitor and $\frac{dQ}{dt}$ of capacitor in the circuit which is initially uncharged in the following situations.

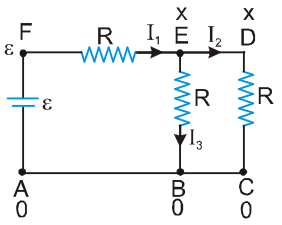
(a) Just after the switch is closed

(b) After a long time when switch is closed.



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Sol. **(a)** Initially the capacitor is uncharged so its behaviour is like a conductor Let potential at A is zero so at B and C also zero and at F it is ε. Let potential at E is x so at D also x. Apply Kirchhoff's I[st] law at point E :



$$\frac{x-\varepsilon}{R}+\frac{x-0}{R}+\frac{x-0}{R}=0 \Rightarrow \frac{3x}{R}=\frac{\varepsilon}{R}$$

$$x=\frac{\varepsilon}{3} \quad ; Q_c=0$$

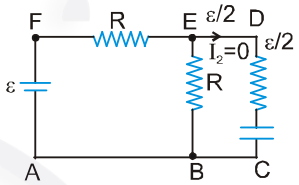
$$\therefore \quad I_1=\frac{-\varepsilon/3+\varepsilon}{R}=\frac{2\varepsilon}{3R} \Rightarrow I_2=\frac{dQ}{dt}=\frac{\varepsilon}{3R} \text{ and } I_3=\frac{\varepsilon}{3R}$$

Alternatively

$$i_1=\frac{\varepsilon}{R_{eq}}=\frac{\varepsilon}{R+\frac{R}{2}}=\frac{2\varepsilon}{3R} \Rightarrow i_2=i_3=\frac{i_1}{2}=\frac{\varepsilon}{3R} \text{ and } \frac{dQ}{dt}=i_2=\frac{\varepsilon}{3R}$$

(b) at t = ∞ (finally)

capacitor completely charged so their will be no current through it.



$$I_2=0, \quad I_1=I_3=\frac{\varepsilon}{2R}$$

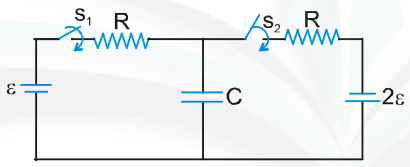
$$V_E-V_B=V_D-V_C=(\varepsilon/2R)R=\varepsilon/2$$

$$\Rightarrow Q_C=\frac{\varepsilon C}{2}, \quad \frac{dQ}{dt}=I_2=0$$

	I_1	I_2	I_3	Q	dQ/dt
Time t = 0	$\frac{2\varepsilon}{3R}$	$\frac{\varepsilon}{3R}$	$\frac{\varepsilon}{3R}$	0	$\frac{\varepsilon}{3R}$
Finally t = ∞	$\frac{\varepsilon}{2R}$	0	$\frac{\varepsilon}{2R}$	$\frac{\varepsilon C}{2}$	0

Ex. At t = 0 switch S_1 is closed and remains closed for a long time and S_2 remains open. Now S_1 is opened and S_2 is closed.

Find out



(i) The current through the capacitor immediately after that moment

(ii) Charge on the capacitor long after that moment.

(iii) Total charge flown through the cell of emf 2ε after S_2 is closed.

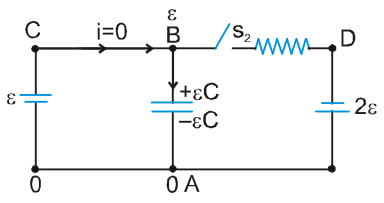
Sol. **(i)** Let Potential at point A is zero. Then at point B and C it will be ε (because current through the circuit is zero).

$V_B-V_A=(\varepsilon-0)$

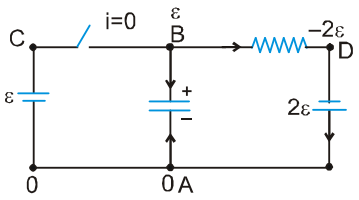
∴ Charge on capacitor = $C(\varepsilon-0)=C\varepsilon$

Now S_2 is closed and S_1 is open. (p.d. across capacitor and charge on it will not change suddenly)

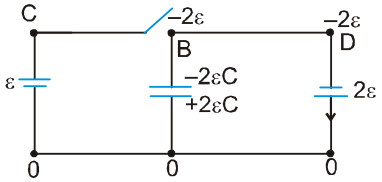
Potential at A is zero so at D it is – 2ε.



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$\therefore$ current through the capacitor $= \dfrac{\varepsilon-(-2\varepsilon)}{R} = \dfrac{3\varepsilon}{R}$ (B to D)



(ii) after a long time, $i = 0$

$V_B - V_A = V_D - V_A = -2\varepsilon$

$\therefore \quad Q = C(-2\varepsilon - 0) = -2\varepsilon C$

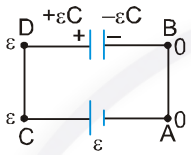
(iii) The charge on the lower plate (which is connected to the battery) changes from $-\varepsilon C$ to $2\varepsilon C$.

$\therefore$ this charge will come form the battery,

$\therefore$ charge flown from that cell is $3\varepsilon C$ downward.

Ex. A capacitor of capacitance C which is initially uncharged is connected with a battery. Find out heat dissipated in the circuit during the process of charging.

Sol. Final status



Let potential at point A is 0, so at B also 0 and at C and D it is ε. finally, charge on the capacitor

$Q_C = \varepsilon C$

$U_i = 0$

$U_f = \dfrac{1}{2} CV^2 = \dfrac{1}{2} C\varepsilon^2$

work done by battery $= \int Pdt$

$W = \int \varepsilon i dt = \varepsilon \int i dt = \varepsilon . Q = \varepsilon . \varepsilon C = \varepsilon^2 C$

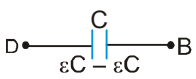
(Now onwards remember that w.d. by battery = εQ if Q has flown out of the cell from high potential and w.d. on battery

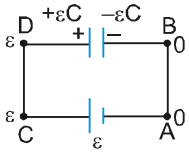
is εQ if Q has flown into the cell through high potential)

Heat produced $= W - (U_f - U_i) = \varepsilon^2 C - \dfrac{1}{2}\varepsilon^2 C = \dfrac{C\varepsilon^2}{2}$.

Ex. A capacitor of capacitance C which is initially charged upto a potential difference ε is connected with a battery of emf ε such that the positive terminal of battery is connected with positive plate of capacitor. Find out heat loss in the circuit during the process of charging.

Sol.





Since the initial and final charge on the capacitor is same before and after connection.

Here no charge will flow in the circuit so heat loss = 0

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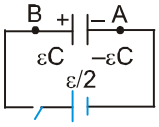
Ex. A capacitor of capacitance C which is initially charged upto a potential difference ε is connected with a battery of emf ε/2 such that the positive terminal of battery is connected with positive plate of capacitor. After a long time

(i) Find out total charge flow through the battery

(ii) Find out total work done by battery

(iii) Find out heat dissipated in the circuit during the process of charging.

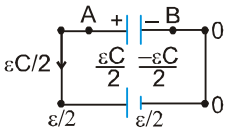
Sol. **(i)** Let potential of A is 0 so at B it is $\frac{\varepsilon}{2}$. So final charge on capacitor = Cε/2



Charge flow through the capacitor = (Cε/2 – Cε) = –Cε/2

So charge is entering into battery.

(ii) finally,



Change in energy of capacitor = $U_{final} - U_{initial}$

$$= \frac{1}{2}C\left(\frac{\varepsilon}{2}\right)^2 - \frac{\varepsilon^2 C}{2}$$

$$= \frac{1}{8}\varepsilon^2 C - \frac{1}{2}\varepsilon^2 C = -\frac{3\varepsilon^2 C}{8}$$

$$\text{Work done by battery} = \frac{\varepsilon}{2} \times \left(-\frac{\varepsilon C}{2}\right) = -\frac{\varepsilon^2 C}{4}$$

(iii) Work done by battery = Change in energy of capacitor + Heat produced

$$\text{Heat produced} = \frac{3\varepsilon^2 C}{8} - \frac{\varepsilon^2 C}{4} = \frac{\varepsilon^2 C}{8}$$

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TIPS&FORMLAS

1. CAPACITOR & CAPACITANCE

A capacitor consist of two conductors carrying charges of equal magnitude and opposite sign. The capacitance C of any capacitor is the ratio of the charge Q on either conductor to the potential difference V between them

$C = \frac{Q}{V}$ The capacitance depends only on the geometry of the conductors and not on an external source of charge or potential difference.

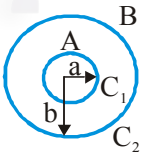
2. Capacitance of an Isolated Spherical Conductor

$C = 4\pi \in_0 \in_r R$ in a medium $C = 4\pi \in_0 R$ in air

This sphere is at infinite distance from all the conductors.

3. Spherical Capacitor :

It consists of two concentric spherical shells. Here capacitance on region between the two shells is C_1 and that outside the shell is C_2. We have



$C_1 = \frac{4\pi \in_0 ab}{b-a}$ and $C_2 = 4\pi \in_0 b$

4. Parallel Plate Capacitor :

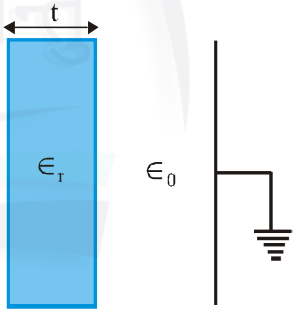
(a) Uniform Di-Electric Medium : If two parallel plates each of area A & separated by a distance d are charged with equal & opposite charge Q, then the system is called a parallel plate capacitor & capacitance is given by,

$C = \frac{4\pi \in_0 \in_r A}{d}$ in a medium ; $C = \frac{\in_0 A}{d}$ with air as medium

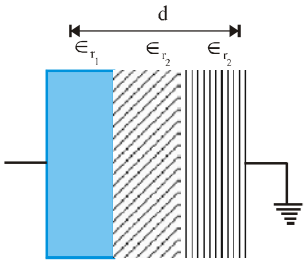
This result is only valid when the electric field between plates of capacitor is constant.

(b) Medium Partly Air : $C = \frac{\in_0 A}{d - \left(t - \frac{t}{\in_r}\right)}$

When a di-electric slab of thickness t & relative permittivity $\in_r$ is introduced between the plates of an air capacitor, then the distance between the plates is effectively reduced by $\left(t - \frac{t}{\in_r}\right)$ irrespective of the position of the di-electric slab.



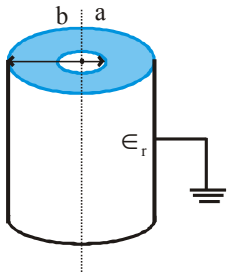
(c) Composite Medium :



$C = \frac{\in_0 A}{\frac{t_1}{\in_{r_1}} + \frac{t_2}{\in_{r_2}} + \frac{t_3}{\in_{r_3}}}$

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5. Cylindrical Capacitor :



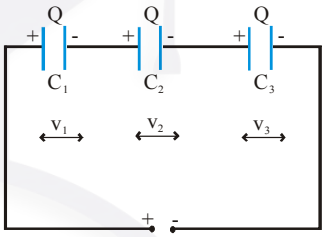
If consists of two co-axial cylinders of radii a & b the outer conductor is earthed. The di-electric constant of the medium filled in the space between the cylinders is $\in_r$.

The capacitance per unit length is $C = \dfrac{2\pi \in_0 \in_r}{\ell n\left(\dfrac{b}{a}\right)}$

6. Combination of Capacitors :

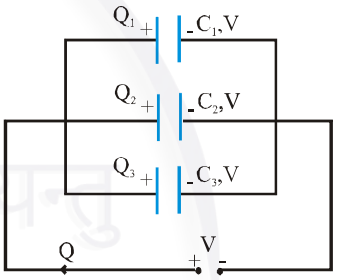
(a) Capacitors in Series : In this arrangement all the capacitors when uncharged get the same charge Q but the potential difference across each will differ (if the capacitance are unequal).

$$\frac{1}{C_{eq.}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ... + \frac{1}{C_n}$$



(b) Capacitors in Parallel : When one plate of each capacitor is connected to the positive terminal of the battery & the other plate of each capacitor is connected to the negative terminals of the battery, then the capacitors are said to be in parallel connection. The capacitors have the same potential difference, V but the charge on each one is different (if the capacitors are unequal).

$$C_{eq.} = C_1 + C_2 + C_3 + ... + C_n$$



7. Energy Stored in a Charged Capacitors :

Capacitors C, charge Q & potential difference V; then energy stored is

$$U = \frac{1}{2}CV^2 = \frac{1}{2}QV = \frac{1}{2}\frac{Q^2}{C}$$

This energy is stored in the electrostatic field set up in the di-electric medium between the conducting plates of the capacitor.

8. Heat Produced in Switching in Capacitive Circuit :

Due to charge flow always some amount of heat is produced when a switch is closed in a circuit which can be obtained by energy conservation as -

Heat = Work done by battery - Energy absorbed by capacitor.

Work done by battery to charge a capacitor $W = CV^2 = QV = \dfrac{Q^2}{C}$

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9. Sharing of Charge :

When two charged conductors of capacitance C_1 & C_2 at potential V_1 & V_2 respectively are connected by a conducting wire, the charge flows from higher potential conductor to lower potential conductor, until the potential of the two condensers becomes equal. The common potential (V) after sharing of charges;

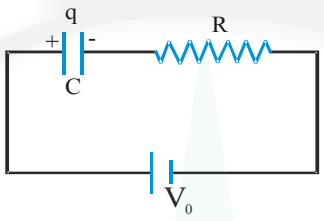
$$V = \frac{\text{net charge}}{\text{net capacitance}} = \frac{q_1 + q_2}{C_1 + C_2} = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}$$

charges after sharing $q_1 = C_1V$ & $q_2 = C_2V$. In this process energy is lost in the connecting wire as heat.

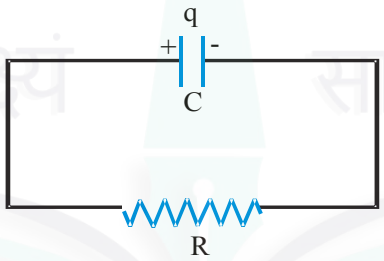
This loss of energy is $U_{initial} - U_{final} = \frac{C_1C_2}{2(C_1 + C_2)}(V_1 - V_2)^2$

10. Attractive force between capacitor plate $F = \left(\frac{\sigma}{2\epsilon_0}\right)(\sigma A) = \frac{Q^2}{2\epsilon_0 A}$

11. Charging of a capacitor : $q = q_0(1 - e^{-t/RC})$ where $q_0 = CV_0$



12. Discharging of a capacitor : $q = q_0e^{-t/RC}$



13. The energy of a charged conductor resides outside the conductor in its electric field, where as in a condenser it is stored within the condenser in its electric field.

14. The energy of an uncharged condenser = 0.

15. The capacitance of a capacitor depends only on its size & geometry & the di-electric between the conducting surface. (i.e. independent of the conductor, like whether it is copper, silver, gold etc.)

16. The two adjacent conductors carrying same charge can be at different potential because the conductors may have different sizes and hence difference capacitance.

17. When a capacitor is charged by a battery, both the plates received charge equal in magnitude, no matter sizes of plates are identical or not because the charge distribution on the plates of a capacitor is in accordance with charge conservation principle.

18. On filling the space between the plates of a parallel plates are identical or not because the charge distribution on the plates of a capacitor is increased because the same amount of charge can be stored at a reduced potential.

19. The potential of a grounded object is taken to be zero because capacitance of the earth is very large.

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SOLVED EXAMPLE

Ex. 1 Seven capacitors, each of capacitance 2μF are to be connected to obtain a capacitance of 10/11 μF. Which of the following combinations is possible ?

(A) 5 in parallel 2 in series

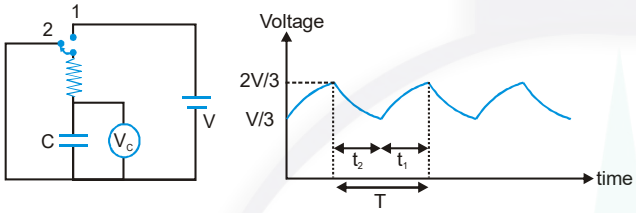
(B) 4 in parallel 3 in series

(C) 3 in parallel 4 in series

(D) 2 in parallel 5 in series

Sol. 5(2μF) in series with $\left(\frac{2\mu F}{2}\right)$, 10μF in series with 1μF, $C_{eq} = \frac{10\times1}{10+1} = \frac{10}{11}\mu F$

Ex. 2 The switch in circuit shifts from 1 to 2 when $V_C > 2V/3$ and goes back to 1 from 2 when $V_C < V/3$. The voltmeter reads voltage as plotted. What is the period T of the wave form in terms of R and C?



Sol. During time 't_2' capacitor is discharging with the help of resistor 'R' $\therefore q = q_0 e^{-t/RC}$

$V = V_0 e^{-t/RC}$ [$\because Q=CV$]

As $V_0 = \frac{2V}{3}$; $V = \frac{V}{3}$; $t_2 = RC\,\ell n2$

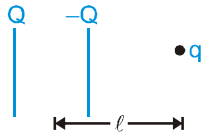
During time 't_1' capacitor is charging with the help of battery.

$\therefore q = q_0(1-e^{-t/RC})$ or $V = V_0(1-e^{-t/RC})$

as $V_0 = \frac{2V}{3}$; $V = \frac{V}{3}$; $t_1 = RC\,\ell n2$

$T = t_1 + t_2 = 2RC\,\ell n2$

Ex. 3 The plates of very small size of a parallel plate capacitor are charged as shown .The force on the charged particle of charge 'q' at a distance 'ℓ' from the capacitor is : (Assume that the distance between the plates is $d << \ell$)



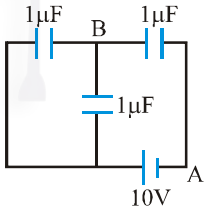
(A) Zero **(B)** $\frac{Qqd}{2\pi\epsilon_0\ell^3}$

(C) $\frac{Qqd}{\pi\epsilon_0\ell^3}$ **(D)** $\frac{Qqd}{4\pi\epsilon_0\ell^3}$

Sol. Assume capacitor as dipole and use $F = qE$,

$E = \frac{2kp}{r^3}$, $p = Qd$

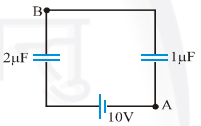
Ex. 4 In the circuit shown, if potential of A is 10V, then potential of B is -



Sol. Given circuit can be reduced as

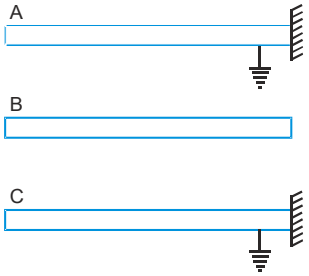
Charge on capacitors $= \left(\frac{2}{3}\right)(10)\mu C$

Now $V_B - V_A = \left(\frac{20}{3}\right)(1) = \frac{20}{3}$



$\Rightarrow V_B = V_A + \frac{20}{3} = 10 + \frac{20}{3} = \frac{50}{3}V$

Ex. 5 A, B and C are three large, parallel conducting plates, placed horizontally. A and C are rigidly fixed and earthed. B is given some charge. Under electrostatic and gravitational forces, B may be –



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(A) in equilibrium midway between A and C.

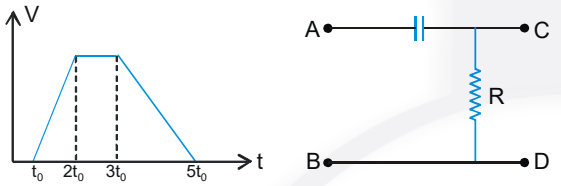
(B) in equilibrium if it is closer to A than to C.

(C) in equilibrium if it is closer to C than to A.

(D) B can never be in stable equilibrium.

Sol. As A and C are earthed, they are connected to each other. Hence, 'A + B' and 'B + C' are two capacitors with the same potential difference. If B is closer to A than to C then the capacitance C_{AB} is > C_{BC}. The upper surface of B will have greater charge than the lower surface. As the force of attraction between the plates of a capacitor is proportional to Q^2, there will be a net upwards force on B. This can balance its weight.

Ex. 6 A varying voltage is applied between the terminals A, B so that the voltage across the capacitor varies as shown in the figure Then.



(A) The voltage between the terminals C and D is constant between $2t_0$ and $3t_0$

(B) The current in the resistor is 0 between $2t_0$ and $3t_0$

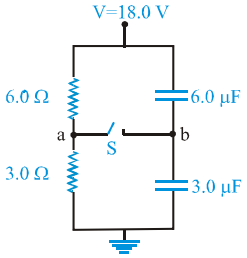
(C) The current in the resistor between t_0 and $2t_0$ is twice the current between $3t_0$ and $5t_0$

(D) None of these

Sol. When the capacitor voltage is constant its charge is constant. No current in the resistor.

Also $C\frac{dV}{dt} = \frac{dq}{dt}$ is double between t_0 and $2t_0$ compared to $3t_0$ and $5t_0$

Ex. 7 Study the following circuit diagram in figure and mark the correct option(s)



(A) The potential of point a with respect to point b when switch S is open is –6V.

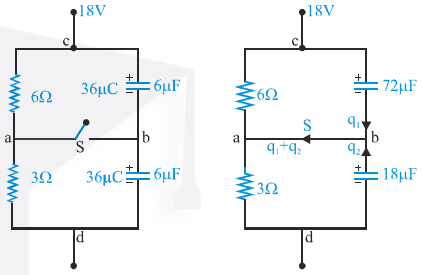
(B) The points a and b, are at the same potential, when S is opened.

(C) The charge flows through switch S when it is closed is 54 μC

(D) The final potential of b with respect to ground when switch S is closed is 8V

Sol. **(AC)**

When S is opened : $V_c - V_a = \frac{18\times 6}{6+3} = 12V$



$V_c - V_b = \frac{18\times 2}{6} = 6V$

$\Rightarrow V_b - V_a = 12 - 6 = 6V$

Charges flown after S is closed :

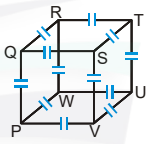
$q_1 = 72 - 36 = 36\mu C, q_2 = 36 - 18 = 18\mu C$

Charges flown through S after it is closed :

$36 + 18 = 54\ \mu C$

Final potential of b is 6V

Ex. 8 Twelve indentical capacitors each of capacitance C are connected as shown in figure.



(A) The effective capacitance between P and T is $\frac{6C}{5}$

(B) The effective capacitance between P and U is $\frac{4C}{3}$

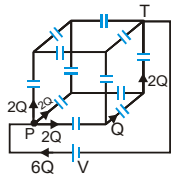
(C) The effective capacitance between P and V is $\frac{12C}{7}$

(D) All of the above statements are incorrect

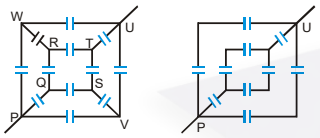
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Sol. **For (A) :** $V = \frac{2Q}{C} + \frac{Q}{C} + \frac{2Q}{C} = \frac{5Q}{C}$,

$$C_{eff} = \frac{6Q}{V} = \frac{6C}{5}$$



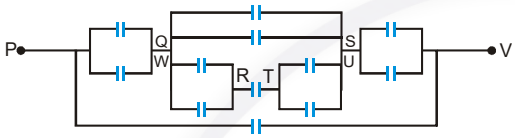
For (B) : Given circuit can be drawn as



Equalvent capacitance between P and

$$U = \frac{C}{3} + \frac{C}{2} + \frac{C}{2} = \frac{4C}{3}$$

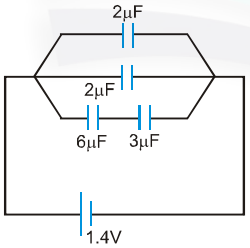
For (C) :



If a battery be connected across the terminals P and V, from symmetry $V_Q = V_W$ and $V_S = V_u$

$$\Rightarrow \text{Equivalent capacitance} = \frac{\left(\frac{5}{2}C\right)(C)}{\frac{5}{2}C + C} + C = \frac{12C}{7}$$

Ex. 9 In the given circuit find energy stored in capacitors in mJ.



Sol. $C_{eq} = 2 + 2 + 2 = 6\ \mu F$

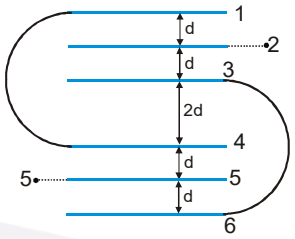
$$\text{Energy stored} = \frac{1}{2}C_{eq}V^2 = \frac{1}{2}(6 \times 10^{-3})(1.4)^2$$

$$= (3 \times 10^{-3})(2) = 6\ mJ$$

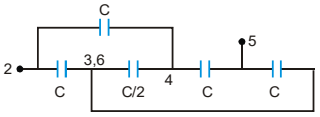
Ex. 10 There are six plates of equal area A and separation between the plates is d (d<<A) are arranged as shown in figure.

The equivalent capacitance between points 2 and 5, is $\alpha \frac{\epsilon_0 A}{d}$.

Then find the value of α.

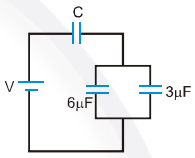


Sol. Redraw the circuit



$$C_{eq} = C = \frac{\epsilon_0 A}{d}$$

Ex. 11 If charge on 3μF capacitor is 3μC. Find the charge on capacitor of capacitance C in μC.



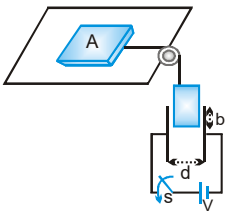
Sol. Potential difference across 3μF = P.D. across 6 μF = 1V

$\Rightarrow$ Charge on 6μF = 6μC

$\Rightarrow$ Total charge on combination of 6μF and 3μF = 9μC

Therefore charge on C = 9μC

Ex. 12 A block A of mass m kept on a rough horizontal surface is connected to a dielectric slab of mass m/6 and dielectric constant K by means of a light and inextensible string passing over a fixed pulley as shown in fig. The dielectric can completely fill the space between the parallel plate capacitor of plate are $\ell \times \ell$ and separation between the plates d kept in vertical position. Initially switch S is open and length of the dielectric inside the capacitor is b.



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The coefficient of friction between the block A and the surface is $\frac{\mu}{4}$. Ignore any other friction.

(A) Find the minimum value of the emf V of the battery so that after closing the switch the block A will move

(B) If $V = 2V_{min}$ find the speed of the block A when the dielectric completely fills the space between the plates of the capacitor.

Sol. **(A)** The forces acting on the dielectric are electrostatic attractive force of field of capacitor and its weight. The block will slip when $F_E + mg \geq \mu Mg$

$$F_E \geq \frac{M}{4}g - \frac{M}{6}g \quad \frac{1}{2}\frac{\varepsilon_0 \ell}{d}(K-1)V^2 \geq \frac{Mg}{12}$$

$$\therefore \; V_{min} = \sqrt{\frac{Mg}{12} \times \frac{2d}{\varepsilon_0 \ell (K-1)}} = \sqrt{\frac{Mgd}{6\varepsilon_0 \ell (K-1)}}$$

(B) Now $V = 2V_{min}$. In this case the block will accelerate

Dielectric : $F_E + mg - T = ma$ ...**(i)** and

Block : $T - \mu Mg = Ma$ ...**(ii)**

eq. **(i)** and **(ii)** give $a = \frac{F_E + (m - \mu M)g}{m + M}$

As $F_E = \frac{1}{2}\frac{\varepsilon_0 \ell}{d}(K-1)V^2$

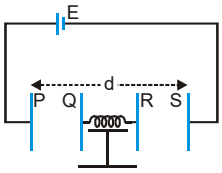
$$= \frac{1}{2}\frac{\varepsilon_0 \ell}{d}(K-1) \times 4 \times \frac{Mgd}{6\varepsilon_0 \ell (K-1)} = 2Mg$$

Thus $a = \frac{2Mg - \frac{M}{12}g}{\frac{7M}{6}} = \frac{23g \times 6}{7} = \frac{138}{7}g$

From equation of motion, $v^2 = 2as$

$$\Rightarrow v^2 = 2\left(\frac{138g}{7}\right) \times (\ell - b) \Rightarrow v = \sqrt{\frac{276}{7}g(\ell - b)}$$

Ex. 13 Two parallel plate capacitors with area A are connected through a conducting spring of natural length ℓ in series as shown. Plates P and S have fixed positions at separation d. Now the plates are connected by a battery of emf E as shown. If the extension in the spring in equilibrium is equal to the separation between the plates, find the spring constant k.



Sol. Let charge on capacitors be q and separation between plates

P and Q and R and S be x at any time distance between plates P and Q

and R and S is same because force acting on them is same.

Capacitance of capacitor PQ, $C_1 = \frac{\varepsilon_0 A}{x}$

Capacitance of capacitor RS, $C_2 = \frac{\varepsilon_0 A}{x}$ From KVL

$$\frac{q}{C_1} + \frac{q}{C_2} = E \Rightarrow q = \frac{\varepsilon_0 AE}{2x}$$

At this moment extension in spring, $y = d - 2x - \ell$.

Force on plate Q towards P,

$$F_1 = \frac{q^2}{2A\varepsilon_0} = \frac{\varepsilon_0^2 A^2 E^2}{8Ax^2 \varepsilon_0} = \frac{A\varepsilon_0 E^2}{8x^2}$$

Spring force on plate Q due to extension in spring, $F_2 = ky$

At equilibrium, separation between plates = extension in spring

Thus $x = y = d - 2x - \ell \Rightarrow x = \frac{d - \ell}{3}$ ...**(i)**

and $F_1 = F_2$ ...**(ii)**

From eq. **(i)** and **(ii)**, $\frac{A\varepsilon_0 E^2}{8x^2} = ky = kx$

$$\Rightarrow \; x = \left(\frac{A\varepsilon_0 E^2}{8K}\right)^{1/3}$$ ...**(iii)**

From eq. **(i)** and **(iii)**, $\left(\frac{d - \ell}{3}\right) = \frac{A\varepsilon_0 E^2}{8K}$

$$\Rightarrow \; k = \frac{A\varepsilon_0 E^2 27}{8(d - \ell)^3}$$

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Exercise # 1 SINGLE OBJECTIVE NEET LEVEL

1. The capacity of a parallel plate condenser is $5\,\mu F$. When a glass plate is placed between the plates of the conductor, its potential becomes $1/8\,th$ of the original value. The value of dielectric constant will be

(A) 1.6 **(B)** 5

(C) 8 **(D)** 40

2. A capacitor is charged by using a battery which is then disconnected. A dielectric slab is then slipped between the plates, which results in

(A) Reduction of charge on the plates and increase of potential difference across the plates

(B) Increase in the potential difference across the plate, reduction in stored energy, but no change in the charge on the plates

(C) Decrease in the potential difference across the plates, reduction in the stored energy, but no change in the charge on the plates

(D) None of the above

3. The energy of a charged capacitor is given by the expression (q = charge on the conductor and C = its capacity)

(A) $\frac{q^2}{2C}$ **(B)** $\frac{q^2}{C}$

(C) $2qC$ **(D)** $\frac{q}{2C^2}$

4. The capacity of a condenser is 4×10^{-6} *farad* and its potential is 100 *volts*. The energy released on discharging it fully will be

(A) 0.02 *Joule* **(B)** 0.04 *Joule*

(C) 0.025 *Joule* **(D)** 0.05 *Joule*

5. The insulated spheres of radii R_1 and R_2 having charges Q_1 and Q_2 respectively are connected to each other. There is

(A) No change in the energy of the system

(B) An increase in the energy of the system

(C) Always a decrease in the energy of the system

(D) A decrease in the energy of the system unless $Q_1R_2 = Q_2R_1$

6. Which one statement is correct? A parallel plate air condenser is connected with a battery. Its charge, potential, electric field and energy are Q_o, V_o, E_o and U_o respectively. In order to fill the complete space between the plates a dielectric slab is inserted, the battery is still connected. Now the corresponding values Q, V, E and U are in relation with the initially stated as

(A) $Q > Q_o$ **(B)** $V > V_o$

(C) $E > E_o$ **(D)** $U > U_o$

7. In a charged capacitor, the energy resides

(A) The positive charges

(B) Both the positive and negative charges

(C) The field between the plates

(D) Around the edge of the capacitor plates

8. The energy stored in a condenser of capacity C which has been raised to a potential V is given by

(A) $\frac{1}{2}CV$ **(B)** $\frac{1}{2}CV^2$

(C) CV **(D)** $\frac{1}{2VC}$

9. If two conducting spheres are separately charged and then brought in contact

(A) The total energy of the two spheres is conserved

(B) The total charge on the two spheres is conserved

(C) Both the total energy and charge are conserved

(D) The final potential is always the mean of the original potentials of the two spheres

10. Two insulated charged spheres of radii 20 *cm* and 25 *cm* respectively and having an equal charge Q are connected by a copper wire, then they are separated

(A) Both the spheres will have the same charge Q

(B) Charge on the 20 cm sphere will be greater than that on the 25 cm sphere

(C) Charge on the 25 cm sphere will be greater than that on the 20 cm sphere

(D) Charge on each of the sphere will be 2Q

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11. Eight drops of mercury of equal radii possessing equal charges combine to form a big drop. Then the capacitance of bigger drop compared to each individual small drop is

(A) 8 times **(B)** 4 times

(C) 2 times **(D)** 32 times

12. A condenser of capacity 50 μF is charged to 10 volts. Its energy is equal to

(A) 2.5×10^{-3} *joule* **(B)** 2.5×10^{-4} *joule*

(C) 5×10^{-2} *joule* **(D)** 1.2×10^{-8} *joule*

13. The potential gradient at which the dielectric of a condenser just gets punctured is called

(A) Dielectric constant **(B)** Dielectric strength

(C) Dielectric resistance **(D)** Dielectric number

14. A parallel plate condenser has a capacitance 50 μF in air and 110 μF when immersed in an oil. The dielectric constant 'k' of the oil is

(A) 0.45 **(B)** 0.55

(C) 1.10 **(D)** 2.20

15. Separation between the plates of a parallel plate capacitor is d and the area of each plate is A. When a slab of material of dielectric constant k and thickness $t(t<d)$ is introduced between the plates, its capacitance becomes

(A) $\dfrac{\varepsilon_0 A}{d+t\left(1-\dfrac{1}{k}\right)}$ **(B)** $\dfrac{\varepsilon_0 A}{d+t\left(1+\dfrac{1}{k}\right)}$

(C) $\dfrac{\varepsilon_0 A}{d-t\left(1-\dfrac{1}{k}\right)}$ **(D)** $\dfrac{\varepsilon_0 A}{d-t\left(1+\dfrac{1}{k}\right)}$

16. The capacity of parallel plate condenser depends on

(A) The type of metal used

(B) The thickness of plates

(C) The potential applied across the plates

(D) The separation between the plates

17. The energy of a charged capacitor resides in

(A) The electric field only

(B) The magnetic field only

(C) Both the electric and magnetic field

(D) Neither in electric nor magnetic field

18. No current flows between two charged bodies connected together when they have the same

(A) Capacitance or $\dfrac{Q}{V}$ ratio

(B) Charge

(C) Resistance

(D) Potential or $\dfrac{Q}{C}$ ratio

19. The capacity of a parallel plate condenser is C. Its capacity when the separation between the plates is halved will be

(A) 4C **(B)** 2C

(C) $\dfrac{C}{2}$ **(D)** $\dfrac{C}{4}$

20. Eight small drops, each of radius r and having same charge q are combined to form a big drop. The ratio between the potentials of the bigger drop and the smaller drop is

(A) 8 : 1 **(B)** 4 : 1

(C) 2 : 1 **(D)** 1 : 8

21. 1000 small water drops each of radius *r* and charge q coalesce together to form one spherical drop. The potential of the big drop is larger than that of the smaller drop by a factor of

(A) 1000 **(B)** 100

(C) 10 **(D)** 1

22. A parallel plate condenser is immersed in an oil of dielectric constant 2. The field between the plates is

(A) Increased proportional to 2

(B) Decreased proportional to $\dfrac{1}{2}$

(C) Increased proportional to $\sqrt{2}$

(D) Decreased proportional to $\dfrac{1}{\sqrt{2}}$

23. The capacitance of a spherical condenser is 1 μF. If the spacing between the two spheres is 1 mm, then the radius of the outer sphere is

(A) 30 cm **(B)** 6 m

(C) 5 cm **(D)** 3m

24. If the dielectric constant and dielectric strength be denoted by k and x respectively, then a material suitable for use as a dielectric in a capacitor must have

(A) High k and high x **(B)** High k and low x

(C) Low k and low x **(D)** Low k and high x

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25. When air in a capacitor is replaced by a medium of dielectric constant K, the capacity

(A) Decreases K times **(B)** Increases K times

(C) Increases K^2 times **(D)** Remains constant

26. Two identical capacitors are joined in parallel, charged to a potential V and then separated and then connected in series *i.e.* the positive plate of one is connected to negative of the other

(A) The charges on the free plates connected together are destroyed

(B) The charges on the free plates are enhanced

(C) The energy stored in the system increases

(D) The potential difference in the free plates becomes $2V$

27. The condensers of capacity C_1 and C_2 are connected in parallel, then the equivalent capacitance is

(A) $C_1 + C_2$ **(B)** $\frac{C_1 C_2}{C_1 + C_2}$

(C) $\frac{C_1}{C_2}$ **(D)** $\frac{C_2}{C_1}$

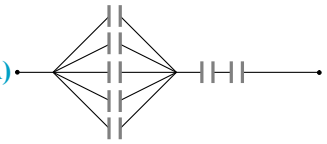
28. A parallel plate capacitor is made by stacking n equally spaced plates connected alternately. If the capacitance between any two plates is C then the resultant capacitance is

(A) C **(B)** nC

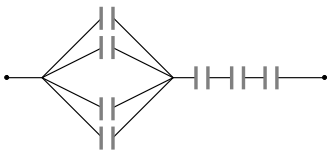
(C) $(n-1)C$ **(D)** $(n+1)C$

29. Seven capacitors each of capacity 2μF are to be so connected to have a total capacity $\frac{10}{11}\mu F$. Which will be the necessary figure as shown

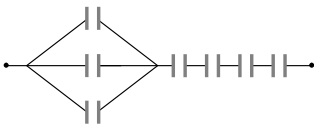
(A)



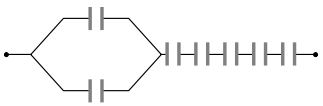
(B)



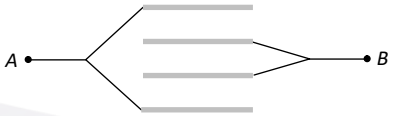
(C)



(D)



30. Four plates of equal area A are separated by equal distances d and are arranged as shown in the figure. The equivalent capacity is



(A) $\frac{2\varepsilon_0 A}{d}$ **(B)** $\frac{3\varepsilon_0 A}{d}$

(C) $\frac{3\varepsilon_0 A}{d}$ **(D)** $\frac{\varepsilon_0 A}{d}$

31. The capacitor of capacitance $4\mu F$ and $6\mu F$ are connected in series. A potential difference of 500 volts applied to the outer plates of the two capacitor system. Then the charge on each capacitor is numerically

(A) 6000 C **(B)** 1200 C

(C) 1200 μC **(D)** 6000 μC

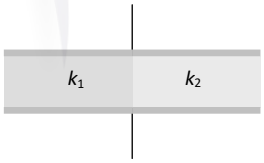
32. A parallel plate capacitor with air as medium between the plates has a capacitance of $10\mu F$. The area of capacitor is divided into two equal halves and filled with two media as shown in the figure having dielectric constant $k_1 = 2$ and $k_2 = 4$. The capacitance of the system will now be

(A) $10\mu F$

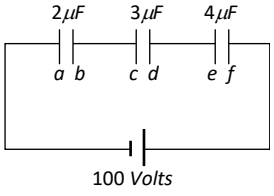
(B) $20\mu F$

(C) $30\mu F$

(D) $40\mu F$



33. Three capacitors are connected to D.C. source of 100 volts shown in the adjoining figure. If the charge accumulated on plates of C_1, C_2 and C_3 are q_a, q_b, q_c, q_d, q_e and q_f respectively, then



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(A) $q_b + q_d + q_f = \frac{100}{9} C$ (B) $q_b + q_d + q_f = 0$

(C) $q_a + q_c + q_e = 50\ C$ (D) $q_b = q_d = q_f$

34. n identical condensers are joined in parallel and are charged to potential V. Now they are separated and joined in series. Then the total energy and potential difference of the combination will be

(A) Energy and potential difference remain same

(B) Energy remains same and potential difference is nV

(C) Energy increases times and potential difference is nV

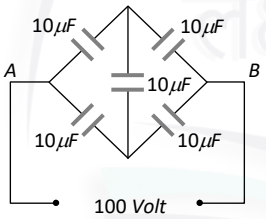
(D) Energy increases n times and potential difference remains same

35. Three capacitors each of capacitance $1\mu F$ are connected in parallel. To this combination, a fourth capacitor of capacitance $1\mu F$ is connected in series. The resultant capacitance of the system is

(A) $4\ \mu F$ (B) 2μF

(C) $\frac{4}{3}\ \mu F$ (D) $\frac{3}{4}\ \mu F$

36. Five capacitors of $10\mu F$ capacity each are connected to a *d.c.* potential of 100 *volts* as shown in the adjoining figure. The equivalent capacitance between the points A and B will be equal to



(A) $40\ \mu F$ (B) $20\ \mu F$

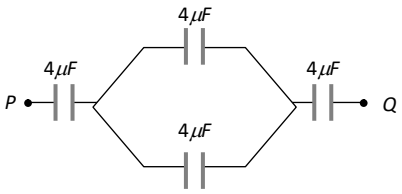
(C) $30\ \mu F$ (D) $10\ \mu F$

37. Three capacitors of capacitances $3\mu F, 9\mu F$ and $18\ \mu F$ are connected once in series and another time in parallel. The ratio of equivalent capacitance in the two cases $\left(\frac{C_s}{C_p}\right)$ will be

(A) 1 : 15 (B) 15 : 1

(C) 1 : 1 (D) 1 : 3

38. Four condensers each of capacity $4\mu F$ are connected as shown in figure. $V_P - V_Q = 15\ volts$. The energy stored in the system is



(A) 2400 *ergs* (B) 1800 *ergs*

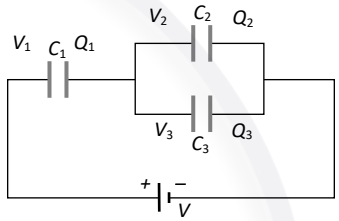
(C) 3600 *ergs* (D) 5400 *ergs*

39. Two capacitors each of 1 μF capacitance are connected in parallel and are then charged by 200 volts *d.c.* supply. The total energy of their charges (in joules) is

(A) 0.01 (B) 0.02

(C) 0.04 (D) 0.06

40. In an adjoining figure are shown three capacitors C_1, C_2 and C_3 joined to a battery. The correct condition will be (Symbols have their usual meanings)



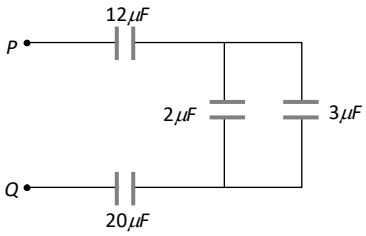
(A) $Q_1 = Q_2 = Q_3$ and $V_1 = V_2 = V_3 = V$

(B) $Q_1 = Q_2 + Q_3$ and $V = V_1 + V_2 + V_3$

(C) $Q_1 = Q_2 + Q_3$ and $V = V_1 + V_2$

(D) $Q_2 = Q_3$ and $V_2 = V_3$

41. In the circuit diagram shown in the adjoining figure, the resultant capacitance between P and Q is



(A) 47μF (B) 3μF

(C) 60μF (D) 10μF

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42. Two condensers of capacity 0.3μF and 0.6μF respectively are connected in series. The combination is connected across a potential of 6 volts. The ratio of energies stored by the condensers will be

(A) $\frac{1}{2}$ **(B)** 2

(C) $\frac{1}{4}$ **(D)** 4

43. The capacitor of capacitance 4μF and 6μF are connected in series. A potential difference of 500 volts is applied to the outer plates of the two capacitor system. The potential difference across the plates of capacitor of 4μF capacitance is

(A) 500 volts **(B)** 300 volts

(C) 200 volts **(D)** 250 volts

44. Two capacitances of capacity C_1 and C_2 are connected in series and potential difference V is applied across it. Then the potential difference across C_1 will be

(A) $V\frac{C_2}{C_1}$ **(B)** $V\frac{C_1+C_2}{C_1}$

(C) $V\frac{C_2}{C_1+C_2}$ **(D)** $V\frac{C_1}{C_1+C_2}$

45. Three capacitances of capacity 10μF, 5μF and 5μF are connected in parallel. The total capacity will be

(A) 10μF **(B)** 5μF

(C) 20μF **(D)** None of the above

46. Three capacitors of capacity $C_1, C_2 C_3$ are connected in series. Their total capacity will be

(A) $C_1+C_2+C_3$ **(B)** $1/(C_1+C_2+C_3)$

(C) $(C_1^{-1}+C_2^{-1}+C_3^{-1})^{-1}$ **(D)** None of these

47. Two capacitors of equal capacity are first connected in parallel and then in series. The ratio of the total capacities in the two cases will be

(A) 2 : 1 **(B)** 1 : 2

(C) 4 : 1 **(D)** 1 : 4

48. Two capacitors connected in parallel having the capacities C_1 and C_2 are given 'g' charge, which is distributed among them. The ratio of the charge on C_1 and C_2 will be

(A) $\frac{C_1}{C_2}$ **(B)** $\frac{C_2}{C_1}$

(C) C_1C_2 **(D)** $\frac{1}{C_1C_2}$

49. Two capacitors of capacities C_1 and C_2 are charged to voltages V_1 and V_2 respectively. There will be no exchange of energy in connecting them in parallel, if

(A) $C_1 = C_2$ **(B)** $C_1V_1 = C_2V_2$

(C) $V_1 = V_2$ **(D)** $\frac{C_1}{V_1} = \frac{C_2}{V_2}$

50. If three capacitors each of capacity 1μF are connected in such a way that the resultant capacity is 1.5μF, then

(A) All the three are connected in series

(B) All the three are connected in parallel

(C) Two of them are in parallel and connected in series to the third

(D) Two of them are in series and then connected in parallel to the third

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Exercise # 2 SINGLE OBJECTIVE AIIMS LEVEL

1. A parallel plate capacitor of capacitance C is connected to a battery and is charged to a potential difference V. Another capacitor of capacitance 2C is connected to another battery and is charged to potential difference 2V. The charging batteries are now disconnected and the capacitors are connected in parallel to each other in such a way that the positive terminal of one is connected to the negative terminal of the other. The final energy of the configuration is

(A) Zero **(B)** $\frac{25CV^2}{6}$

(C) $\frac{3CV^2}{2}$ **(D)** $\frac{9CV^2}{2}$

2. A 40 μF capacitor in a defibrillator is charged to 3000 V. The energy stored in the capacitor is sent through the patient during a pulse of duration 2 ms. The power delivered to the patient is :–

(A) 45 kW **(B)** 90 kW

(C) 180 kW **(D)** 360 kW

3. An automobile spring extends 0.2 m for 5000 N load. The ratio of potential energy stored in this spring when it has been compressed by 0.2 m to the potential energy stored in a 10 μF capacitor at a potential difference of 10000 V will be :–

(A) 1/4 **(B)** 1

(C) 1/2 **(D)** 2

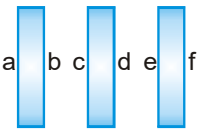
4. Three parallel metallic plates, each of area A are kept as shown in the figure and charges Q_1, Q_2 and Q_3 are given to them. Edge effects are negligible. Calculate the charges on the two outermost surfaces 'a' and 'f'.

(A) $\frac{Q_1+Q_2+Q_3}{2}$

(B) $\frac{Q_1+Q_2+Q_3}{3}$

(C) $\frac{Q_1-Q_2+Q_3}{3}$

(D) $\frac{Q_1-Q_2+Q_3}{2}$



5. The distance between plates of a parallel plate capacitor is 'd'. Another thick metal plate of thickness d/2 and area same as that of plates is so placed between the plates, that it does not touch the plates. The capacity of the resultant capacitor :–

(A) remain same **(B)** becomes double

(C) becomes half **(D)** becomes one fourth

6. Two conducting spheres of radii R_1 and R_2 are charged with charges Q_1 and Q_2 respectively. On bringing them in contact there is :–

(A) no change in the energy of the system

(B) an increase in the energy of the system if $Q_1 R_2 \neq Q_2 R_1$

(C) always a decrease in energy of the system

(D) a decrease in energy of the system if $Q_1 R_2 \neq Q_2 R_1$

7. A capacitor of value 4 μF charged at 50V is connected with another capacitor of value 2μF charged at 100V, in such a way that plates of similar charges are connected together. Before joining and after joining the total energy in multiples 10–2 J will be :–

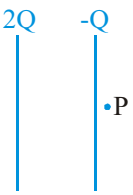
(A) 1.5 and 1.33 **(B)** 1.33 and 1.5

(C) 3.0 and 2.67 **(D)** 2.67 and 3.0

8. In the figure shown the plates of a parallel plate capacitor have unequal charges. Its capacitance is 'C'. P is a point outside the capacitor and close to the plate of charge–Q. The distance between the plates is 'd' then which statement is wrong

(A) A point charge at point 'P' will experience electric force due to capacitor

(B) The potential difference between the plates will be $\frac{3Q}{2C}$



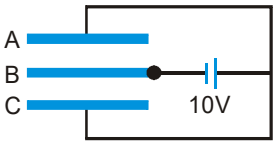
(C) The energy stored in the electric field in the region between the plates is $\frac{9Q^2}{8C}$

(D) The force on one plate due to the other plate is $\frac{Q^2}{2\pi \in_0 d^2}$

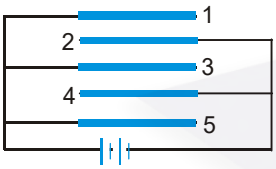
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9. Three plates A,B and C each of area 0.1 m^2 are separated by 0.885 mm from each other as shown in the figure. A 10V battery is used to charge the system. The energy stored in the system is:

(A) 1 μJ
(B) 10^{-1} μJ
(C) 10^{-2} μJ
(D) 10^{-3} μJ



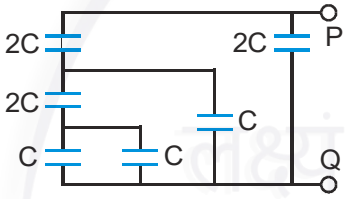
10. Five identical plates are connected across a battery as follows :



If the charge on plate 1 be +q, then the charges on the plates 2,3,4 and 5 are

(A) –q, +q,–q,+q
(B) –2q, +2q,–2q,+q
(C) –q, +2q,–2q,+q
(D) None of the above

11. The value of equivalent capacitance of the combination shown in figure between the points P and Q is :–



(A) 3 C
(B) 2 C
(C) C
(D) C/3

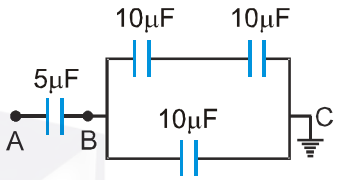
12. N identical capacitor are joined in parallel and the combination is charged to a potential V. Now if they are separated and then joined in series then energy of combination will :–

(A) remain same and potential difference will also remain same
(B) remain same and potential difference will become NV
(C) increase N times and potential difference will become NV
(D) increase N time and potential difference will remains same

13. A parallel plate capacitor is made by stacking n equally spaced plates connected alternatively. If the capacitance between any two adjacent plates is C, then the resultant capacitance is–

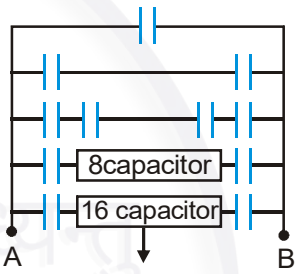
(A) (n – 1)C
(B) (n + 1)C
(C) C
(D) nC

14. In the given circuit if point C is connected to the earth and a potential of +2000 V is given to point A, the potential at B is :–



(A) 1500 V
(B) 1000 V
(C) 500 V
(D) 400 V

15. An infinite number of identical capacitors each of capacitance 1μ F are connected as in adjoining figure. Then the equivalent capacitance between A and B is



(A) 1μ F
(B) 2μ F
(C) 1/2 μF
(D) ∞

16. A parallel plate capacitor with air between the plates has a capacitance of 9 pF. The separation between its plates is 'd'. The space between the plates is now filled with two dielectrics. One of the dielectric has dielectric constant $K_1 = 3$ and thickness $\frac{d}{3}$ while the other one has dielectric constant $K_2 = 6$ and thickness $\frac{2d}{3}$. Capacitance of the capacitor is now

(A) 1.8 pF
(B) 45 pF
(C) 40.5 pF
(D) 20.25 pF

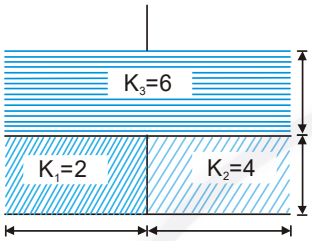
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17. Two parallel plate capacitors whose capacities are C and 2 C respectively, are joined in parallel. These are charged by V potential difference. If the battery is now removed and a dielectric of dielectric constant K is filled in between the plates of the capacitor C, then what will be the potential difference across each capacitor ?

(A) $\frac{V}{K+2}$ **(B)** $\frac{2V}{K+2}$

(C) $\frac{3V}{K+2}$ **(D)** $\frac{2+K}{3V}$

18. A parallel plate capacitor of capacitance C (without dielectrics) is filled by dielectric slabs as shown in figure. Then the new capacitance of the capacitor is



(A) 3.9 C **(B)** 4 C

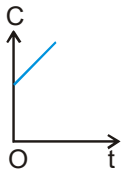
(C) 2.4 C **(D)** 3 C

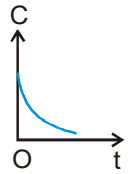
19. A fully charged capacitor has a capacitance C. It is discharged through a small coil of resistance wire embedded in a thermally insulated block of specific heat capacity s and mass m. If the temperature of the block is raised by ΔT, the potential difference V across the capacitance is–

(A) $\sqrt{\frac{2mC\Delta T}{s}}$ **(B)** $\frac{mC\Delta T}{s}$

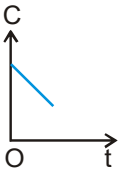
(C) $\frac{ms\Delta T}{C}$ **(D)** $\sqrt{\frac{2ms\Delta T}{C}}$

20. Dielectric sheet placed between the plates of parallel plate capacitor. Now capacitor is charged and battery is disconnected. Now t = 0 sheet is taken out very slowly then which of the following is correct for the variation of capacitance with time

(A) 

(B) 

(C) 

(D) 

21. Two capacitor having capacitance 8 μF and 16μF have breaking voltage 20V & 80 V. They are combined in series. The maximum charge they can store individually in the combination is-

(A) 160 μC **(B)** 200 μC

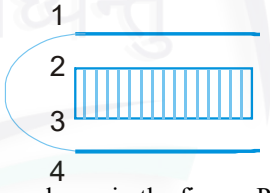
(C) 1280 μC **(D)** None of these

22. The capacitance (C) for an isolated conducting sphere of radius (A) is given by $4\pi\varepsilon_0 a$. This sphere is enclosed within an earthed concentric sphere. The ratio of the radii of the spheres being $\frac{n}{(n-1)}$ then the capacitance of such a sphere will be increased by a factor-

(A) n **(B)** $\frac{n}{(n-1)}$

(C) $\frac{(n-1)}{n}$ **(D)** a.n

23. Four identical plates 1,2,3 and 4 are placed parallel to each other at equal



distance as shown in the figure. Plates 1 and 4 are joined together and the space between 2 and 3 is filled with a dielectric of dielectric constant k=2.

The capacitance of the system between 1 and 3 & 2 and 4 are C_1 and C_2 respectively. The ratio $\frac{C_1}{C_2}$ is-

(A) $\frac{5}{3}$ **(B)** 1

(C) $\frac{3}{5}$ **(D)** $\frac{5}{7}$

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24. A capacitor of capacitance 1 μF withstands the maximum voltage 6 kV while a capacitor of 2μF withstands the maximum voltage 4 kV. What maximum voltage will the system of these two capacitor withstands if they are connected in series ?

(A) 10 kV **(B)** 12 kV

(C) 8 kV **(D)** 9 kV

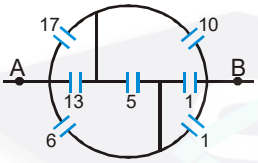
25. The equivalent capacitance across AB (all capacitance in μF) is

(A) $\frac{20}{3}$ μF

(B) 9μF

(C) 48μF

(D) None of these



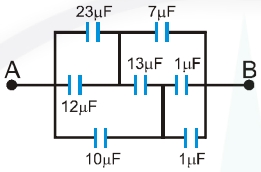
26. The equivalent capacitance across A & B is

(A) $\frac{28}{3}$ μf

(B) $\frac{15}{2}$ μF

(C) 15 μF

(D) None of these



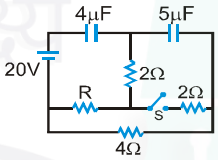
27. The heat produced in the capacitors on closing the switch S is

(A) 0.0002 J

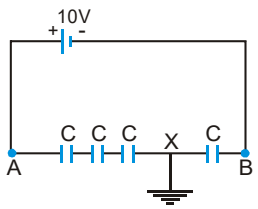
(B) 0.0005 J

(C) 0.00075

(D) Zero



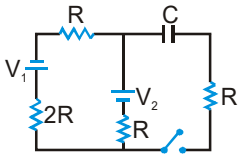
28. Four identical capacitors are connected in series with a battery of emf 10V. The point X is earthed. Than the potential of point A is–



(A) 10 V **(B)** 7.5 V

(C) –7.5 V **(D)** 0 V

29. The time constant of the shown circuit for charging is



(A) $\frac{5}{3}$RC **(B)** $\frac{5}{2}$RC

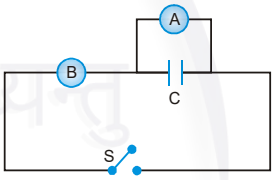
(C) $\frac{7}{4}$RC **(D)** $\frac{7}{3}$RC

30. The area of the plates of a parallel plate capacitor is A and the gap between them is d. The gap is filled with a non–homogeneous dielectric whose dielectric constant varies with the distance 'y' from one plate as : $K = \lambda \sec\left(\frac{\pi y}{2d}\right)$, where λ is a dimensionless constant. The capacitance of this capacitor is

(A) $\frac{\pi\varepsilon_0\lambda A}{2d}$ **(B)** $\frac{\pi\varepsilon_0\lambda A}{d}$

(C) $\frac{2\pi\varepsilon_0\lambda A}{d}$ **(D)** None

31. A capacitor of capacitance C is connected to two voltmeters A and B. A is ideal, having infinite resistance, while B has resistance R. The capacitor is charged and then the switch S is closed. The readings of A and B will be equal



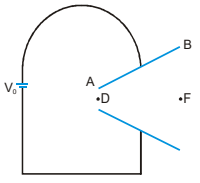
(A) At all times

(B) After time RC

(C) After time RC ℓn 2

(D) Only after a very long time

32. In the given figure, a capacitor of non–parallel plates is shown. The plates of capacitor are connected by a cell of emf V_0. If σ denotes surface charge density and E denotes electric field. Then

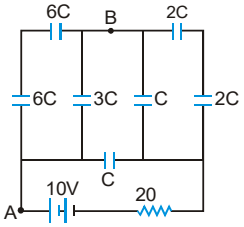


(A) $\sigma_A > \sigma_B$ **(B)** $E_F > E_D$

(C) $E_F = E_D$ **(D)** $\sigma_A = \sigma_B$

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33. For the circuit shown here, the potential difference between points A and B is



(A) 2.5 V **(B)** 7.5 V
(C) 10 V **(D)** Zero

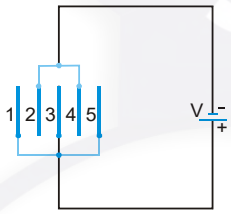
34. Five identical capacitor plates, each of area A, are arranged such that adjacent plates are at distance d apart. The plates are connected to a source of emf V as shown in figure. Then the charges on plates 1 and 4 are, respectively

(A) $\frac{\varepsilon_0 AV}{d}, \frac{2\varepsilon_0 AV}{d}$

(B) $\frac{2\varepsilon_0 AV}{d}, \frac{-2\varepsilon_0 AV}{d}$

(C) $\frac{\varepsilon_0 AV}{d}, \frac{-2\varepsilon_0 AV}{d}$

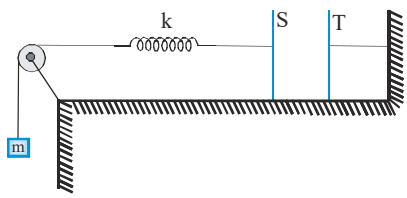
(D) $\frac{\varepsilon_0 AV}{d}, \frac{-\varepsilon_0 AV}{d}$



35. A number of capacitors, each of capacitance 1 μF and each one of which gets punctured if a potential difference just exceeding 500 volt is applied are provided. Then an arrangement suitable for giving a capacitor of capacitance 3 μF across which 2000 volt may be applied requires at least :–

(A) 4 component capacitors
(B) 12 component capacitors
(C) 48 component capacitors
(D) 16 component capacitors

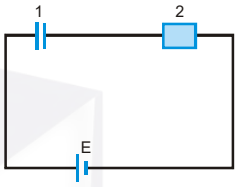
36. The plates S and T of an uncharged parallel plate capacitor are connected across a battery. The battery is then disconnected and the charged plates are now connected in a system as shown in the figure. The system shown is in equilibrium. All the strings and spring are insulating and massless. The magnitude of charge on one of the capacitor plates is : [Area of plates = A]



(A) $\sqrt{2mg A\varepsilon_0}$ **(B)** $\sqrt{\frac{4mg A\varepsilon_0}{k}}$

(C) $\sqrt{mg A\varepsilon_0}$ **(D)** $\sqrt{\frac{2mg A\varepsilon_0}{k}}$

37. Two identical capacitors 1 and 2 are connected in series to a battery as shown in figure. Capacitor 2 contains a dielectric slab of dielectric constant k as shown. Q_1 and Q_2 are the charges stored in the capacitors. Now the dielectric slab is removed and the corresponding charges are Q'_1 and Q'_2. Then



(A) $\frac{Q'_1}{Q_1} = \frac{k+1}{k}$ **(B)** $\frac{Q'_2}{Q_2} = \frac{k+1}{2}$

(C) $\frac{Q'_2}{Q_2} = \frac{k+1}{2k}$ **(D)** $\frac{Q'_1}{Q_1} = \frac{k}{2}$

38. A capacitor of capacitance C is charged to a potential difference V from a cell and then disconnected from it. A charge +Q is now given to its positive plate. The potential difference across the capacitor is-

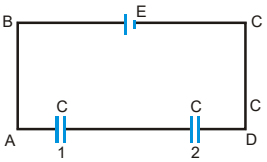
(A) V **(B)** $V + \frac{Q}{C}$

(C) $V + \frac{Q}{2C}$ **(D)** $V - \frac{Q}{C}$, if $V < CV$

39. In the adjoining figure, capacitor (1) and (2) have a capacitance 'C' each.When the dielectric of dielectric constant K is inserted between the plates of one of the capacitor, the total charge flowing through battery is-

(A) $\frac{KCE}{K+1}$ from B to C

(B) $\frac{KCE}{K+1}$ from C to B

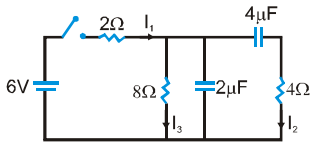


(C) $\frac{(K-1)CE}{2(K+1)}$ from B to C

(D) $\frac{(K-1)CE}{2(K+1)}$ from C to B

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40. In the circuit shown in the figure, the switch S is initially open and the capacitor is initially uncharged. I_1, I_2 and I_3 represent the current in the resistance 2Ω, 4Ω and 8Ω respectively.



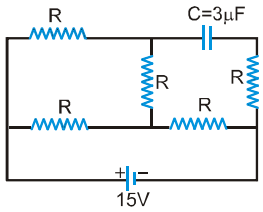
(A) Just after the switch S is closed, $I_1 = 3A$, $I_2 = 3A$ and $I_3 = 0$

(B) Just after the switch S is closed, $I_1 = 3A$, $I_2 = 0$ and $I_3 = 0$

(C) Long time after the switch S is closed, $I_1 = 0.6A$, $I_2 = 0$ and $I_3 = 0$

(D) Long time after the switch S is closed, $I_1 = I_2 = I_3 = 0.6A$.

41. In the circuit shown, the cell is ideal, with emf = 15V. Each resistance is of 3Ω. The potential difference across the capacitor is



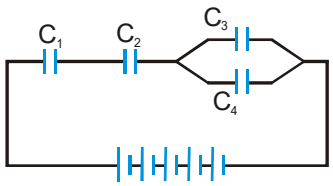
(A) zero **(B)** 9V

(C) 12V **(D)** 15V

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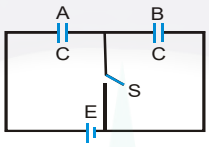
Exercise # 3 PART - 1 MATRIX MATCH COLUMN

1. In the circuit shown in figure. $C_1=C$, $C_2=2C$, $C_3=3C$, $C_4=4C$.



	Column I		Column II
(A)	Maximum potential difference	(P)	across C_1
(B)	Minimum potential difference	(Q)	across C_2
(C)	Maximum potential energy	(R)	across C_3
(D)	Minimum potential energy	(S)	across C_4

2. Consider the situation shown. The switch S is open for a long time and then closed. Then :



	Column–I		Column–II
(A)	Charge flown through battery when S is closed	(P)	$\frac{CE^2}{2}$
(B)	Work done by battery	(Q)	$\frac{CE}{2}$
(C)	Charge on capacitor A when switch S is closed	(R)	$\frac{CE^2}{4}$
(D)	Heat developed in the system	(S)	CE

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Exercise # 3 PART - 2 ASSERTION & REASONING

These questions contains, Statement I (assertion) and Statement II (reason).

(A) If both assertion and reason are true and the reason is the correct explanation of the assertion.

(B) If both assertion and reason are true but reason is not the correct explanation of the assertion.

(C) If assertion is true but reason is false.

(D) If assertion is false but reason is true.

(E) If the assertion and reason both are false.

1. **Assertion :** Increasing the charge on the plates of a capacitor means increasing the capacitance.
Reason : Because $Q = CV \Rightarrow Q \propto C$.

2. **Assertion :** When dielectric is filled between plates of capacitor battery is disconnected then its potential energy increases.
Reason : Work is done on capacitor by external system when dielectric is inserted.

3. **Assertion :** Capacitor is filled with, same thickness of dielectric ($t < d$) and conducting sheet one after another, then capacitance are C_1 and C_2 respectively then $C_1 < C_2$.
Reason : Capacitance is more in presence of metal sheet in compare to dielectric sheet as $K_{Conduct} > K_{dielectric}$.

4. **Assertion :** A dielectric slab is inserted between the plates of an isolated charged capacitor. The charge on the capacitor will remain the same.
Reason : Charge on a isolated system is conserved.

5. **Assertion :** If the distance between parallel plates of a capacitor is halved and dielectric constant is made three times, then the capacitance becomes 6 times.
Reason : Capacitance of the capacitor does not depend upon the nature of the material of the plates of the capacitor.

6. **Assertion :** The capacitance of a capacitor depends on the shape, size and geometrical placing of the conductors and its medium between them.
Reason When a charge q passes through a battery of emf E from the negative terminal to an positive terminal, an amount qE of work is done by the battery.

7. **Assertion :** When charges are shared between any two bodies, no charge is really lost, but some loss of energy does occur.
Reason Some energy disappears in the form of heat, sparking etc.

8. **Assertion :** Surface of a symmetrical conductor can be treated as equipotential surface.
Reason : Charges can easily flow in a conductor.

9. **Assertion :** A charged capacitor is disconnected from a battery. Now if its plate are separated farther, the potential energy will fall.
Reason : Energy stored in a capacitor is equal to the work done in charging it.

10. **Assertion :** The surface charge densities of two spherical conductors of different radii are equal. Then the electric field intensities near their surface are also equal.
Reason : Surface charge density is equal to charge per unit area.

11. **Assertion :** The force with which one plate of a parallel plate capacitor is attracted towards the other plate is equal to square of surface density per per unit area.
Reason : The electric field due to one charged plate of the capacitor at the location of the other is equal to surface density per .

12. **Assertion :** The lightening conductor at the top of high building has sharp pointed ends.
Reason : The surface density of charge at sharp points is very high resulting in setting up of electric wind.

13. **Assertion :** Circuit containing capacitors should be handled cautiously even when there is no current.
Reason : The capacitors are very delicate and so quickly break down.

14. **Assertion :** A bird perches on a high power line and nothing happens to the bird.
Reason : The level of bird is very high from the ground.

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Exercise # 4 PART - 1 PREVIOUS YEAR (NEET/AIPMT)

1. A capacitor is charged by connecting a battery across its plates. It stores energy U. Now the battery is disconnected and another identical capacitor is connected across it, then the energy stored by both capacitors of the system will be

(A) U **(B)** $\frac{U}{2}$

(C) 2U **(D)** $\frac{3}{2}U$

2. In a parallel plate capacitor, the distance between the plates is d and potential difference across plates us V. Energy stored per unit volume between the plates of capacitor is

(A) $\frac{Q^2}{2V^2}$ **(B)** $\frac{1}{2}\frac{\varepsilon_0 V^2}{d^2}$

(C) $\frac{1}{2}\frac{V^2}{\varepsilon_0 d^2}$ **(D)** $\frac{1}{2}\varepsilon_0\frac{V^2}{d}$

3. Some charge is being given to a conductor, then its potential is

(A) Maximum at surface

(B) Maximum at centre

(C) Same throughout the conductor

(D) Maximum somewhere between surface and centre

4. A capacitor of capacity C_1 is charged upto potential V volt and then connected in parallel to an uncharged capacitor of capacity C_2. The final potential difference across each capacitor will be

(A) $\frac{C_2 V}{C_1 + C_2}$ **(B)** $\frac{C_1 V}{C_1 + C_2}$

(C) $\left(1+\frac{C_2}{C_1}\right)V$ **(D)** $\left(1-\frac{C_2}{C_1}\right)V$

5. Three capacitors each of capacity 4 μE are to be connected in such a way that the effective capacitance is 6μF. This can be done by

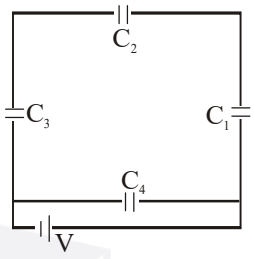
(A) Connecting two in series and one in parallel

(B) Connecting two in parallel and one in series

(C) Connecting all of them in series

(D) Connecting all of them in parallel

6. A network of four capacitors of capacity equal to $C_1 = C$, $C_2 = 2C$, $C_3 = 3C$ and $C_4 = 4C$ are connected to a battery as shown in the figure. The ratio of the charges on C_2 and C_4 is



(A) $\frac{22}{3}$ **(B)** $\frac{3}{22}$

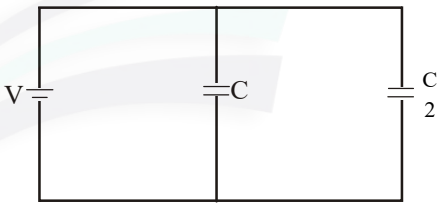
(C) $\frac{7}{4}$ **(D)** $\frac{4}{7}$

7. A parallel plate air capacitor is charged to a potential difference of V volts. After disconnecting the charging battery the distance between the plates of the capacitor is increased using an insulating handle. As a result the potential difference between the plates

(A) Decreases **(B)** Does not change

(C) Becomes zero **(D)** Increases

8. Two condensers, one of capacity C and the other of capacity $\frac{C}{2}$, are connected to a V volt battery, as shown.



The work done in charging fully both the condensers is

(A) $2CV^2$ **(B)** $\frac{1}{4}CV^2$

(C) $\frac{3}{4}CV^2$ **(D)** $\frac{1}{2}CV^2$

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9. Three capacitors each of capacitance C and of breakdown voltage V are joined in series. The capacitance and breakdown voltage of the combination will be

(A) $\frac{C}{3}, \frac{V}{3}$ **(B)** $3C, \frac{V}{3}$

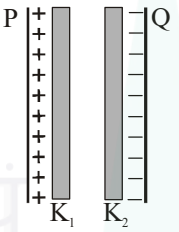
(C) $\frac{C}{3}, 3V$ **(D)** $3C, 3V$

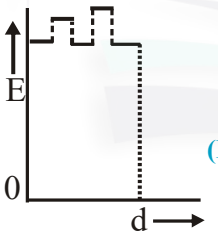
10. A series combination of n_1 capacitors, each of value C_1, is charged by a source of potential difference 4V. When another parallel combination of n_2 capacitors, each of value C_2, is charged by a source of potential difference V, it has the same (total) energy stored in it, as the first combination has. The value of C_2, in terms of C_1, is then

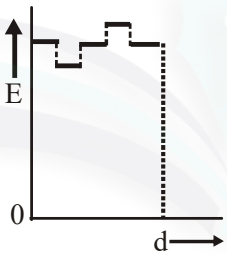
(A) $\frac{2C_1}{n_1 n_2}$ **(B)** $16\frac{n_2}{n_1}C_1$ **(C)** $2\frac{n_2}{n_1}C_1$

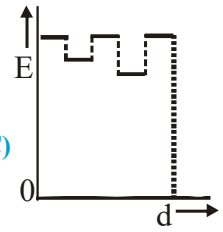
(D) $\frac{16C_1}{n_1 n_2}$

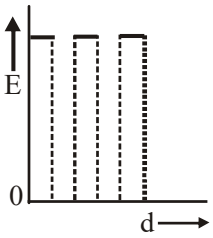
11. Two thin dielectric slabs of dielectric constants K_1 and K_2 ($K_1 < K_2$) are inserted between plates of a parallel plate capacitor, as shown in the figure. The variation of electric field E between the plates with distance d as measured from plate P is correctly shown by



(A)


(B)


(C)


(D)


12. A parallel plate air capacitor has capacity C, distance of separation between plates is d and potential difference V is applied between the plates. Force of attraction between the plates of the parallel plate air capacitor is

(A) $\frac{C^2V^2}{2d}$ **(B)** $\frac{CV^2}{2d}$

(C) $\frac{CV^2}{d}$ **(D)** $\frac{C^2V^2}{2d^2}$

13. A parallel plate air capacitor of capacitance C is connected to a cell of emf V and then disconnected from it. A dielectric slab of dielectric constant K, which can just fill the air gap of the capacitor, is now inserted in it. Which of the following is incorrect ?

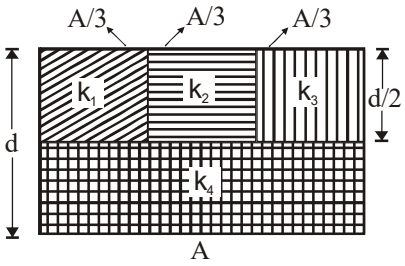
(A) The potential difference between the plates decreases K times

(B) The energy stored in the capacitor decreases K times

(C) The change in energy stored is $\frac{1}{2}CV^2\left(\frac{1}{K}-1\right)$

(D) The charge on the capacitor is not conserved

14. A parallel-plate capacitor of area A, plate separation d and capacitance C is filled with four dielectric materials having dielectric constant k_1, k_2, k_3 and k_4 as shown in the figure below. If a single dielectric material is to be used to have the same capacitance C in this capacitor, then its dielectric constant k is given by



(A) $k = k_1 + k_2 + k_3 + 3k_4$

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(B) $k = \frac{2}{3}(k_1 + k_2 + k_3) + 2k_4$

(C) $\frac{2}{k} = \frac{3}{k_1 + k_2 + k_3} + \frac{1}{k_4}$

(D) $\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \frac{3}{2k_4}$

15. A small signal voltage $V(t) = V_0 \sin \omega t$ is applied across an ideal capacitor C

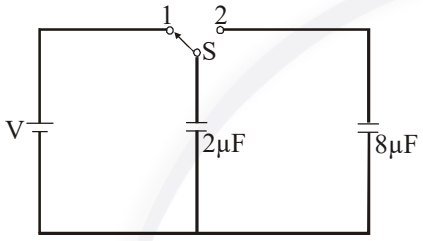
(A) Over a full cycle the capacitor C does not consume any energy from the voltage source

(B) Current I(t) is in phase with voltage V(t)

(C) Current I(t) leads voltage V(t) by 180°

(D) Current I(t), lags voltage V(t) by 90°

16. A capacitor of 2μF is charged as shown in the figure. When the switch S is turned to position 2, the percentage of its stored energy disspated is



(A) 20% **(B)** 75%

(C) 80% **(D)** 0%

17. Suppose the charge of a proton and an electron differ slightly. One of them is – e, the other is (e + Δe). If the net of electrostatic force and gravitational force between two hydrogen atoms placed at a distance d (much greater than atomic size) apart is zero, then Δe is of the order of [Given mass of hydrogen $m_h = 1.67 \times 10^{-27}$ kg]

(A) 10^{-20} C **(B)** 10^{-23} C

(C) 10^{-37} C **(D)** 10^{-47} C

18. A capacitor is charged by a battery. The battery is removed and anothert identical uncharged capacitor is connected in parallel. The total electrostatic enrgy of resulting system

(A) Increasing by a factor of 4

(B) Decreases by a factor of 2

(C) Remains the same

(D) Increases by a factor of 2

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Exercise # 4 PART - 2 PREVIOUS YEAR (AIIMS)

1. Given a number of capacitors labelled as 8 μF, 250 V. Find the minimum number of capacitors needed to get an arrangement equivalent to 16 μF, 1000 V is
(A) 4 **(B)** 16
(C) 32 **(D)** 64

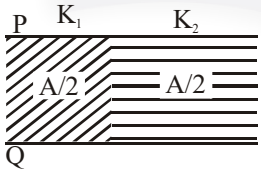
2. An insulated charged metal sphere of radius 5 cm has a potential of 10 V at the surface. What is the potential at centre ?
(A) 10 V
(B) zero
(C) same as that at 5 cm from the surface
(D) same as that at 25 cm from the surface.

3. Seven capacitors each of capacitance 2 μf are to be connected to obtain a capacitance of $\frac{10}{11}$ μF. Which of the following combination is possible ?
(A) 5 in parallel, 2 in series
(B) 4 in parallel, 3 in series
(C) 3 in parallel, 4 in series
(D) 2 in parallel, 5 in series

4. Potential energy of equal +ve charges 1 μC held 1 m apart in air is
(A) 1 J **(B)** 9×10^{-3} eV
(C) zero **(D)** 9×10^{-3} J

5. Electric potential V at any point x, y, z in space is given by $V = 6z^2$. The value of the electric field at the point (2, –1, 3) is
(A) 24 **(B)** –12
(C) –36 **(D)** 12

6. From the figure find the capacitance of the capacitor ?

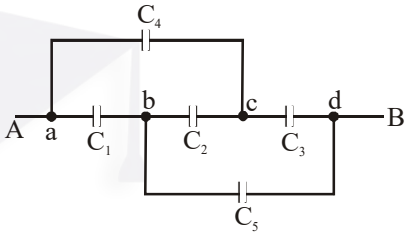


(A) $C = \frac{\varepsilon_0 A}{d}\left(\frac{K_1 + K_2}{2}\right)$ **(B)** $C = \frac{\varepsilon_0 A}{2d}\left(\frac{K_1 K_2}{K_1 + K_2}\right)$

(C) $C = \frac{\varepsilon_0 A}{d}\left(\frac{K_1}{K_2}\right)$ **(D)** $C = \frac{\varepsilon_0 A}{d}\left(\frac{2K_1 K_2}{K_1 + K_2}\right)$

7. IF a unit positive charge is taken from one point to another over an equipotential surface, then
(A) work is done on the charge
(B) work is done by the charge
(C) work done is constant
(D) no work is done

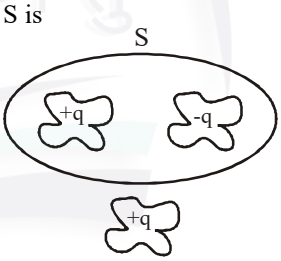
8. In the given figure, the capacitance C_1, C_3, C_4, C_5 have a capacitance 4 μF each. If the capacitor C_2 has a capacitance 10 μF, then effective capacitance between A and B will be



(A) 2 μF **(B)** 6 μF
(C) 4 μF **(D)** 8 μF

9. A conducting sphere of radius 10 cm is charged with 10 μC. Another uncharged sphere of radius 20 cm is allowed to touch it for some time. After that is the spheres are separated, then surface density of charges on the spheres will be in the ratio of
(A) 1 : 4 **(B)** 2 : 1
(C) 1 : 3 **(D)** 1 : 1

10. Figure shown is a distribution of charges. The flux of electric field due to these charges through the surface S is



(A) $3q/\varepsilon_0$ **(B)** $2q/\varepsilon_0$]
(C) $2q/\varepsilon_0$ **(D)** zero

11. Equipotential surfaces associated with an electric field which is increasing in magnitude along the x-direction are
(A) planes parallel to yz-plane
(B) planes parallel to xy-plane
(C) planes parallel to xz-plane
(D) coaxial cylinders of increasing radii around the x-axis.

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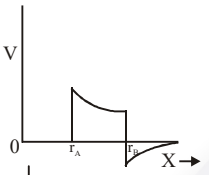
12. A 40 μF capacitor in a defibrillator is charged to 3000 V. The energy stored in the capacitor is sent through the patient during a pulse of duration 2 ms. The power delivered to the patient is

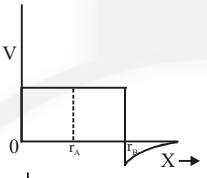
(A) 45 kW **(B)** 90 kW
(C) 180 kW **(D)** 360 kW

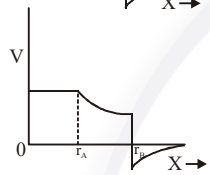
13. Two infinitely long parallel conducting plates having surface charge densities $+\sigma$ and $-\sigma$ respectively, are separated by a small distance. The medium between the plates is vacuum. If ε_0 is the dielectric permittivity of vacuum, then the electric field in the region between the plates is electric field in the region between the plates is

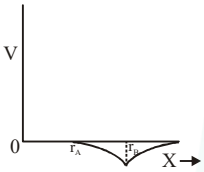
(A) 0 volt/meter **(B)** $\sigma/2\varepsilon_0$ volt/meter
(C) σ/ε_0 volt/meter **(D)** $2\sigma/\varepsilon_0$ volt/meter

14. Two concentric conducting thin spherical shells A and B having radii r_A and r_B ($r_B > r_A$) are charged to Q_A and $-Q_B$($|Q_B|>|Q_A|$). The electrical potential along a line, (passing through the centre is)

(A)


(B)


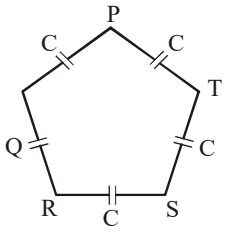
(C)


(D)


15. The voltage of clouds is 4×10^6 volt with respect to ground. In a lightening strike lasting 100 milli sec, a charge of 4 coulombs is delivered to the ground. The power of the lightening strike is

(A) 160 MW **(B)** 80 MW
(C) 20 MW **(D)** 500 MW

16. Five capacitors, each of capacitance value C are connected as shown in the figure. The ratio of capacitance between P and R, and the capacitance between P and Q if the battery is connected to P and R first and then P and Q

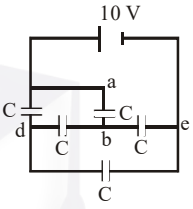


(A) 3 : 1 **(B)** 5 : 2
(C) 2 : 3 **(D)** 1 : 1

17. A conducting sphere of radius R carrying charge Q lies inside an uncharged conducting shell of radius 2R. If they are joined by a metal wire, the amount of heat that will be produced is

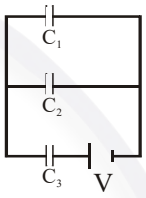
(A) $\frac{1}{4\pi\varepsilon_0}\cdot\frac{Q^2}{4R}$ **(B)** $\frac{1}{4\pi\varepsilon_0}\cdot\frac{Q^2}{2R}$
(C) $\frac{1}{4\pi\varepsilon_0}\cdot\frac{Q^2}{R}$ **(D)** $\frac{2}{4\pi\varepsilon_0}\cdot\frac{Q^2}{3R}$

18. What is the energy stored in the capacitor between terminals a and b of the network shown in the figure ? (Capacitance of each capacitance C = 1 μF)



(A) 12.5 μJ **(B)** zero
(C) 25 μJ **(D)** 50 μJ

19. What would be the voltage across C_3 ?

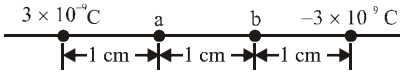


(A) $\frac{(C_1+C_2)V}{C_1+C_2+C_3}$ **(B)** $\frac{C_1V}{C_1+C_2+C_3}$
(C) $\frac{C_2V}{C_2+C_2+C_3}$ **(D)** $\frac{C_3V}{C_1+C_2+C_3}$

20. An electric charge 10^{-3} μC is placed at the origin (0, 0) of (x-y) co-ordinate system. Two points A and B are situated at $\left(\sqrt{2},\sqrt{2}\right)$ and (2, 0) respectively. The potential difference between the points A and B will be

(A) 4.5 volt **(B)** 9 volt
(C) zero **(D)** 2 volt

21. In figure, a particle having mass m = 5 g and charge $q' = 2 \times 10^{-9}$ C starts from rest at point a and moves in a straight line to point b. What is its speed v at point b ?



(A) 2.65 cms^{-1} **(B)** 3.65 cms^{-1}
(C) 4.65 cms^{-1} **(D)** 5.65 cms^{-1}

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22. Energy stored in between the plates of parallel plate capacitor of area A, separated by distance d is

(A) $\frac{1}{2}\varepsilon_0 E^2 Ad$ (B) $\frac{1}{2}\varepsilon_0 E^2 \frac{A}{d}$

(C) $\frac{1}{2}\varepsilon_0 \frac{A}{E^2 d}$ (D) $\frac{1}{2}\frac{Ad}{\varepsilon_0 E^2}$

23. The diameter of the plate of a parallel plate condenser is 6 cm. If its capacity is equal to that of a sphere of diameter 200 cm, the separation between the plates of the condenser is

(A) 4.5×10^{-4} m (B) 2.25×10^{-4} m

(C) 6.75×10^{-4} m (D) 9×10^{-4} m

24. In a uniform electric field a charge of 3 C experiences a force of 3000 N. The potential difference between two points 1 cm apart along the electric line of force will be

(A) 10 V (B) 30 V

(C) 300 V (D) 100 V

25. A hexagon of side 8 cm has a charge 4 mC at each of its vertices. The potential at the centre of the hexagon is

(A) 2.7×10^6 V (B) 7.2×10^{11} V

(C) 2.5×10^{12} V (D) 3.4×10^4 V

ASSERTION AND REASON

26. **Assertion :** Electric potential of earth is taken zero.

Reason : No electric field exists on earth surface.

27. **Assertion :** An electric field is preferred in comparison to magnetic field for detecting the electron beam in a television picture tube.

Reason : Electric field requires low voltage.

28. **Assertion :** Lines of force are perpendicular to conductor surface.

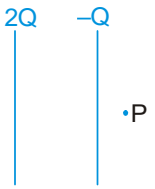
Reason : Generally electric field is perpendicular to equipotential surface.

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MOCK TEST

STRAIGHT OBJECTIVE TYPE

1. In the figure shown the plates of a parallel plate capacitor have unequal charges. Its capacitance is 'C'. P is a point outside the capacitor and close to the plate of charge –Q. The distance between the plates is 'd', select incorrect alternative :



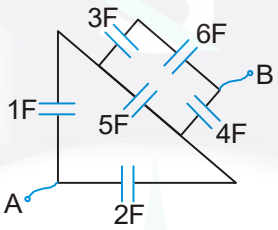
(A) A point charge at point 'P' will experience electric force due to capacitor

(B) The potential difference between the plates will be $\frac{3Q}{2C}$

(C) The energy stored in the electric field in the region between the plates is $\frac{9Q^2}{8C}$

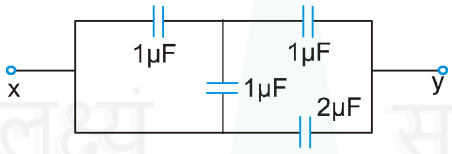
(D) The force on one plate due to the other plate is $\frac{Q^2}{2\pi \in_0 d^2}$

2. In the figure shown the equivalent capacitance between 'A' and 'B' is :



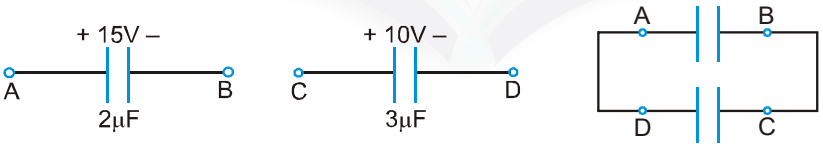
(A) 3.75 F **(B)** 2 F **(C)** 21 F **(D)** 16 F

3. The equivalent capacitance between x & y is:



(A) $\frac{5}{6}$ μF **(B)** $\frac{7}{6}$ μF **(C)** $\frac{8}{3}$ μF **(D)** 1 μF

4. In the figure initial status of capacitance and their connection is shown. Which of the following is incorrect about this circuit :



(A) Final charge on each capacitor will be zero

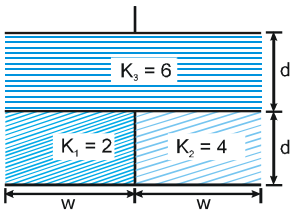
(B) Final total electrical energy of the capacitors will be zero

(C) Total charge flown from A to D is 30μC

(D) Total charge flown from A to D is – 30μC

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5. A parallel plate capacitor of capacitance C (without dielectrics) is filled by dielectric slabs as shown in the figure. Then the new capacitance of the capacitor is:



(A) 3.9 C **(B)** 4 C **(C)** 2.4 C **(D)** 3 C

6. A capacitor (without dielectric) is discharging through a resistor. At some instant a dielectric is inserted between the plates, then

(A) Just after the insertion of the dielectric, current will increase.

(B) Just after the insertion of the dielectric, charge on capacitor will increase.

(C) Just after the insertion of the dielectric, energy stored in the capacitor will increase.

(D) after the insertion of the dielectric, time constant will increase

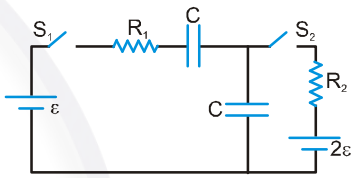
7. In the circuit shown, switch S_2 is closed first and is kept closed for a long time. Now S_1 is closed. Just after that instant the current through S_1 is:

(A) $\frac{\varepsilon}{R_1}$ towards right

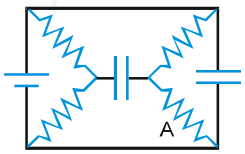
(B) $\frac{\varepsilon}{R_1}$ towards left

(C) zero

(D) $\frac{2\varepsilon}{R_1}$



8. Each resistor in the following circuit has a resistance of 2MΩ and the capacitors have capacitances of 1μF. The battery voltage is 3V. The voltage across the resistor 'A' in the following circuit in steady state is :



(A) 0 V **(B)** 0.5 V **(C)** 0.75 V **(D)** 1.5 V

9. An uncharged capacitor is connected in series with a resistor and a battery. The charging of the capacitor starts at t = 0. The rate at which energy in capacitor is stored :

(A) first increases then decreases

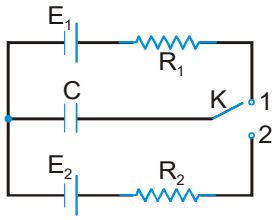
(B) first decreases then increases

(C) remains constant

(D) continuously decreases

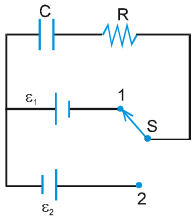
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10. The key K (figure) is connected in turn to each of the contacts over short identical time intervals so that the change in the charge on the capacitor over each connection is small. The final charge q_r on the capacitor is :



(A) $\frac{(E_1R_2+E_2R_1)C}{R_1+R_2}$ **(B)** $\frac{(E_1\ E_2)\ C}{E_1+E_2}$ **(C)** $\frac{(E_1R_1+E_2R_2)\ C}{R_1+R_2}$ **(D)** none of these

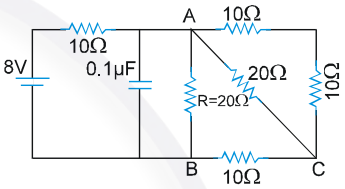
11. Initially switch S is connected to position 1 for a long time. The net amount of heat generated in the circuit after it is shifted to position 2 is



(A) $\frac{C}{2}(\varepsilon_1+\varepsilon_2)\varepsilon_2$ **(B)** $C(\varepsilon_1+\varepsilon_2)\varepsilon_2$

(C) $\frac{C}{2}(\varepsilon_1+\varepsilon_2)^2$ **(D)** $C(\varepsilon_1+\varepsilon_2)^2$

12. A capacitor of capacitance 0.1 μ F is connected to a battery of emf 8V as shown in the fig. Under steady state condition.



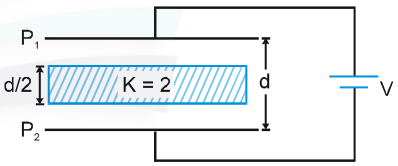
(A) Charge on the capacitor is 0.4 μ C.

(B) Charge on the capacitor is 0.2 μ C.

(C) Current in the resistor(R) between points A & B is 0.1 A.

(D) Current in the resistor(R) between point A & B is 0.4 A.

13. In the figure shown a parallel plate capacitor has a dielectric of width d/2 and dielectric constant K = 2. The other dimensions of the dielectric are same as that of the plates. The plates P_1 and P_2 of the capacitor have area 'A' each. The energy of the capacitor is :



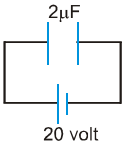
(A) $\frac{\epsilon_0\ AV^2}{3d}$

(B) $\frac{2\ \epsilon_0\ AV^2}{d}$

(C) $\frac{3}{2}\frac{\epsilon_0\ AV^2}{d}$

(D) $\frac{2\ \epsilon_0\ AV^2}{3d}$

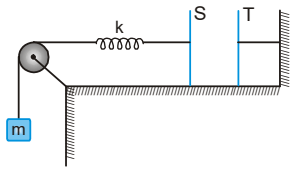
14. In the figure a capacitor of capacitance 2μF is connected to a cell of emf 20 volt. The plates of the capacitor are drawn apart slowly to double the distance between them. The work done by the external agent on the plates is :



(A) – 200 μJ **(B)** 200 μJ **(C)** 400 μJ **(D)** – 400 μJ

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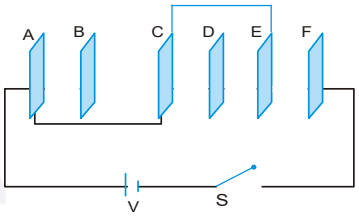
15. The plates S and T of an uncharged parallel plate capacitor are connected across a battery. The battery is then disconnected and the charged plates are now connected in a system as shown in the figure. The system shown is in equilibrium. All the strings and spring are insulating and massless. The magnitude of charge on one of the capacitor plates is: [Area of plates = A]



(A) $\sqrt{2mg\,A\epsilon_0}$ **(B)** $\sqrt{\frac{4mg\,A\epsilon_0}{k}}$

(C) $\sqrt{mg\,A\epsilon_0}$ **(D)** $\sqrt{\frac{2mg\,A\epsilon_0}{k}}$

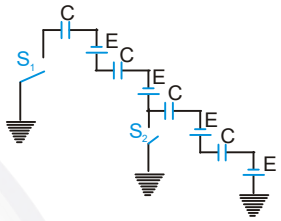
16. In the figure shown A, B, C, D, E, F are conducting plates each of area A and any two consecutive plates separated by a distance d. The net energy stored in the system after the switch S is closed is:



(A) $\frac{3\varepsilon_0 A}{2d}V^2$ **(B)** $\frac{5\varepsilon_0 A}{12d}V^2$

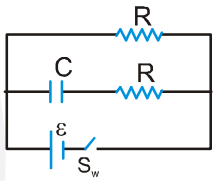
(C) $\frac{\varepsilon_0 A}{2d}V^2$ **(D)** $\frac{\varepsilon_0 A}{d}V^2$

17. In the given circuit, all the capacitors are initially uncharged. After closing the switch S_1 for a long time suddenly S_2 is also closed and kept closed for a long time. Total heat produced after closing S_2 will be:



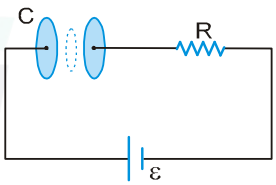
(A) $4C\varepsilon^2$ **(B)** $\frac{1}{2}C\varepsilon^2$ **(C)** $2C\varepsilon^2$ **(D)** 0

18. If at t = 0 the switch S_w is closed, then the charge on capacitor in the given circuit (initially uncharged) when the current through battery becomes 50% of its maximum value is (assume battery is ideal):



(A) $\frac{C\varepsilon}{3}$ **(B)** $\frac{C\varepsilon}{2}$ **(C)** $\frac{C\varepsilon}{4}$ **(D)** $C\varepsilon$

19. In the circuit shown the capacitor of capacitance C is initially uncharged. Now the capacitor is connected in the circuit as shown. The charge passed through an imaginary circular loop parallel to the plates (also circular) and having the area equal to half of the area of the plates, in one time constant is:



(A) $C\varepsilon\left(1-\frac{1}{e}\right)$ **(B)** $\frac{C\varepsilon}{2}\left(1-\frac{1}{e}\right)$ **(C)** $\frac{C\varepsilon}{4}$ **(D)** zero

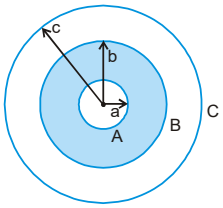
20. A parallel plate capacitor (without dielectric) is charged by a battery and kept connected to the battery. A dielectric slab of dielectric constant 'k' is inserted between the plates fully occupying the space between the plates. The energy density of electric field between the plates will:

(A) increase k^2 times k^2 **(B)** decrease k^2 times

(C) increase k times **(D)** decrease k times

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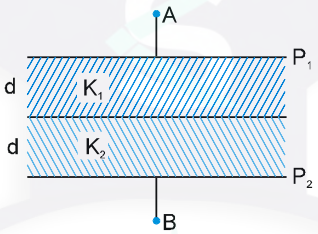
21. In the figure shown A and C are concentric conducting spherical shells of radius a and c respectively. A is surrounded by a concentric dielectric medium of inner radius a, outer radius b and dielectric constant k. If sphere A is given a charges Q, the potential at the outer surface of the dielectric is.



(A) $\frac{Q}{4\pi \in_0 kb}$ **(B)** $\frac{Q}{4\pi \in_0}\left(\frac{1}{a}+\frac{1}{k(b-a)}\right)$

(C) $\frac{Q}{4\pi \in_0 b}$ **(D)** None of these

22. In the figure shown P_1 and P_2 are two conducting plates having charges of equal magnitude and opposite sign. Two dielectrics of dielectric constant K_1 and K_2 fill the space between the plates as shown in the figure. The ratio of electrical energy in 1st dielectric to that in the 2nd dielectric is



(A) 1 : 1 **(B)** $K_1 : K_2$ **(C)** $K_2 : K_1$ **(D)** $K_2^2 : K_1^2$

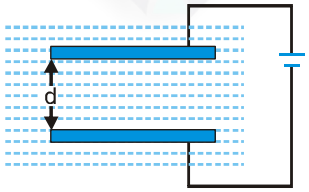
23. In the figure shown two long straight wires with the same cross-section are arranged in air, parallel to one another. The distance between the axis of the wire is η times larger then the radius of wire's cross-section. Capacitance of the wires per unit length would be (Take $\eta >> 1$)



Top view of the arrangement

(A) $\frac{2\pi \in_0}{\ln \eta}$ **(B)** $\frac{\pi \in_0}{2\ln \eta}$ **(C)** $\frac{\pi \in_0}{\ln \eta}$ **(D)** Information insufficient

24. A parallel plate capacitor is immersed in a liquid dielectric having dielectric constant ε as shown in the figure. Find the force acting on a unit surface of the plate from the dielectric.

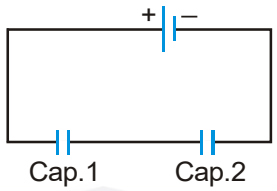


(A) $\frac{\varepsilon \varepsilon_0 V^2}{2d^2}$ **(B)** $\frac{\varepsilon_0(\varepsilon-1)V^2}{2d^2 \times \varepsilon}$ **(C)** $\frac{\varepsilon V^2}{2d^2}$ **(D)** $\frac{\varepsilon(\varepsilon-1)\varepsilon_0 V^2}{2d^2}$

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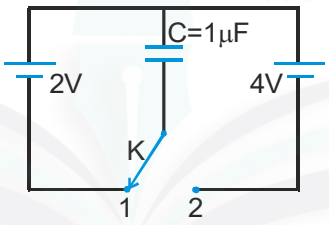
MATRIX - MATCH TYPE

25. Two identical capacitors are connected in series, and the combination is connected with a battery, as shown. Some changes in the capacitor 1 are now made independently after the steady state is achieved, listed in column-I. Some effects which may occur in new steady state due to these changes on the capacitor 2 are listed in column-II. Match the changes on capacitor 1 in column-I with corresponding effect on capacitor 2 in column-II.



	Column I		Column II
(A)	A dielectric slab is inserted.	(P)	Charge on the capacitor increases.
(B)	Separation between plates increased.	(Q)	Charge on the capacitor decreases.
(C)	A metal plate is inserted connecting both plates	(R)	Energy stored in the capacitor increases.
(D)	The left plate is grounded.	(S)	Energy stored in capacitor is decreased
		(T)	No change is occurred.

26. The circuit involves two ideal cells connected to a 1 μF capacitor via a key K. Initially the key K is in position 1 and the capacitor is charged fully by 2V cell. The key is pushed to position 2. Column I gives physical quantities involving the circuit after the key is pushed from position 1. Column II gives corresponding results. Match the statements in Column I with the corresponding values in Column II.



	Column I		Column II
(A)	The net charge crossing the 4 volt cell in μC is	(P)	2
(B)	The magnitude of work done by 4 Volt cell in μJ is	(Q)	6
(C)	The gain in potential energy of capacitor in μJ is	(R)	8
(D)	The net heat produced in circuit in μJ is	(S)	16

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ASSERTION AND REASON TYPE

These questions contains, Statement 1 (assertion) and Statement II (reason).

(A) Statement-1 is True, Statement-2 is True; Statement-2 **is** a correct explanation for Statement-1

(B) Statement-1 is True, Statement-2 is True; Statement-2 **is NOT** a correct explanation for Statement-1

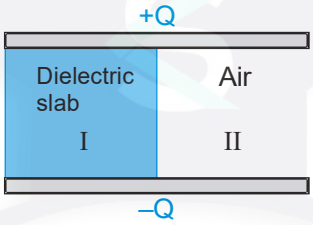
(C) Statement-1 is True, Statement-2 is False

(D) Statement-1 is False, Statement-2 is True.

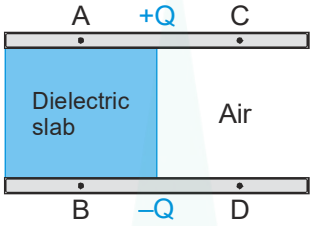
27. **Assertion :** If the potential difference across a plane parallel plate capacitor is doubled then the potential energy of the capacitor becomes four times under all conditions.

Reason : The potential energy U stored in the capacitor is $U = \frac{1}{2}CV^2$, where C and V have usual meaning.

28. **Assertion :** A charged plane parallel plate capacitor has half interplanar region (I) filled with dielectric slab. The other half region II has air. Then the magnitude of net electric field in region I is less than that in region II.



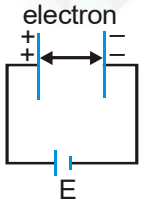
Assertion : In a dielectric medium induced (or polarised) charges tend to reduce the electric field.



29. **Assertion :** A dielectric is inserted between the plates of an isolated fully-charged capacitor. The dielectric completely fills the space between the plates. The magnitude of electrostatic force on either metal plate decreases, as it was before the insertion of dielectric medium.

Reason : Due to insertion of dielectric slab in an isolated parallel plate capacitor (the dielectric completely fills the space between the plates), the electrostatic potential energy of the capacitor decreases.

30. **Statement I :** During the charging of a capacitor using a battery, the electrons transferred from positive plate of capacitor to negative plate via dielectric medium in between the plates as shown.



Statement II : The direction of electric field in between the capacitor plates is from positive plate to negative plate.

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ANSWER KEY

EXERCISE - 1

1 C **2** C **3** A **4** A **5** D **6** AD **7** C **8** B **9** B **10** C **11** C **12** A **13** B
14 D **15** C **16** D **17** A **18** D **19** B **20** B **21** B **22** B **23** D **24** A **25** B **26.** D
27. A **28.** C **29.** A **30.** A **31.** C **32.** C **33.** D **34.** B **35.** D **36.** D **37.** A **38.** B **39.** C
40. C **41.** B **42.** B **43.** B **44.** C **45.** C **46.** C **47.** C **48.** A **49.** C **50.** D

EXERCISE - 2

1. C **2.** D **3.** B **4.** A **5.** B **6.** D **7.** A **8.** D **9.** B **10.** B **11.** A **12.** B **13.** A
14. C **15.** B **16.** C **17.** C **18.** A **19.** D **20.** D **21.** A **22.** A **23.** B **24.** D **25.** B **26.** B
27. D **28.** B **29.** C **30.** A **31.** A **32.** A **33.** A **34.** C **35.** C **36.** A **37.** C **38.** C **39.** D
40. B **41.** C

EXERCISE - 3 : PART # 1

1. A → P ; B → R,S ; C → P ;D → R **2.** A → Q ; B → P ; C → S ;D → R

PART # 2

1. D **2.** C **3.** A **4.** A **5.** B **6.** B **7.** B **8.** A **9.** E **10.** B **11.** D **12.** A **13.** C
14. C

EXERCISE - 4 : PART # 1

1. B **2.** B **3.** C **4.** B **5.** A **6.** A **7.** D **8.** C **9.** C **10.** D **11.** C **12.** B **13.** D
14. ..... **15.** A **16.** C **17.** C **18.** D

PART # 2

1. C **2.** A **3.** A **4.** D **5.** C **6.** A **7** D **8.** C **9.** B **10.** D **11.** A **12.** B **13.** C
14. C **15.** B **16.** C **17.** A **18.** A **19.** A **20.** C **21.** C **22.** A **23.** B **24.** A **25.** A **26.** C
27. D **28.** A

MOCK TEST

1. D **2.** B **3.** C **4.** D **5.** A **6.** D **7.** B **8.** D **9.** A **10.** A **11.** C **12.** A **13.** D
14. B **15.** A **16.** C **17.** D **18.** D **19.** D **20.** C **21.** C **22.** C **23.** C **24.** D
25. A → P, R ; B → Q, S ; C → P, R ; D → T **26.** A → P ; B → R ; C → Q ; D → P **27.** D **28.** D **29.** D
30. D

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HINTS & SOLUTIONS

EXERCISE - 1
NEET LEVEL

1. (C) $V' = \frac{V}{8} \Rightarrow \frac{V}{K} = \frac{V}{8} \Rightarrow K = 8$

2. (C) Battery in disconnected so Q will be constant as $C \propto K$. So with introduction of dielectric slab capacitance will increase using $Q = CV$, V will decrease and using $U = \frac{Q^2}{2C}$, energy will decrease.

3. (A) $q = CV$ and $U = \frac{1}{2}CV^2 = \frac{q^2}{2C}$

4. (A) $U = \frac{1}{2}CV^2 = \frac{1}{2} \times 4 \times 10^{-6} \times (100)^2 = 0.02\,J$

5. (D) When $\frac{Q_1}{R_1} \neq \frac{Q_2}{R_2}$; current will flow in connecting wire so that energy decreases in the form of heat through the connecting wire.

6. (AD) Capacitance will be increased when a dielectric is introduced in the capacitor but potential difference will remain the same because battery is still connected. So according to $q = CV$, charge will increase i.e. $Q > Q_0$ and

$U = \frac{1}{2}QV_0, U_0 = \frac{1}{2}Q_0V_0 \Rightarrow Q > Q_0$ so $U > U_0$

7. (C)

8. (B) $U = \int_0^V CV\,dV = \frac{1}{2}CV^2$

9. (B) Law of conservation of charge.

10. (C) After the connection of wire $V_1 = V_2$

$\therefore \frac{Q_1}{25} = \frac{Q_2}{20} \Rightarrow \frac{Q_1}{Q_2} = \frac{25}{20} \Rightarrow Q_1 > Q_2$

11. (C) Volume of 8 small drops = Volume of big drop

$8 \times \frac{4}{3}\pi r^3 = \frac{4}{3}\pi R^3 \Rightarrow R = 2r$

As capacity is r, hence capacity becomes 2 times.

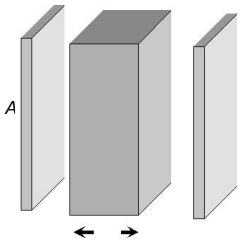
12. (A) $U = \frac{1}{2}CV^2 = \frac{1}{2} \times 50 \times 10^{-6} \times (10)^2 = 2.5 \times 10^{-3}\,J$

13. (B)

14. (D) $C_{medium} = KC_{air} \Rightarrow K = \frac{C_{medium}}{C_{air}} = \frac{110}{50} = 2.20$

15. (C) Potential difference between the plates V = Vair + Vmedium

$= \frac{\sigma}{\varepsilon_0} \times (d - t) + \frac{\sigma}{K\varepsilon_0} \times t$



$\Rightarrow V = \frac{\sigma}{\varepsilon_0}(d - t + \frac{t}{K})$

$= \frac{Q}{A\varepsilon_0}(d - t + \frac{t}{K})$

Hence capacitance $C = \frac{Q}{V} = \frac{Q}{\frac{Q}{A\varepsilon_0}(d - t + \frac{t}{K})}$

$= \frac{\varepsilon_0 A}{(d - t + \frac{t}{k})} = \frac{\varepsilon_0 A}{d - t\left(1 - \frac{1}{k}\right)}$

16. (D) $C = \frac{K\varepsilon_0 A}{d}$

17. (A) Stationary charge produces electric field only.

18. (D)

19. (B) $C = \frac{\varepsilon_0 A}{d}.C' = \frac{\varepsilon_0 A}{d/2} \Rightarrow 8r^3 = R^3$

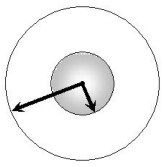
20. (B) By using $V_{big} = n^{2/3}v_{small} \Rightarrow \frac{V_{Big}}{V_{small}} = (8)^{2/3} = \frac{4}{1}$

21. (B) $V_{Big} = n^{2/3}v_{small} = (1000)^{2/3}v_{small} = 100\,v_{small}$

22. (B) $E_{medium} = \frac{E_{air}}{K} = \frac{E}{2}$

23. (D) Given : $(b - a) = 1 \times 10{-}3\,m$ ..... (i)

and $C = 4\pi\varepsilon_0\left(\frac{ab}{b-a}\right) = 1 \times 10^{-6}$



$\Rightarrow 1 \times 10^{-6} = \frac{1}{9 \times 10^9}\left(\frac{ab}{10^{-3}}\right)$

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$\Rightarrow$ ab = 9 ..... (ii)

From equations (i) and (ii)

$$b-\frac{9}{b}=\frac{1}{1000} \Rightarrow 1000\,b2-b-9000=0$$

$$\Rightarrow b=\frac{1\pm\sqrt{(-1)^2-4(1000)(-9000)}}{2\times1000}$$

{Solving of quadratic equation}

$$\Rightarrow b=\frac{1\pm\sqrt{36\times10^6}}{2000}\approx\frac{\sqrt{36\times10^6}}{2000}=3\,\text{m}.$$

24. (A) High K means good insulating property and high x means able to withstand electric field gradient to a higher value.

25. (B) $C_{medium}=K\times C_{air}$

26. (D) $Q_1=CV$ and $Q_2=CV$

Applying charge conservation $CV_1+CV_2=Q_1+Q_2$

$CV_1+CV_2=2CV \Rightarrow V_1+V_2=2V$

27. (A)

28. (C) The given arrangement becomes an arrangement of $(n-1)$ capacitors connected in parallel. So $C_R=(n-1)C$

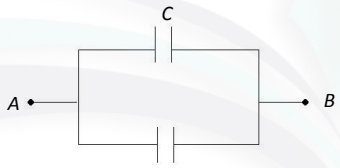
29. (A)

30. (A) The given circuit is equivalent to a parallel combination two identical capacitors

Hence equivalent capacitance between A and B is

$$C=\frac{\varepsilon_0 A}{d}+\frac{\varepsilon_0 A}{d}$$

$$=\frac{2\varepsilon_0 A}{d}$$



31. (C) $C_{eq}=\frac{C_1C_2}{C_1+C_2}=2.4\mu\text{F}.$

Charge flown = 2.4 × 500 × 10–6 C =1200 μC.

32. (C) $C_R=C_1+C_2=\frac{k_1\varepsilon_0A_1}{d}+\frac{k_2\varepsilon_0A_2}{d}$

$$=\frac{2\times\varepsilon_0\frac{A}{2}}{d}+\frac{4\times\varepsilon_0\frac{A}{2}}{d}=2\times\frac{10}{2}+4\times\frac{10}{2}=30\mu\text{F}$$

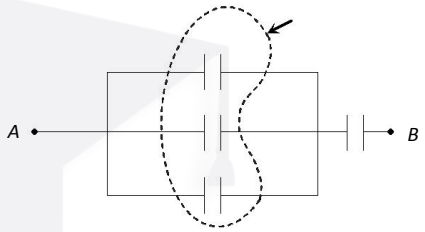
33. (D) In series combination, charge is same on each capacitor.

34. (B) According to energy conservation, energy remains the same

$$\Rightarrow U_{parallel}=U_{series}\Rightarrow\frac{1}{2}(nC)V^2=\frac{1}{2}\left(\frac{C}{n}\right)V'^2\Rightarrow V'=nV$$

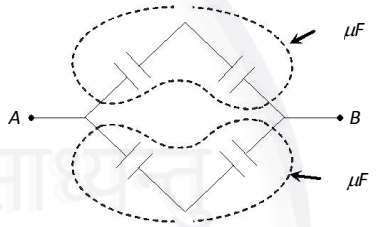
(V = potential difference across series combination)

35. (D) The circuit can be drawn as follows



$$\Rightarrow C_{AB}=\frac{3\times1}{3+1}=\frac{3}{4}\mu\text{F}$$

36. (D) In the given system, no current will flow through the branch CD so it can be removed



Effective capacitance of the system = 5 + 5 = 10μF

37. (A) $\frac{1}{C_s}=\frac{1}{3}+\frac{1}{9}+\frac{1}{18}=\frac{1}{2}\Rightarrow C_s=2\mu\text{F}$

$$C_p=3+9+18=30\mu\text{F}\Rightarrow\frac{C_s}{C_p}=\frac{2}{30}=\frac{1}{15}$$

38. (B) Total capacitance of given system $C_{eq}=\frac{8}{5}\mu\text{F}$

$$U=\frac{1}{2}C_{eq}V^2=\frac{1}{2}\times\frac{8}{5}\times10^{-6}\times225=180\times10^{-6}\,\text{J}$$

$$=180\times10^{-6}\times10^7\,\text{erg}=1800\,\text{erg}$$

39. (C) $U=\frac{1}{2}CV^2=\frac{1}{2}\times2\times(200)^2\times10^{-6}=0.04\text{J}$

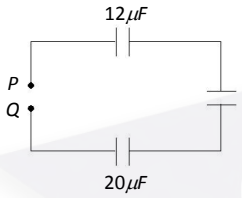
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40. **(C)** $Q_1 = Q_2 + Q_3$ because in series combination charge is same on both the condenser and $V = V_1 + V_2$ because in parallel combination $V_2 = V_3$.

Hence $V = V_1 + V_2$

41. **(B)** The given circuit can be drawn as

where $C = (3+2)\mu F = 5\mu F$



$$\frac{1}{C_{PQ}} = \frac{1}{5} + \frac{1}{20} + \frac{1}{12} = \frac{20}{60} = \frac{1}{3}$$

$$\Rightarrow C_{PQ} = 3\mu F$$

42. **(B)** In series combination Q is constant, hence according to

$$U = \frac{Q^2}{2C} \Rightarrow U \propto \frac{1}{C} \Rightarrow \frac{U_1}{U_2} = \frac{C_2}{C_1} = \frac{0.6}{0.3} = \frac{2}{1}$$

43. **(B)** Potential difference across $4\mu F$ capacitor

$$V = \left(\frac{6}{4+6}\right) \times 500 = 300 \text{ volt}$$

44. **(C)** Charge flowing $= \frac{C_1 C_2}{C_1 + C_2} V$. So potential difference across $C_1 = \frac{C_1 C_2 V}{C_1 + C_2} \times \frac{1}{C_1} = \frac{C_2 V}{C_1 + C_2}$

45. **(C)** In parallel, $C = C_1 + C_2 + C_3 = 20\mu F$

46. **(C)** $\frac{1}{C_R} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \Rightarrow C_R = (C_1^{-1} + C_2^{-1} + C_3^{-1})^{-1}$

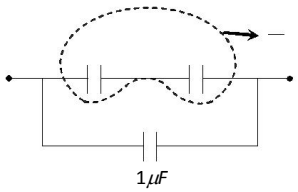
47. **(C)** $C_1 = 2C$ and $C_2 = C/2$, so $C_1 / C_2 = 4:1$

48. **(A)** In parallel combination $V_1 = V_2$

or $\frac{q_1}{C_1} = \frac{q_2}{C_2} \Rightarrow \frac{q_1}{q_2} = \frac{C_1}{C_2}$

49. **(C)**

50. **(D)** The circuit can be drown as follows

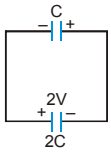


EXERCISE - 2

AIIMS LEVEL

1. **(C)** $V_0 (C + CV) = CV + (2C)(2V)$

$V_0 = V$ (Final pot. diff.)



$$\therefore U_{final} = \frac{1}{2}(C + 2C) V_2 = \frac{3CV^2}{2}$$

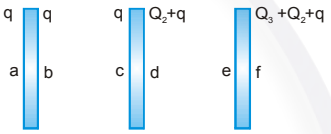
2. **(D)** $P = \frac{\Delta U}{\Delta t} = \frac{\frac{1}{2} CV^2}{\Delta t}$

$$= \frac{\frac{1}{2} \times 40 \times 10^{-6} \times 9 \times 10^6}{2 \times 10^{-3}} = 90 kW$$

3. **(B)** $k = \frac{f}{x} = \frac{5000}{0.2} = 2{,}5000 \text{ N/m}$

$$\frac{U_{SPR}}{U_{CAP}} = \frac{\frac{1}{2} kx^2}{\frac{1}{2} CV^2} = \frac{25000 \times 0.2 \times 0.2}{10 \times 10^{-6} \times 10^8} = 1$$

4. **(A)**



Here $Q_1 - q = Q_2 + Q_3 + q \Rightarrow q = \frac{Q_1 - (Q_2 + Q_3)}{2}$

Charge on a= Charge on f

$$\Rightarrow Q_1 - q = \frac{\Sigma Q}{2} = \frac{Q_1 + Q_2 + Q_3}{2}$$

5. **(B)** $C = \frac{\epsilon_0 A}{d - t + \frac{t}{K}} \left(t = \frac{d}{2}, K = \infty\right)$

$$= \frac{\epsilon_0 A}{d - \frac{d}{2} + \frac{d}{2K}} = \frac{2\epsilon_0 A}{d} = 2C_0$$

6. **(D)** Before sharing $U_i = \frac{Q_1^2}{2C_1} + \frac{Q_2^2}{2C_2}$

After sharing $U_f = \frac{(Q_1 + Q_2)^2}{2(C_1 + C_2)}$

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$$\Delta U = U_f - U_i = \frac{(Q_1+Q_2)^2}{2(C_1+C_2)} - \frac{Q_1^2}{2C_1} + \frac{Q_2^2}{2C_2}$$

$$= -\frac{(Q_1C_2 - Q_2C_1)^2}{2C_1C_2(C_1+C_2)}$$

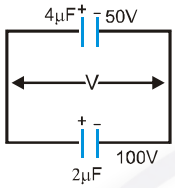
–ve sign indicates there is decrease in energy

But $Q_1C_2 - Q_2C_1 \neq 0 \quad \Rightarrow \quad Q_1C_2 \neq Q_2C_1$

$\Rightarrow Q_1 4\pi\varepsilon_0 R_2 \neq Q_2 4\pi\varepsilon_0 R_1 \quad \Rightarrow \quad Q_1R_2 \neq Q_2R_1$

7. (A) $(4+2)\,V = (4\times 50) + (2\times 100)$

$$V = \frac{400}{6} = \frac{200}{3}\,V$$



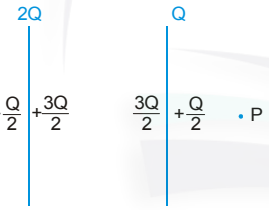
$$U_{initial} = \left(\frac{1}{2}\times 4\times (50)^2 + \frac{1}{2}\times 2\times (100)^2\right)\times 10^{-6}$$

$$= (5000+10000)\times 10^{-6} = 1.5\times 10^{-2}\,J$$

$$U_{final} = \frac{1}{2}(4+2)\times 10^{-6}\times\frac{200}{3}\times\frac{200}{3}$$

$$= 1.33\times 10^{-2}\,J$$

8. (D)



Force on either plate $= \frac{(3Q/2)^2}{2A\,\epsilon_0} = \frac{9Q^2}{8A\,\epsilon_0}$

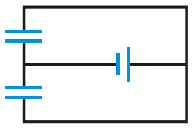
Force on point 'P' due to capacitor = 0

Potential diff. between the plates $= \frac{3Q}{2C}$

Energy stored in electric field between the plates

$$= \frac{1}{2}C\times\left(\frac{3Q}{2C}\right)^2 = \frac{9Q^2}{8C}$$

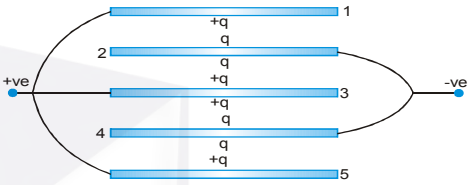
9. (B)



$$U = \frac{1}{2}C_1V^2 + \frac{1}{2}C_2V^2 = \frac{1}{2}(C_1+C_2)V^2$$

$$= \frac{1}{2}\left(\frac{8.85\times 10^{-12}\times 0.1}{0.885\times 10^{-3}}\times 2\right)\times 10^2 = 10^{-1}\mu J$$

10. (B)

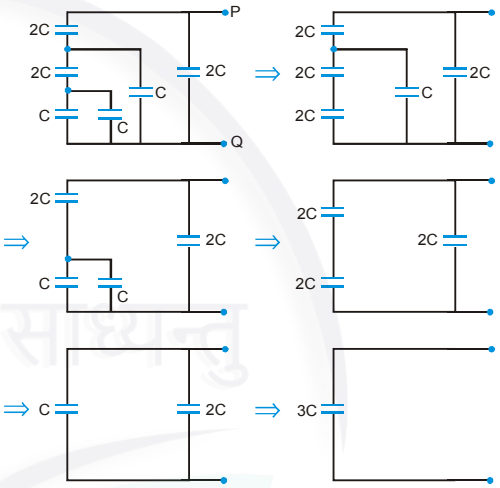


Therefore

$q_2 = -2q,\ q_3 = +2q,$

$q_4 = -2q$ and $q_5 = +q$

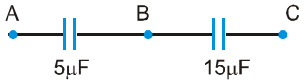
11. (A)



12. (B) Each capacitor has potential difference 'V' and energy $\frac{1}{2}CV^2$. After reconnecting total energy remains constant and total voltage becomes NV.

13. (A) For 'n' plates; effective C will be (n–1)C.

14. (C)



$5(V_A - V_B) = 15\,(V_B - V_C)$

$\Rightarrow 5(2000 - V_B) = 15(V_B - 0)$

$\Rightarrow 2000 - V_B = 3V_B$

$\Rightarrow V_B = 500V$

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15. (C) $C_{eff}=C+\frac{C}{2}+\frac{C}{4}+\frac{C}{8}+\frac{C}{16}+....$

$$=\frac{C}{1-1/2}=2C=2\mu F$$

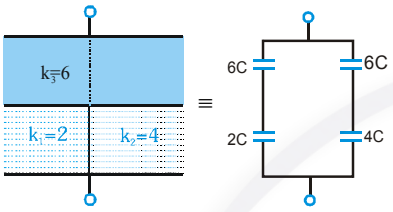
16. (C) $C=\frac{\epsilon_0 A}{d}=9pF$

$$C'=\frac{\epsilon_0 A}{d-t_1+\frac{t_1}{K_2}-t_2+\frac{t_2}{K_2}}=\frac{\epsilon_0 A}{d-\frac{d}{3}+\frac{d}{9}-\frac{2d}{3}+\frac{d}{9}}$$

$$=\frac{9}{2}\frac{\epsilon_0 A}{d}=\frac{81}{2}pF=40.5pF$$

17. (C) $CV+2CV=KCV'+2CV'\Rightarrow V'=\frac{3V}{K+2}$

18. (A)

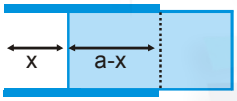


where $C=\frac{\epsilon_0 A}{d}$

$$C_{eq}=\frac{6C\times 2C}{8C}+\frac{6C\times 4C}{10C}=3.9\ C$$

19. (D) $\frac{1}{2}CV^2=ms\Delta T\ \Rightarrow\ V=\sqrt{\frac{2ms\Delta T}{C}}$

20. (D)



$$C=\frac{\epsilon_0 ax}{d}+\frac{K\epsilon_0(a-x)a}{d}$$

$$C=\frac{K\epsilon_0 a^2}{d}-\frac{\epsilon_0 a(K-1)}{d}x \text{ where } x=vt$$

$\therefore$ C– t graph is linear with negative slope.

21. (A)



Breaking voltage	20 V	80 V
Safe Voltage	20 V	10 V

$\therefore$ Charge on each capacitor = 20 × 8 = 160 μC

22. (A) $C=4\pi\epsilon_0 a$

$$C'=\frac{4\pi\epsilon_0 ab}{b-a}=\frac{4\pi\epsilon_0 a}{1-\frac{a}{b}}=\frac{4\pi\epsilon_0 a}{1-\left(\frac{n-1}{n}\right)}=n(4\pi\epsilon_0 a)C$$

23. (B) Capacitance between 1 and 3 and between 2 and 4 are symmetrical.

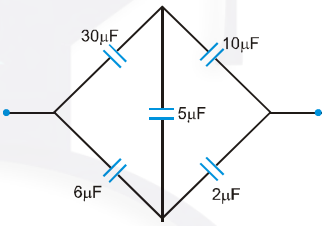
24. (D)



Breaking voltage	6 kV	4 kV
Safe Voltage	6 kV	3 kV

$\therefore$ Total voltage = 9 kV

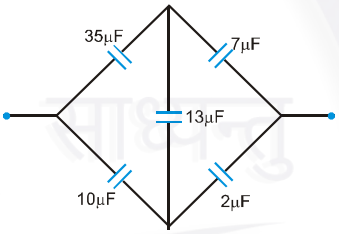
25. (B)



The system is a balanced Wheatstone bridge.

$$\therefore C_{eff}=\left(\frac{10\times 30}{10+30}+\frac{6\times 2}{6+2}\right)=9\mu F$$

26. (B)



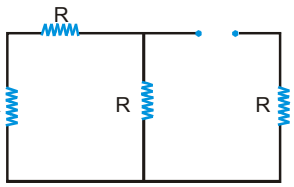
The system is a balanced Wheatstone bridge.

$$\therefore C_{eff}=\left(\frac{35\times 7}{35+7}+\frac{10\times 2}{10+2}\right)=\frac{15}{2}\mu F$$

27. (D) There is no closed path for flow of current. Hence no current flows. Hence heat developed is zero.

28. (B) $VA=3\left(\frac{q}{C}\right)=3\times 2.5=7.5$ volt

29. (C)

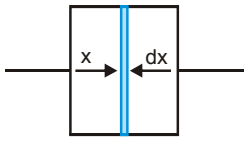


To find the time constant of a RC circuit, Short circuit the battery

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$R_{eff} = \frac{7R}{4}$ $\quad \therefore \tau = \frac{7RC}{4}$

30.



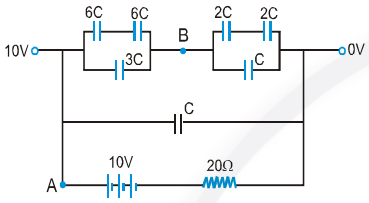
$$\int \frac{1}{dC} = \int \frac{dy}{K \epsilon_0 A} = \int_0^d \frac{dy}{\lambda \epsilon_0 A \sec\left(\frac{\pi y}{2d}\right)}$$

$$\Rightarrow C = \frac{\lambda \epsilon_0 A \pi}{2d}$$

31. Both A and B are always in parallel.

32. $E = \frac{V_0}{d} \Rightarrow E_F < E_D$ Also $\sigma_A > \sigma_B$

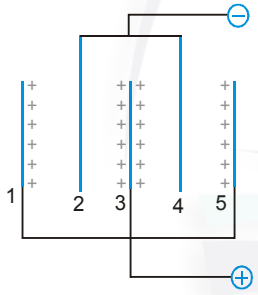
33.



$(V_A - V_B)6C = (V_B - 0)2C \Rightarrow V_B = 7.5\ V$

$\therefore V_A - V_B = 10 - 7.5 = 2.5\ V$

34.



Charge on plate $\neq 1 = \frac{\epsilon_0 AV}{d}$

Charge on plate $\neq 4 = -\frac{2\epsilon_0 AV}{d}$

35.



$C_{eff} = 1/4\ \mu F$

$\therefore$ Total no. of rows of capacitor $= \frac{C_{net}}{C_{eff}} = \frac{3}{1/4} = 12$

$\therefore$ Total no. of capacitors needed $= 12 \times 4 = 48$

36. Force on plate

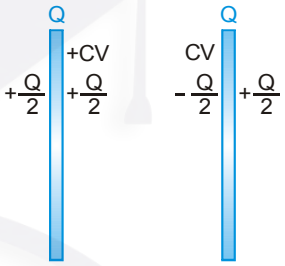
$$= \frac{\sigma^2 A}{2\epsilon_0} = \frac{Q^2}{2A\epsilon_0} = Kx = mg$$

$$\therefore Q = \sqrt{2mgA\epsilon_0}$$

37. $C_{eq} = \frac{KC}{K+1}, C'_{eq} = \frac{C}{2}$

$$\Rightarrow \frac{Q'_2}{Q_2} = \frac{K+1}{2K}$$

38. Final charge distribution



Therefore potential difference across the capacitor

$$= \frac{CV + \frac{Q}{2}}{C} = V + \frac{Q}{2C}$$

39. $Q = \frac{C}{2}E$

$$Q' = \frac{KCC}{KC + C}E = \frac{KC}{K+1}E$$

$$\therefore Q' - Q = \frac{KCE}{K+1} - \frac{CE}{2} = \frac{(K-1)CE}{2(K+1)}$$

This charge is supplied by battery.

40. At t=0, $V_{capacitors} = 0$

$\Rightarrow I_2 = I_3 = 0$ and $I_1 = \frac{6}{2} = 3A$

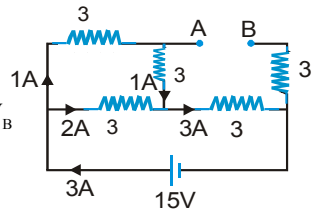
At $t \to \infty$, $I_1 = I_3 = \frac{6}{2+8} = 0.6\ A, I_2 = 0$

41. At t= ∞, capacitor gets open circuited

$\therefore I = \frac{15}{5} = 3A$

$\Rightarrow V_A - 3 \times 1 - 3 \times 3 = V_B$

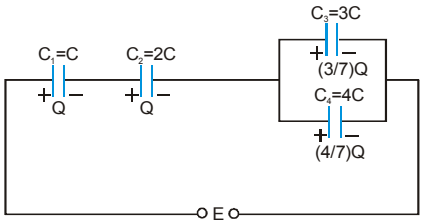
$\Rightarrow V_A - V_B = 12\ V$



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EXERCISE - 3
P-1 (Matrix Match)

1.



$$\text{At } C_1 = V_1 = \frac{Q}{C} \quad \text{and} \quad U_1 = \frac{Q^2}{2C}$$

$$\text{At } C_2 = V_2 = \frac{Q}{2C} \quad \text{and} \quad U_2 = \frac{Q^2}{4C}$$

$$\text{At } C_3 = V_3 = \frac{Q}{7C} \quad \text{and} \quad U_3 = \frac{3Q^2}{98C}$$

$$\text{At } C_4 = V_4 = \frac{Q}{7C} \quad \text{and} \quad U_4 = \frac{4Q^2}{98C}$$

Therefore $V_{max} = V_1$ and $V_{min} = V_3 = V_4$
and $U_{max} = U_1$ and $U_{min} = U_3$

2. Initial charge $q_1 = \frac{CE}{2}$

Final charge $q_2 = CE$
Initial stored energy

$$U_1 = \frac{1}{2}C(E/2)^2 + \frac{1}{2}C(E/2)^2 = \frac{CE^2}{4}$$

Final stored shergy $U_2 = \frac{CE^2}{2}$

Charge supplied by battery

$$\Delta Q = q_2 - q_1 = CE - \frac{CE}{2} = \frac{CE}{2}$$

Work done by battery $W_B = \Delta QE = \frac{CE^2}{2}$

Heat developed in the system

$$H = W_B - \Delta U = \frac{CE^2}{2} - \left(\frac{CE^2}{2} - \frac{CE^2}{4}\right) = \frac{CE^2}{4}$$

EXERCISE - 3
P-2 (Assertion & Reason)

1. D **2.** C **3.** A **4.** A **5.** B **6.** B
7. B **8.** A **9.** E **10.** B **11.** D **12.** A
13. C **14.** C

EXERCISE - 4
P-1 (NEET/AIPMT)

1. **(B)** When a capacitor is charged by connecting a battery across its plates, the initial energy stored.

$$U = \frac{q^2}{2C}$$

When the battery is disconnected, then the charge remains constant i.e. q = constant. Now, another identical capacitors are connected in parallel, so the equivalent capacitance

$$C_{eq} = C_1 + C_2$$
$$= C + C = 2C$$

Thus, final energy stored by the system of capacitors,

$$U' = \frac{q^2}{2C_{eq}} \Rightarrow U' = \frac{q^2}{(2C)}$$

$$U' = \frac{1}{2}U \quad \therefore \; U' = \frac{1}{2}$$

2. **(B)** Energy stored, in parallel plate capacitor is given by

$$U = \frac{1}{2}\frac{q^2}{C}$$

but $\sigma = \frac{q}{A}$ and $C = \frac{\varepsilon_0 A}{d}$

$$\therefore \quad U = \frac{1}{2}\frac{(\sigma A)^2}{\left(\frac{\varepsilon_0 A}{d}\right)}$$

$$\text{or} \quad = \frac{A\sigma^2 d}{2\varepsilon_0}$$

$$\text{or} \quad = \frac{1}{2}\left(\frac{\sigma}{\varepsilon_0}\right)^2 \times \varepsilon_0 Ad$$

$$\text{or} \quad U = \frac{1}{2}E^2\varepsilon_0 Ad$$

Energy stored per unit volume i.e. energy density is thus given by

$$u = \frac{U}{V} = \frac{U}{Ad} = \frac{1}{2}\varepsilon_0 E^2$$

$$\Rightarrow = \frac{1}{2}\varepsilon_0\left(\frac{V}{d}\right)^2 = \frac{1}{2}\varepsilon_0\frac{V^2}{d^2}$$

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3. **(C) Concept** An equipotential surface has a constant value of potential at all points on its surface.

The surface and interior of a charged conductor is equipotential. Therefore, the potential is same throughout the charged conductor.

4. **(B)** The common potential difference across two capacitors connected in parallel.

$$V_{eq} = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}$$

Here, potential of charged capacitor

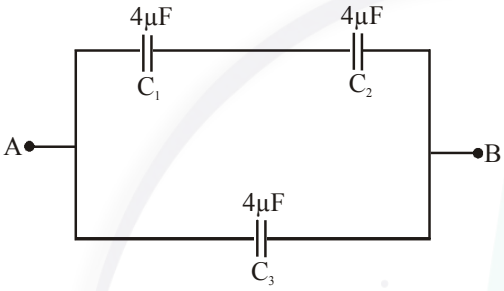
$V_1 = V.$

potential of uncharged capacitor $V_2 = 0$

$$\therefore \quad V_{eq} = \frac{C_1V}{C_1 + C_2}$$

5. **(A)** Given, $C_1 = C_2 = C_3 = 4\ \mu F$

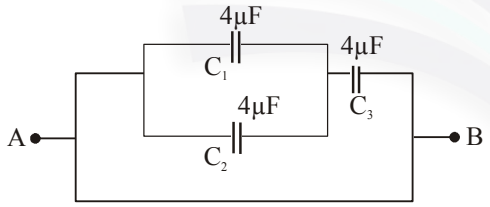
(A)



Here, C_1 and C_2 are in series and the combination of two is in parallel with C_3.

$$C_{net} = \frac{C_1C_2}{C_1 + C_2} + C_3 = \left(\frac{4\times4}{4+4}\right) + 4$$

(B) The corresponding network in shown in figure below



Here C_1 and C_2 are in parallel and this combination is in series with C_3.

So, $C_{net} = \frac{(C_1 + C_2)\times C_3}{(C_1 + C_2) + C_3} = \frac{(4+4)\times4}{(4+4)+4}$

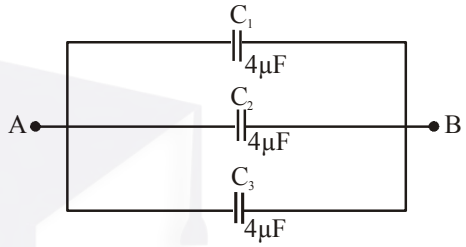
$$= \frac{32}{12} = \frac{8}{3}\mu F$$

(C) The corresponding network is shown below. All the three capacitors are in series.

So, $\frac{1}{C_{net}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{4} + \frac{1}{4} + \frac{1}{4} = \frac{3}{4}$

$$\therefore\ C = \frac{4}{3}\mu F$$

(D) The corresponding network is shown below



All of them are in parallel.

So, $C_{net} = C_1 + C_2 + C_3$

$= 4 + 4 + 4 = 12\ \mu F$

Thus, options **(A)** is correct.

6. **(A)** The charge flowing through C_4 is

$q_4 = C_4 \times V = 4CV$

The series combination of C_1, C_2 and C_3 gives

$$\frac{1}{C_{eq}} = \frac{1}{C} + \frac{1}{2C} + \frac{1}{3C}$$

$$= \frac{6+3+2}{6C} = \frac{11}{6C} \Rightarrow C_{eq} = \frac{6C}{11}$$

Charge flowing through capacitors C_1, C_2 and C_3 will be same as they are in series.

So q_1 flowing through C_1, C_2 and C_3 is given by

$$q_1 = C_{eq}V = \frac{11}{6C}\times V$$

Now, ratio of charge on C_4 and C_2 is given by,

$$\frac{q_1}{q_4} = \frac{4CV\times11}{6CV} = \frac{22}{3}$$

7. **(D)** If the battery is removed after charging, then the change stored in the capacitor remains constant.

q = constant

Change in capacitance,

$$C' = \frac{\varepsilon_0 A}{d'}$$

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As $d' > d$

Hence $C' < C$

As potential difference between the plates of capacitor is given by

$$V = \frac{q}{C}$$

So, for the new capacitor formed

$$V = \frac{q}{C}$$

As capacitance decreases, so potential difference increases.

Note : If the battery remains connected the charge stored increases. Also, the potential difference V becomes constant.

8. **(C)** The two condensers in the circuit are in parallel order, hence

$$C' = C + \frac{C}{2} = \frac{3C}{2}$$

The work done in charging the equivalent capacitor is stored in the form of potential energy.

Hence, $W = U = \frac{1}{2}CV^2$

So, fo the equivalent capacitor C′

$$= \frac{1}{2}\left(\frac{3C}{2}\right)V^2 \left(C' = \frac{3C}{2}\right) \quad = \frac{3}{4}CV^2$$

9. **(C)** In series arrangement charge on each plate of all the capacitors have same magnitude. The potential difference is distributed inversely in the ratio of capacitors, i.e.

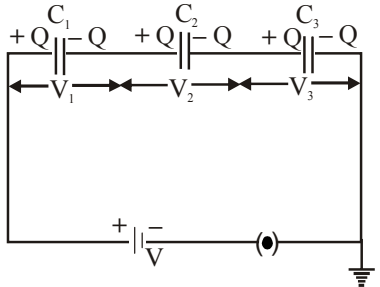
$V = V_1 + V_2 + V_3$ $[\because V_1 = V_2 = V_3 = V]$

Here, $V = 3V$

The equivalent capacitance C_s is given by

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \qquad [\because C_1 = C_2 = C_3 = C]$$

$$C_s = \frac{C}{3}$$



10. **(D)** **Case - I** When the capacitors are joined in series,

$$U_{series} = \frac{1}{2}\frac{C_1}{n_1}(4V)^2$$

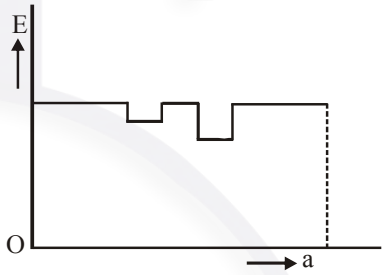
Case II When the capacitors are joined in parallel.

$$U_{parallel} = \frac{1}{2}(n_2C_2)V^2$$

Given, $U_{series} = U_{parallel}$

So, $\frac{1}{2}\frac{C_1}{n_1}(4V)^2 = \frac{1}{2}(n_2C_2)V^2 \Rightarrow C_2 = \frac{16C_1}{n_2n_1}$

11. **(C)** Graph **(C)** will be the right graph, the electric field inside the dielectrics will be less than the electric field outside the dielectrics. The electric field inside the dielectrics could not be zero.



As $K_2 > K_1$, the drop in electric field for K_2 dielectric must be more than K_1.

12. **(B)** Force between plates of parallel capacitor,

$$F = qE = q\left[\frac{\sigma}{2\varepsilon_0}\right]$$

$\because$ Surface charge density $\sigma = \frac{q}{A}$

$$\therefore \quad F = q\left[\frac{q}{2A\varepsilon_0}\right] \Rightarrow F = \frac{q^2}{2A\varepsilon_0}$$

So, net charge across a capacitor, $q = CV$

$$F = \frac{C^2V^2}{2A\varepsilon_0} \quad \left[C = \frac{A\varepsilon_0}{d}\right]$$

$$\Rightarrow \quad F = \frac{\left(\frac{A\varepsilon_0}{d}\right) \times CV^2}{2A\varepsilon_0} = \frac{CV^2}{2d}$$

13. **(D)** When a parallel plate air capacitor connected to a cell of emf V, then charge stored will be

$$q = CV \Rightarrow V = \frac{q}{C}$$

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Also energy stored is $U = \frac{1}{2}CV^2 = \frac{q^2}{2C}$

As the battery is disconnected from the capacitor the charge will not be destroyed. i.e. q′ = q with the introduction of dielectric in the gap of capacitor the new capacitance will be

$$C' = CK \Rightarrow V' = \frac{q}{C'} = \frac{q}{CK}$$

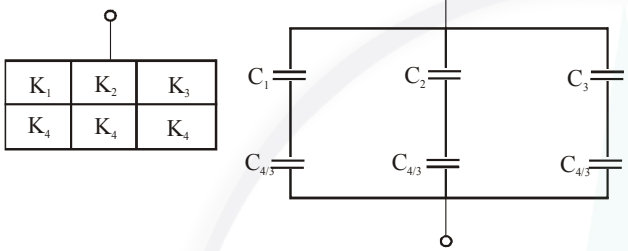
The new energy stored will be

$$U' = \frac{q^2}{2CK} \Rightarrow \Delta U = U' - U$$

$$= \frac{q^2}{2C}\left(\frac{1}{K} - 1\right) = \frac{1}{2}CV^2\left(\frac{1}{K} - 1\right)$$

Hence, option **(D)** is incorrect.

14. (*) Given capacitor is equivalent to capacitors K_1, K_2 and K_3 in parallel and part of K_4 in series with them.



$$\frac{1}{C_1} + \frac{3}{C_4} = \frac{3d}{2K_1\varepsilon_0 A} + \frac{3d}{2K_4\varepsilon_0 A} = \frac{3d}{2\varepsilon_0 A}\left[\frac{1}{K_1} + \frac{1}{K_4}\right]$$

$$\Rightarrow C_{eq} = \frac{K\varepsilon_0 A}{d}$$

$$= \frac{2\varepsilon_0 A}{3d}\left[\frac{K_1K_4}{K_1 + K_4} + \frac{K_2K_4}{K_2 + K_4} + \frac{K_3K_4}{K_3 + K_4}\right]$$

$$K = \frac{2}{3}\left[\frac{K_1K_4}{K_1 + K_4} + \frac{K_2K_4}{K_2 + K_4} + \frac{K_3K_4}{K_3 + K_4}\right]$$

No option is matching.

15. (A) For an AC circuit containing capacitor only, the phase difference between current and voltage will be $\frac{\pi}{2}$ (i.e. 90°)

In this case current is ahead of voltage by $\frac{\pi}{2}$.

Hence, power in this case is given by

$P = VI\cos\phi$

(ϕ = phase difference between voltage and current)

$P = VI\cos 90° = 0$

16. (C) Consider the given figure,

When the switch S is connected to point 1, then initial energy stored in the capacitor can be given as = $\frac{1}{2}(2\mu F) \times V^2$

When the switch S is connected to point 2, energy dissipated on connection across 8 μF will be

$$= \frac{1}{2}\left(\frac{C_1C_2}{C_1 + C_2}\right).V^2$$

$$= \frac{1}{2} \times \frac{2\mu F \times 8\mu F}{10\mu F} \times V^2$$

$$= \frac{1}{2} \times (1.6\mu F) \times V^2$$

Therefore, % loss of energy = $\frac{16}{2} \times 100 = 80\%$

17. (C) Net charge on one H-atom

$q = -e + e + \Delta e = \Delta e$

net electrostatic repulsive force between two H-atoms

$$F_r = \frac{Kq^2}{d^2} = \frac{K(\Delta e)^2}{d^2}$$

Similarly, net gravitational attractive force between two H-atoms $F_G = \frac{Gm_r^2}{d^2}$

It is given that

$$F_r - F_G = 0$$

$$\Rightarrow \frac{K(\Delta e)^2}{d^2} - \frac{Gm_r^2}{d^2} = 0 \Rightarrow (\Delta e)^2 = \frac{Gm_r^2}{K}$$

$$(\Delta e)^2 = \frac{(6.67 \times 10^{-11})(1.67 \times 10^{-27})^2}{9 \times 10^9}$$

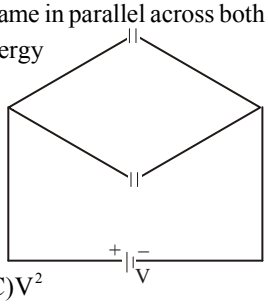
$$\Rightarrow \Delta e = 1.437 \times 10^{-37}\,C$$

18. (D) Thinking Process Energy stored in a system of capacitors

$$= \Sigma\frac{1}{2}CV^2$$

Also, potential drop remains same in parallel across both capacitors. Initially stored energy

$$U_1 = \frac{1}{2}CV^2$$



Finally, potential drop across each capacitor will be still V. So, finally stired energy

$$U_2 = \frac{1}{2}CV^2 + \frac{1}{2}CV^2 = \frac{1}{2}(2C)V^2$$

$$= 2\left(\frac{1}{2}CV^2\right) = 2U_1$$

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EXERCISE - 4

P-2 (AIIMS)

1. **(C)** Let m capacitors are joined in series and n such groups are joined in parallel.

So, $C = 8/m$ and $C_{equl.} = n \times \frac{8}{m} = 16$

or, $n = 2m$.

Potential of arrangement, $mV = 1000$

or, $m = \frac{1000}{250} = 4$ $\quad \therefore n = 2 \times 4 = 8.$

So, total number of capacitors required.

$= nm = 8 \times 4 = 32.$

2. **(A)** Each point of the sphere must be at the same potential and at any point interior to the sphere, the potential is same as that at the surface.

3. **(A)** 5 capacitors in parallel gives

$5 \times 2\ \mu F = 10\ \mu F.$

The 2 capacitors in series give 1 μF.

When they are connected in series, total capacitance will be $\frac{10 \times 1}{10+1} = \frac{10}{11}\ \mu F.$

4. **(D)** The potential energy is given by

$$U_P = \frac{1}{4\pi\varepsilon_0} \times \frac{q_1 q_2}{r}$$

$$= 9 \times 10^9 \times \frac{1 \times 10^{-6} \times 1 \times 10^{-6}}{1} = 9 \times 10^{-3}\ J$$

5 **(C)** The electric potential at any point (x, y, z) in space is given as $v = 6z^2$

Electric field $\vec{E} = -\vec{\nabla} V$

$$\Rightarrow \quad \vec{E} = -\left[\frac{\partial V}{\partial x}\hat{i} + \frac{\partial V}{\partial y}\hat{j} + \frac{\partial V}{\partial z}\hat{k}\right] = -12z\hat{k}$$

$\therefore \quad E(2, -1, 3) = -12 \times 3 = -36$

6. **(A)** The given capacitor can be viewed as a parallel combination of two capacitors C_1 and C_2 where

$$C_1 = \frac{\varepsilon_0 K_1 A/2}{d}; \qquad C_2 = \frac{\varepsilon_0 K_2 A/2}{d};$$

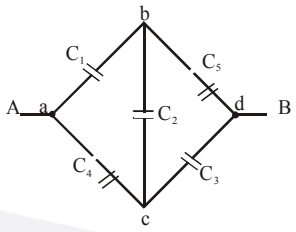
where d is the separation between the plates,

$\therefore$ The effective capacitance $C = C_1 + C_2$

$$= \frac{\varepsilon_0 K_1 A/2}{d} + \frac{\varepsilon_0 K_2 A/2}{d} = \frac{\varepsilon_0 A}{d}\left(\frac{K_1 + K_2}{2}\right)$$

7. **(D)** Since the potential at each point of an equipotential surface is the same, the potential does not change while we move a unit positive charge from one point to another. Therefore work done in the process is zero.

8. **(C)**



Capacitance of capacitors $C_1, C_3, C_4, C_5 = 4\ \mu F$ each and capacitance of capacitor $C_2 = 10\ \mu F$. If a battery is applied across A and B, the points b and c will be at the same potential (since $C_1 = C_4 = C_3 = C_5 = 4\ \mu F$). Therefore no charge flows through C_2.

We have the capacitors C_1 and C_5 in series.

Therefore their equivalent capacitance,

$$C' = \frac{C_1 \times C_5}{C_1 + C_5} = \frac{4 \times 4}{4+4} = 2\mu F.$$

Similarly, C_4 and C_3 are in series. Therefore their equivalent capacitance,

$$C'' = \frac{C_3 \times C_4}{C_3 + C_4} = \frac{4 \times 4}{4+4} = 2\mu F.$$

Now C' and C'' are in parallel. Therefore effective capacitance between A and B = C' + C''

$= 2 + 2 = 4\ \mu F$

9. **(B)** Surface density of charge $= \frac{\text{Charge}}{\text{area of surface}}$

$$\therefore \quad \sigma_1 = \frac{C_1 V_1}{4\pi r_1^2}, \sigma_2 = \frac{C_2 V_2}{4\pi r_2^2}$$

The spheres are in contact. They therefore acquire the same potential V

$$\therefore \quad \frac{\sigma_1}{\sigma_2} = \frac{C_1}{r_1^2} \times \frac{r_2^2}{C_2} = \frac{C_1}{C_2} \times \left(\frac{r_2}{r_1}\right)^2 = \left(\frac{r_1}{r_2}\right)\left(\frac{r_2}{r_1}\right)^2$$

or $\quad \frac{\sigma_1}{\sigma_2} = \frac{r_2}{r_1} = \frac{20}{10} = \frac{2}{1}$

10. **(D)** According to Gauss's law, the total electric flux through a closed surface is given by

$$\phi = \oint_S \vec{E}.d\vec{S} = \frac{Q}{\varepsilon_0}$$

where Q is the total charge enclosed by the surface.

The total charge enclosed by the given surface is

$Q = +q - q = 0.$ $\quad \therefore$ The total flux $\phi = 0.$

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11. (A) Any surface which has same electrostatic potential at every point is called an equipotential surface. Electric field is always perpendicular to an equipotential surface. Therefore x-direction is perpendicular only yz plane.

12. (B) The energy stored in capacitor $= \frac{1}{2}CV^2$

$= \frac{1}{2} \times 40 \times 10^{-6} \times (3000)^2$

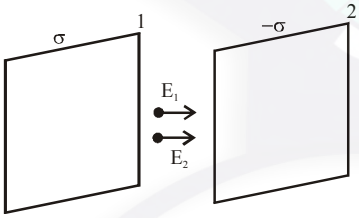
$= 20 \times 9 \times 10^6 \times 10^{-6} = 180$ J.

The power delivered in 2 ms is

$= \frac{180}{2 \times 10^{-3}} = 90 \times 10^3$ W $= 90$ kW.

13. (C) Electric field between the plates is

$= \frac{\sigma}{\varepsilon_0}$ volt / meter.



14. (C) $|Q_B| > |Q_A|$ (given). Inside the shell B, the potential is a constant and negative.

But V_A inside r_A is positive and greater than that of B because $r_A < r_B$. Upto r_A, one as hence positive potential. Beyond r_A, $V_A \propto (1/r)$, this is $> V_B$, one gets the course μ 1/r. At B, the negative potential is more therefore the potential line is still negative. **(C)** explains all these factors.

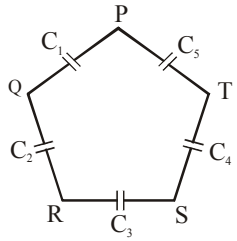
15. (B) Work done $= \frac{1}{2} \times$ charge $\times$ potential difference

$W = \frac{1}{2} \times 4 \times (4 \times 10^6 - 0) = 8 \times 10^6$ J.

Power of the lightening strike, $P = \frac{W}{t}$

$= \frac{8 \times 10^6}{100 \times 10^{-3}} = 80$ MW.

16. (C) Between the points P and Q, a capacitor C_1 and series combination of C_2, C_3, C_4, C_5 are connected in parallel.



$\therefore \quad \frac{1}{C_s} = \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4} + \frac{1}{C_5}$

$= \frac{1}{C} + \frac{1}{C} + \frac{1}{C} + \frac{1}{C} = \frac{4}{C}$ or, $C_s = C/4$

The equivalent capacitance between P and Q is

$C' = C_1 + C_s = C + \frac{4}{C} = \frac{5C}{4}$.

Between the points P and R a series combination of C_1, C_2 and a series combination of C_3, C_4, C_5 are connected in parallel.

$\therefore \quad \frac{1}{C_s'} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{C} + \frac{1}{C} = \frac{2}{C}$ or, $C_s' = \frac{C}{2}$

$\frac{1}{C_s''} = \frac{1}{C_3} + \frac{1}{C_4} + \frac{1}{C_5} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C} = \frac{3}{C}$, $C_s'' = \frac{C}{3}$.

The equivalent capacitance between P and R is

$C'' = C_s' + C_s'' = \frac{C}{2} + \frac{C}{3} = \frac{5C}{6}$

$\therefore \quad \frac{C''}{C'} = \frac{(5C/6)}{(5C/4)} = \frac{4}{6} = \frac{2}{3}$.

17. (A) The capacitances of two are $C_1 = 4\pi\varepsilon_0 R$ and $C_2 = 4\pi\varepsilon_0(2R)$

Initial energy $= E_1 = \frac{Q^2}{2C_1}$

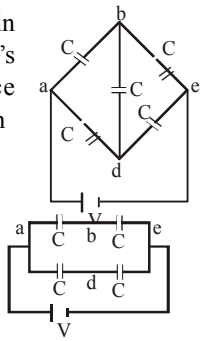
Final energy $= E_f = \frac{Q^2}{2C_2}$

Heat produced $= E_i - E_f$

$= \frac{Q^2}{2}\left[\frac{1}{4\pi\varepsilon_0 R} - \frac{1}{2 \times 4\pi\varepsilon_0 R}\right] = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Q^2}{2R}\left[1 - \frac{1}{2}\right]$

$= \frac{1}{4\pi\varepsilon_0} \cdot \frac{Q^2}{4R}$

18. (A) Network is redrawn as shown in figure. This is a balanced Wheatstone's network. Equivalent capacitance $C_{eq} = C$ Charge on capacitor between the terminals a and b



$\frac{Q}{2} = \frac{CV}{2}$

Energy stored in that capacitor

$= \frac{1\left(\frac{Q}{2}\right)^2}{2C} = \frac{Q^2}{8C} = \frac{C^2V^2}{8C} = \frac{CV^2}{8}$

Given : $C = 1$ μF, $V = 10$ V

$= \frac{(1 \times 10^{-6}) \times 10^2}{8} = \frac{100}{8} \times 10^{-6} = 12.5$ μJ

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19. (A) Capacitors C_1 and C_2 are in parallel, their equivalent capacitance is in series with capacitor C_3. Hence, the equivalent capacitance of the given circuit is

$$C_{eq} = \frac{(C_1 + C_2)C_3}{C_1 + C_2 + C_3}$$

Charge on capacitor C3 is

$$Q = V C_{eq}$$

$$= \frac{V(C_1 + C_2)C_3}{C_1 + C_2 + C_3}$$

Voltage across C_3 is

$$= \frac{Q}{C_3} = \frac{V(C_1 + C_2)}{C_1 + C_2 + C_3}$$

20. (C) $\vec{r}_1 = \sqrt{2}\hat{i} + \sqrt{2}\hat{j}$

$$|\vec{r}_1| = r_1 = \sqrt{\left(\sqrt{2}\right)^2 + \left(\sqrt{2}\right)^2} = 2$$

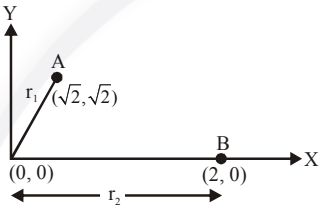
$\vec{r}_2 = 2\hat{i} + 0\hat{j}$

or $|\vec{r}_2| = r_2 = 2$

Potential at point A is

$$V_A = \frac{1q}{4\pi\varepsilon_0 r_1}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{10^{-3}\times10^{-6}}{2}$$

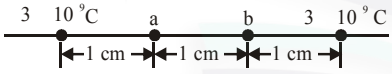


Potential at point B is

$$V_B = \frac{1}{4\pi\varepsilon_0}\frac{q}{r_2} = \frac{1}{4\pi\varepsilon_0}\frac{10^{-3}\times10^{-6}}{2}$$

$\therefore \quad V_A - V_B = 0.$

21. (B)



According to conservation of energy, we get

$K_a + U_a = K_b + U_b.$

Here, $K_a = 0$ and the potential energies are

$U_a = q'V_a$ and $U_b = q'V_b.$

$\therefore \quad 0 + q'V_a = \frac{1}{2}mv^2 + q'V_b.$

or $\quad v = \sqrt{\frac{2q'(V_a - V_b)}{m}}$

$V_a = (9.0\times10^9\ Nm^2C^{-2})$

$$\left(\frac{3\times10^{-9}\,C}{0.01m} + \frac{-3\times10^{-9}\,C}{0.02\,m}\right) = 1350\,V$$

$V_b = (9.0\times10^9\ Nm^2C^{-2})$

$$\left(\frac{3\times10^{-9}\,C}{0.02m} + \frac{-3\times10^{-9}\,C}{0.01m}\right) = -1350\,V$$

$$\therefore \quad \sqrt{\frac{2(2\times10^{-9}\,C)(2700\,V)}{5\times10^{-3}\ kg}} = 4.65\times10^{-2}\ ms^{-1}$$

$$= 4.65\ cm\ s^{-1}$$

22. (A) Energy stored in capacitor of capacitance C with voltage V is, $U = \frac{1}{2}CV^2$

but $U = \frac{\varepsilon_0 A}{d}, V = Ed$

where A is the area of capacitor plate and d is the distance of separation and E is the electric field.

$$\therefore \quad U = \frac{1}{2}\frac{\varepsilon_0 A}{d}E^2d^2 = \frac{1}{2}\varepsilon_0 E^2 Ad$$

23. (B) As $\frac{\varepsilon_0 A}{d} = 4\pi\varepsilon_0 R$

$$d = \frac{A}{4\pi R} = \frac{\pi(6/2)^2}{4\pi(100)} = 2.25\times10^{-2}\,cm$$

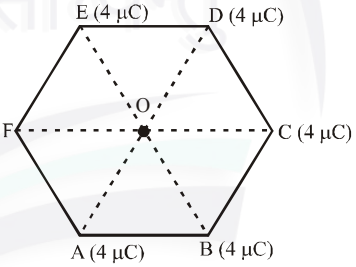
$= 2.25\times10^{-4}\,m$

24. (A) As $E = \frac{F}{q} = \frac{3000\ N}{3\ C} = 1000\ NC^{-1}.$

$dr = 1\ cm = 10^{-2}\,m$

$dV = E(dr) = 1000\times10^{-2} = 10\,V$

25. (A)



As shown in the figure, O is the centre of hexagon ABCDEF of each side 8 cm. As it is a regular hexagon OAB, OBC, etc are equilateral triangles.

$\therefore \quad OA = OB = OC = OD = OE = OF = 8\,cm$

$= 8\times10^{-2}\,m$

The potential at O is

$$V = 6\times\frac{q}{4\pi\varepsilon_0 r}$$

$$= \frac{6\times9\times10^9\times4\times10^{-6}}{8\times10^{-2}} = 2.7\times10^6\ V$$

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25. **(C)** Electric potential of earth is taken as zero, because the capacitance of earth is taken infinite.

27. **(D)** If electric field is used for detecting the electron beam, then very high voltage will have to be applied or very long tube will have to be taken.

28. **(A)**

MOCK TEST

1. **(D)**

(i) $E = \frac{2Q}{2A\epsilon_0} + \frac{Q}{2A\epsilon_0}$

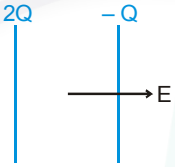
$\Rightarrow E = \frac{3Q}{2A\epsilon_0}$

$E = \frac{3}{2}\frac{Q}{Cd} \Rightarrow E_d = \frac{3Q}{2C} = V$

(ii) $F = EQ/2$

$F = \left(\frac{2Q}{2A\epsilon_0}\right) \times \frac{(-Q)}{1} = -\frac{Q^2}{A\epsilon_0}$

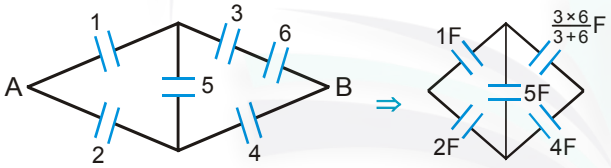
$F = \frac{Q^2}{A\epsilon_0}$

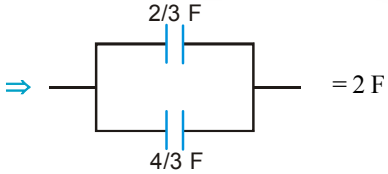


(iii) Energy $= \frac{1}{2}\epsilon_0 E_2 Ad$

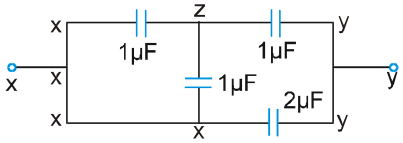
$= \frac{1}{2}\epsilon_0\left(\frac{3Q}{2Cd}\right)^2 Ad = \frac{9}{8}\frac{Q^2}{C}$

2. **(B)** Equivalent circuit is

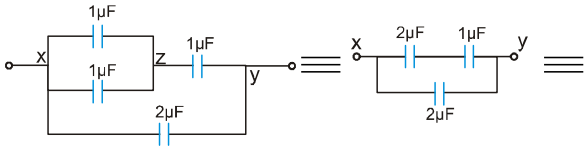


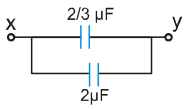


3. **(C)**



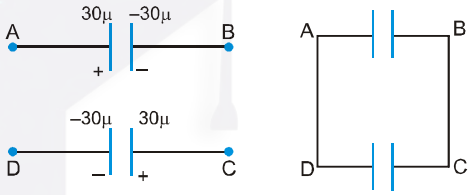
Rearrange the circuit





$\Rightarrow C_{eq} = \frac{8}{3}\mu F$

4. **(D)** $V = \frac{Q_1 + Q_2}{C_1 + C_2} = 0$

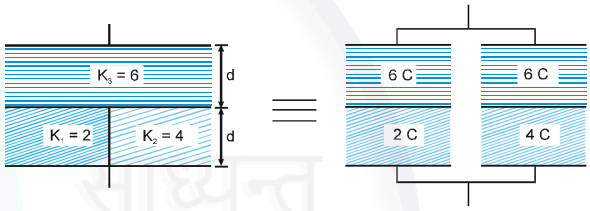


Final potential difference = zero

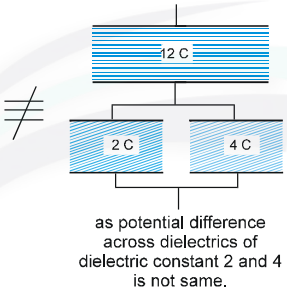
Final charge = Zero

Charge flow 30 μc from A to D

5. **(A)**



(right)



as potential difference across dielectrics of dielectric constant 2 and 4 is not same.

The equivalent capacitance $C_{eq} = \frac{2C \times 6C}{2C + 6C} + \frac{6C \times 4C}{6C + 4C}$

$= 3.9\,C$

6. **(D)** Let the capacitance before insertion of dielectric be C and the resistance be R.

$\therefore \quad q = q_0\, e^{-\frac{t}{RC}} \qquad \text{and } i = \frac{q/C}{R} = \frac{q}{RC}$

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∵ Just after insertion of dielectric the capacitance increases.

∴ The charge just after insertion of dielectric remains same, but the current decreases.

⇒ **(A)** and **(B)** are false

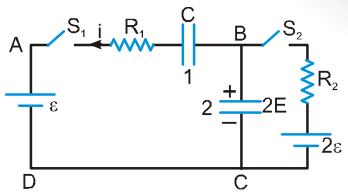
The energy stored in capacitor is $\frac{q^2}{2C}$, hence energy decreases

⇒ **(C)** is false

The time constant is RC and hence increases.

⇒ **(D)** is true

7. **(B)**



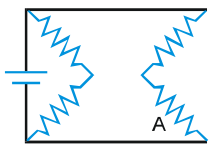
just before S_1 is closed the potential difference across capacitor 2 is 2E.

just after S_1 is closed the potential difference across capacitors 1 and 2 are 0 and 2E respectively. Applying KVL to loop ABCD immediately after S_1 is closed.

$$E = -iR_1 + 0 + 2E$$

or $i = \frac{E}{R_1}$ towards left

8. **(D)** This is a DC circuit because the battery is the only source of voltage. Hence the capacitors behave like open circuits. An equivalent circuit is then two parallel sets of two identical series resistors, see figure. The voltage drop across each parallel branch must be the battery voltage of 3V. Since the resistors are identical there is an equal voltage drop of 1.5V across each resistor. In particular there is a drop of 1.5 V across resistor A.



9. **(A)** Rate of change of energy = V.I.

Initially V = 0 hence VI = 0

finally I = 0 hence VI = 0

∴ first increases then decreases

10. **(A)** As the key is connected to 1 and 2 frequently and at equal intervals, the two emf's E_1 & E_2 behave as d.c. sources in continuous contact.

The potential due to the two cells is :

$$V = \left(\frac{E_1R_2 + E_2R_1}{R_1 + R_2}\right)$$

Hence the charge on the capacitor is q = CV

$$= \frac{(E_1R_2 + E_2R_1)C}{(R_1 + R_2)}$$

11. **(C)** $Ui = \frac{1}{2}C\varepsilon_1^2$

$Uf = \frac{1}{2}C\varepsilon_2^2$ $\quad \Delta U = \frac{1}{2}C(\varepsilon_2^2 - \varepsilon_1^2)$

$Qin = +C\varepsilon_1$; $\quad Qfinal = -C\varepsilon_2$

$\Delta Q = c(\varepsilon_1 + \varepsilon_2)$

work done by battery $W_b = E_2 . \Delta Q$

$= C(\varepsilon_2 + \varepsilon_1)\varepsilon_2$

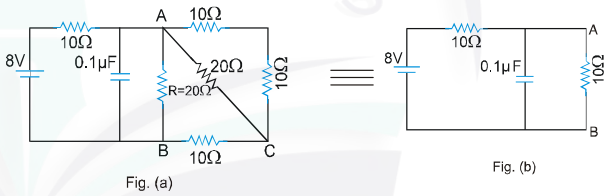
Heat generated $= W_b - \Delta U$

$= c\varepsilon_2^2 + c\varepsilon_1\varepsilon_2 - \frac{1}{2}C(\varepsilon_2^2 - \varepsilon_1^2)$

$= \frac{1}{2}C(\varepsilon_2^2 + \varepsilon_1^2 + 2\varepsilon_1\varepsilon_2)$

$= \frac{1}{2}C(\varepsilon_1 + \varepsilon_2)^2$

12. **(A)** The equivalent circuit is as shown in figure (b).



In the steady state the potential difference across AB is 4 volts.

∴ Charge on capacitor in steady state is

$q = CV = 0.4\ \mu C$

Current through resistor R is $I = \frac{V}{R} = \frac{4}{20} = 0.2\ A$

13. **(D)** $U = \frac{1}{2}C_{eq}V^2 \Rightarrow C_1 = \frac{k\epsilon_0 A}{d/2} = \frac{2\epsilon_0 A}{(d/2)}$

$C_{eq} = \frac{C_1C_2}{C_1 + C_2} \Rightarrow C_2 = \frac{\epsilon_0 A}{d/2}$;

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$$C_{eq} = \frac{\left(2\frac{\epsilon_0 A}{d/2}\right)\times\frac{\epsilon_0 A}{d/2}}{3\frac{\epsilon_0 A}{d/2}} = \frac{4}{3}\frac{\epsilon_0 A}{d}$$

$$U = \frac{1}{2}\left(\frac{4}{3}\frac{\epsilon_0 A}{d}\right)V^2 = \frac{2}{3}\left(\frac{\epsilon_0 A}{d}\right)V^2$$

14. (B) Method I

Force between plates

$$F = \frac{Q^2}{2A\epsilon_0} = \frac{\left(\frac{\epsilon_0 A}{x}V\right)^2}{2A\epsilon_0} = \frac{\epsilon_0 AV^2}{2x^2}$$

where x is separation between plates

$dW = F\,dx$

$$W = \int_d^{2d}\frac{\epsilon_0 AV^2}{2x^2}dx = \left[\frac{\epsilon_0 AV^2}{4x}\right]_d^{2d} = \frac{CV^2}{4} = 200\,\mu J$$

Method II

$U_\ell + W_B + W_{ext} = U_f + \text{loss}$

Process is slow so energy loss is zero work done by battery $= W_B = Q_E$

$Q = Q_f - Q_i = 20 - 40 = -20$

$W_B = -20\times 20$

$$\frac{1}{2}2\times 202 - 20\times 20 + W_{ext} = \frac{1}{2}1\times 202 + 0$$

$W_{ext} = 200\,\mu J$

15. (A) Force on metal plate S due to electrostatic attraction by plate T is $F = \frac{Q^2}{2A\epsilon_0}$

Force exerted on plate S by spring is = mg

In equilibrium $\Rightarrow \frac{Q^2}{2A\epsilon_0} = mg$ or

$Q = \sqrt{2mgA\epsilon_0}$

16. (C) Ceff $= \frac{\varepsilon_0 A}{d}$ since effective capacitance between plates A and E is zero.

$\therefore U = \frac{1}{2}CV^2 = \frac{\varepsilon_0 A}{2d}V^2$

17. (D) When switch S_2 is closed, due to symmetry no charge will flow through S_2.

Alternate solution :

After closing and before closing the switch there is no change in potential of any point.

18. (D) $I_{max} = \frac{2\varepsilon}{R}$ at $t = 0$

$I = \frac{\varepsilon}{R}$ at $t = \infty$

so charge on the capacitor is $C\varepsilon$, when current is 50% of maximum current.

19. (D) In the given cross-section which lies inside the capacitor plates, no charge flows. hence the required charge is 0.

20. (C) Energy density $= \frac{1}{2}k\epsilon_0 E^2$

Since the cell remains connected, V remains unchanged (and therefore E remains unchanged)

$\Rightarrow$ Energy density will increase k times.

21. (C) Charge on outer surface of C = – charge on inner surface of C

Hence potential at B due to charge on conductor C = 0

charge on outer surface of dielectric = – charge on inner surface of dielectric

$\therefore$ Potential at B due to charge on dielectric = 0

Potential at B due to charge on A $= \frac{Q}{4\pi\epsilon_0 b}$

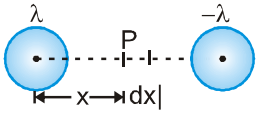
$\therefore$ net potential at B $= \frac{Q}{4\pi\epsilon_0 b}$.

22. (C) Let σ be the charge density of conducting plate and V be the volume of either dielectric

$$\therefore \frac{U_1}{U_2} = \frac{\left(\frac{1}{2}K_1\epsilon_0 E_1^2\right)V}{\left(\frac{1}{2}K_2\epsilon_0 E_2^2\right)V} = \frac{K_1}{K_2}\frac{\left(\frac{\sigma}{K_1\epsilon_0}\right)^2}{\left(\frac{\sigma}{K_2\epsilon_0}\right)^2} = \frac{K_2}{K_1}$$

23. (C) Let us give equal and opposite charges to two wires so that they would have linear charge density as $+\lambda$ and $-\lambda$.

Electric field at point P,



$$E = \frac{\lambda}{2\pi\epsilon_0 x} + \frac{\lambda}{2\pi\epsilon_0(\eta a - x)}$$

$$\int dV = -\int E\,dx = -\int_a^{\eta a - a} E\,dx$$

where a is radius of wire $\Rightarrow C = \frac{\lambda}{|V|} = \frac{\pi\epsilon_0}{\ln\eta}$

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24. (D) The resultant force acting per unit area of each plate can be written as $F = F_0 - F'$.

where F_0 is the force acting on unit area of plate due to other plate and F' is the force acting on unit area of plate from the dielectric.

$$\text{Now } F = \frac{\frac{q^2}{2\varepsilon_0\varepsilon A}}{A} = \frac{\left(\frac{\varepsilon_0\varepsilon A}{d}V\right)^2}{2\varepsilon_0\varepsilon A}\times\frac{1}{A} \Rightarrow F = \frac{\varepsilon_0\varepsilon V^2}{2d^2}$$

$$\text{Also } F_0 = F\times\varepsilon$$

$$\text{So } F' = F_0 - \frac{F_0}{\varepsilon} = F_0\left(1-\frac{1}{\varepsilon}\right) = \varepsilon F\left(1-\frac{1}{\varepsilon}\right) = \frac{\varepsilon(\varepsilon-1)\varepsilon_0 V^2}{2d^2}$$

25. A → P, R ; B → Q, S ; C → P, R ; D → T

(A) By inserting dielectric slab, capacitance of 1 increases there by increasing charge on capacitor 2 as more charge is flown through the battery. Energy stored in capacitor also increases.

(B) By increasing separation between the plates, capacitor C_1 decreases. Charge on C_2 also decreases.

(C) By shorting capacitor-1, only capacitor 2 remains in the circuit. Potential difference across C_2 increases thereby increasing charge on 2 as well as energy stored.

(D) By earthing plate of capacitor 1 potentials will change but there will be no potential difference change, making no overall change in the circuit.

26. A → P ; B → R ; C → Q ; D → P

The initial charge on capacitor $= CV_i = 1\times 2\ \mu C = 2\ \mu C$

The final charge on capacitor $= CV_f = 1\times 4\ \mu C = 4\ \mu C$

$\therefore$ Net charge crossing the cell of emf 4V is

$q_f - q_i = 4 - 2 = 2\ \mu C$

The magnitude of work done by cell of emf 4V is

$W = (q_f - q_i)\,4 = 8\ \mu J$

The gain in potential energy of capacitor is

$$\Delta U = \frac{1}{2}C(V_f^2 - V_i^2) = \frac{1}{2}\,1\times[42-22]\ \mu J = 6\ \mu J$$

Net heat produced in circuit is

$\Delta H = W - \Delta U = 8 - 6 = 2\ \mu J$

27. (D)

If potential difference across an isolated charged capacitor is doubled by doubling separation between plates, the energy stored is capacitor from $U = \frac{Q^2}{2C}$ becomes double of previous value. Hence statement–1 is false.

28. (D)

Let the electric field in region I and II be E_1 and E_2. The potential difference across left half capacitor and right half capacitor is same.

Therefore $E_1 d = E_2 d$ where d = inter planar gap.

$\therefore \quad E_1 = E_2$

Hence statement – 1 is false, statement – 2 is correct by definition.

29. (D)

The electrostatic force on metal of capacitor is

$= \text{pressure} \times \text{area of plate} = \frac{\sigma^2}{2\epsilon_0}A$

σ = charge per unit area on plate.

Since charge on metal plate of an "isolated" capacitor does not change, force on metal plate remains same.

Electric field decreases due to induced charges in dielectric, but this does not effect the charge distribution on isolated metal plate.

30. (D)

The battery energizes the circuit and maintains the flow of electron from positive plate of capacitor to positive terminal of battery through wires and from wires to negative plate on other side.

No transfer of charge takes place within the plates in spite of having the electric field in between the plates.

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CHAPTER 03

CURRENT ELECTRICITY

"Electricity is really just organized lightning"

"GEORGE CARLIN"

INTRODUCTION

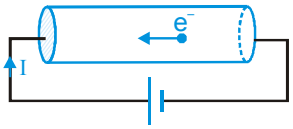
In electrostatics, our discussion of electric phenomena has been focused on charges at rest. In the previous chapter, we treated the concept of electric potential, which is measured in volt. Now we will see that this voltage acts like an "electrical pressure" that can produces a flow of charge or current, which is measured in ampere (or simply, amp and abbreviated as A) and that the resistance that restrains this flow is measured in ohm (Ω).

Example of electric currents about and involve many professions. Meteorologists are concerned with lightning and with the less dramatic slow flow of charge through the atmosphere. Biologists, physiologists, and engineers working in medical technology are concerned with the nerve currents that control muscles and especially with how those currents can be reestablished after spinal cord injuries. Electrical engineers are concerned with countless electrical systems, such as power systems, lightning protection systems, information storage systems, and music systems. Space engineers monitor and study the flow of charged particles from our Sun because that flow can wipe out telecommunication systems in orbit and even power transmission systems on the ground.

In this chapter we discuss the basic physics of electric currents and why they can be established in some materials but not in others. We begin with the meaning of electric current.

ELECTRIC CURRENT

Electric charges in motion constitute an electric current. Any medium having practically free electric charges, free to migrate is a conductor of electricity. The electric charge flows from higher potential energy state to lower potential energy state.



Positive charge flows from higher to lower potential and negative charge flows from lower to higher. Metals such as gold, silver, copper, aluminium etc. are good conductors. When charge flows in a conductor from one place to the other, then the rate of flow of charge is called electric current (I). When there is a transfer of charge from one point to other point in a conductor, we say that there is an electric current through the area. If the moving charges are positive, the current is in the direction of motion of charge. If they are negative the current is opposite to the direction of motion. If a charge ΔQ crosses an area in time Δt then the average electric current through the area, during this time as

(a) Average current $I_{av} = \frac{\Delta Q}{\Delta t}$

(b) Instantaneous current $I = \underset{\Delta t \to 0}{\text{Lim}} \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt}$

CLASSIFICATION OF MATERIALS ACCORDING TO CONDUCTIVITY

(i) Conductor

In some materials, the outer electrons of each atoms or molecules are only weakly bound to it. These electrons are almost free to move throughout the body of the material and are called free electrons. They are also known as conduction electrons. When such a material is placed in an electric field, the free electrons move in a direction opposite to the field. Such materials are called conductors.

(ii) Insulator

Another class of materials is called insulators in which all the electrons are tightly bound to their respective atoms or molecules. Effectively, there are no free electrons. When such a material is placed in an electric field, the electrons may slightly shift opposite to the field but they can't leave their parent atoms or molecules and hence can't move through long distances. Such materials are also called dielectrics.

(iii) Semiconductor

In semiconductors, the behaviour is like an insulator at low levels of temperature. But at higher temperatures, a small number of electrons are able to free themselves and they respond to the applied electric field. As the number of free electrons in a semiconductor is much smaller than that in a conductor, its behaviour is in between a conductor and an insulator and hence, the name semiconductor. A freed electron in a semiconductor leaves a vacancy in its normal bound position. These vacancies also help in conduction.

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(i) Current is a fundamental quantity with dimension $[M^0L^0T^0A^1]$

(ii) Current is a scalar quantity with its SI unit **ampere.**

Ampere : The current through a conductor is said to be one ampere if one coulomb of charge is flowing per second through a cross–section of wire.

(iii) The conventional direction of current is the direction of flow of positive charge or applied field. It is opposite to direction of flow of negatively charged electrons.



(iv) The conductor remains uncharged when current flows through it because the charge entering at one end per second is equal to charge leaving the other end per second.

(v) For a given conductor current does not change with change in its cross–section because current is simply rate of flow of charge.

(vi) If n particles each having a charge q pass per second per unit area then current associated with cross–sectional area A is $I = \frac{\Delta q}{\Delta t} = nqA$.

(vii) If there are n particles per unit volume each having a charge q and moving with velocity v then current through cross–sectional area A is $I = \frac{\Delta q}{\Delta t} = nqvA$

(viii) If a charge q is moving in a circle of radius r with speed v then its time period is $T = 2\pi r/v$. The equivalent current $I = \frac{q}{T} = \frac{qv}{2\pi r}$.

Behavior of conductor in absence of applied potential difference :

In absence of applied potential difference electrons have random motion. The average displacement and average velocity is zero. There is no flow of current due to thermal motion of free electrons in a conductor.

The free electrons present in a conductor gain energy from temperature of surrounding and move randomly in the conductor.

The speed gained by virtue of temperature is called as thermal speed of an electron $\frac{1}{2}mv_{rms}^2 = \frac{3}{2}kT$

So thermal speed $v_{rms} = \sqrt{\frac{3kT}{m}}$ where m is mass of electron

At room temperature T = 300 K, $v_{rms} = 10^5$ m/s

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(a) Mean free path λ : $(\lambda \sim 10\text{Å})$, $\lambda = \dfrac{\text{total distance travelled}}{\text{number of collisions}}$

(b) Relaxation time : The time taken by an electron between two successive collisions is called as relaxation time τ : $(\tau \sim 10^{-14}\text{s})$, Relaxation time : $\tau = \dfrac{\text{total time taken}}{\text{number of collisions}}$

Behavior of conductor in presence of applied potential difference :

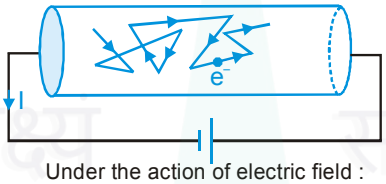
When two ends of a conductors are joined to a battery then one end is at higher potential and another at lower potential. This produces an electric field inside the conductor from point of higher to lower potential $E = \dfrac{V}{L}$ where V = emf of the battery, L = length of the conductor.

The field exerts an electric force on free electrons causing acceleration of each electron.

Acceleration of electron $\vec{a} = \dfrac{\vec{F}}{m} = \dfrac{-e\vec{E}}{m}$

DRIFT VELOCITY

Drift velocity is defined as the velocity with which the free electrons get drifted towards the positive terminal under the effect of the applied external electric field. In addition to its thermal velocity, due to acceleration given by applied electric field, the electron acquires a velocity component in a direction opposite to the direction of the electric field. The gain in velocity due to the applied field is very small and is lost in the next collision.



Under the action of electric field :
Random motion of an electron
with superimposed drift

At any given time, an electron has a velocity $\vec{v}_1 = \vec{u}_1 + \vec{a}\tau_1$, where $\vec{u}_1$ = the thermal velocity and

$\vec{a}\tau_1$ = the velocity acquired by the electron under the influence of the applied electric field.

τ_1 = the time that has elapsed since the last collision. Similarly, the velocities of the other electrons are

$$\vec{v}_2 = \vec{u}_2 + \vec{a}\tau_2, \vec{v}_3 = \vec{u}_3 + \vec{a}\tau_3, \ldots \vec{v}_N = \vec{u}_N + \vec{a}\tau_N .$$

The average velocity of all the free electrons in the conductor is equal to the drift velocity $\vec{v}_d$ of the free electrons

$$\vec{v}_d = \frac{\vec{v}_1 + \vec{v}_2 + \vec{v}_3 + \ldots \vec{v}_N}{N} = \frac{(u_1 + \vec{a}\tau_1) + (\vec{u}_2 + \vec{a}\tau_2) + \ldots + (\vec{u}_N + \vec{a}\tau_N)}{N} = \frac{(\vec{u}_1 + \vec{u}_2 + \ldots + \vec{u}_N)}{N} + \vec{a}\left(\frac{\tau_1 + \tau_2 + \ldots + \tau_N}{N}\right)$$

$$\because \frac{\vec{u}_1 + \vec{u}_2 + \ldots + \vec{u}_N}{N} = 0 \quad \therefore \vec{v}_d = \vec{a}\left(\frac{\tau_1 + \tau_2 + \ldots + \tau_N}{N}\right) \Rightarrow \vec{v}_d = \vec{a}\tau = -\frac{e\vec{E}}{m}\tau$$

Note : Order of drift velocity is 10^{-4} m/s.

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Relation between current and drift velocity :

Let n= number density of free electrons and A= area of cross–section of conductor.

Number of free electrons in conductor of length L = nAL, Total charge on these free electrons $\Delta q = neAL$

Time taken by drifting electrons to cross conductor $\Delta t = \frac{L}{v_d}$ $\therefore$ current $I = \frac{\Delta q}{\Delta t} = neAL\left(\frac{v_d}{L}\right) = neAv_d$

Ex. Find free electrons per unit volume in a metallic wire of density 10^4 kg/m^3, atomic mass number 100 and number of free electron per atom is one.

Sol. Number of free charge particle per unit volume (n) $= \frac{\text{total free charge particle}}{\text{total volume}}$

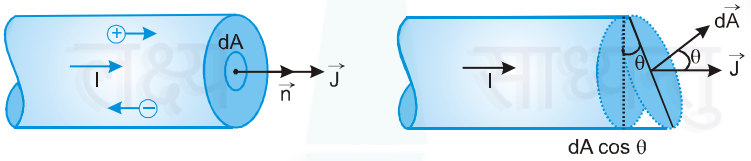
$\therefore$ No. of free electron per atom means total free electrons = total number of atoms= $\frac{N_A}{M_W} \times M$

$$\text{So } n = \frac{\frac{N_A}{M_W} \times M}{V} = \frac{N_A}{M_W} \times d = \frac{6.023 \times 10^{23} \times 10^4}{100 \times 10^{-3}} = 6.023 \times 10^{28}$$

CURRENT DENSITY (J)

Current is a macroscopic quantity and deals with the overall rate of flow of charge through a section. To specify the current with direction in the microscopic level at a point, the term current density is introduced. Current density at any point inside a conductor is defined as a vector having magnitude equal to current per unit area surrounding that point. Remember area is normal to the direction of charge flow (or current passes) through that point.

(a) Current density at point P is given by $\vec{J} = \frac{dI}{dA}\vec{n}$



(b) If the cross–sectional area is not normal to the current, but makes an angle θ with the direction of current then

$$J = \frac{dI}{dA\cos\theta} \Rightarrow dI = JdA\cos\theta = \vec{J}.d\vec{A} \Rightarrow I = \int \vec{J} \cdot \overrightarrow{dA}$$

(c) Current density $\vec{J}$ is a vector quantity. It's direction is same as that of $\vec{E}$. It's S.I. unit is ampere/m^2 and dimension [$L^{-2}A$].

Ex. The current density at a point is $\vec{J} = \left(2 \times 10^4\,\tilde{j}\right) Jm^{-2}$.

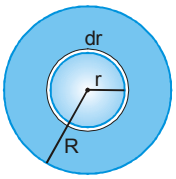
Find the rate of charge flow through a cross sectional area $\vec{S} = \left(2\tilde{i} + 3\tilde{j}\right) cm^2$

Sol. The rate of flow of charge = current = $I = \int \vec{J}.d\vec{S} \Rightarrow I = \vec{J}.\vec{S} = (2 \times 10^4)\left[\tilde{j} \cdot \left(2\tilde{i} + 3\tilde{j}\right)\right] \times 10^{-4} A = 6A$

Ex. A potential difference applied to the ends of a wire made up of an alloy drives a current through it. The current density varies as $J = 3 + 2r$, where r is the distance of the point from the axis. If R be the radius of the wire, then the total current through any cross section of the wire.

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Sol. Consider a circular strip of radius r and thickness dr

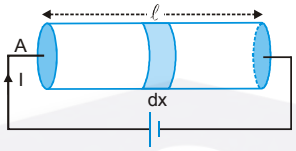


$dI = \vec{J}.d\vec{S} = (3+2r)(2\pi r dr)\cos 0° = 2\pi(3r+2r^2)\,dr$

$I = \int_0^R 2\pi(3r+2r^2)dr = 2\pi\left(\frac{3r^2}{2}+\frac{2}{3}r^3\right)_0^R = 2\pi\left(\frac{3R^2}{2}+\frac{2R^3}{3}\right)$ units

Relation between Current density, Conductivity and electric field

Let the number of free electrons per unit volume in a conductor = n



Total number of electrons in dx distance = n (Adx)

Total charge dQ = n (Adx)e

Current $I = \frac{dQ}{dt} = nAe\frac{dx}{dt} = neAv_d$, Current density $J = \frac{I}{A} = nev_d$

$= ne\left(\frac{eE}{m}\right)\tau \quad \because v_d = \left(\frac{eE}{m}\right)\tau \Rightarrow J = \left(\frac{ne^2\tau}{m}\right)E \Rightarrow J = \sigma E$, where conductivity $\sigma = \frac{ne^2\tau}{m}$

σ depends only on the material of the conductor and its temperature.

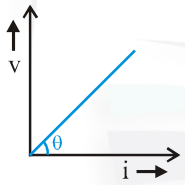
In vector form $\vec{J} = \sigma\vec{E}$ *Ohm's law (at microscopic level)*

OHM'S LAW

If the physical conditions of the conductor (length, temperature, mechanical strain etc). remains same, then the current flowing through the conductor is directly proportional to the potential difference across it's two ends i.e., $i \propto V \Rightarrow V = iR$ where R is a proportionality constant, known as electric resistance.

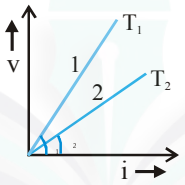
(i) Ohm's law is not a universal law, the substances, which obey ohm's law are known as ohmic substance,

(ii) Graph between V and i for a metallic conductor is a straight line as shown. At different temperatures V-i curves are different.



(A) slope of the line

$= \tan\theta = \frac{V}{i} = R$



(B) Here $\tan\theta_1 > \tan\theta_2$

So $R_1 > R_2$ i.e., $T_1 > T_2$

Resistance

(a) The property of substance by virtue of which it opposes the flow of current through it, is known as the resistance.

(b) **Formula of resistance :** For a conductor if *l* = length of a conductor A = Area of cross-section of conductor, n = No. of free electrons per unit volume in conductor, τ = relaxation time then resistance of conductor $R = \rho\frac{1}{A} = \frac{m}{ne^2\tau}.\frac{1}{A}$ where ρ = resistivity of the material of conductor

(c) **Unit and Dimension :** It's S.I. unit is Volt/amp. or Ohm (Ω). Also ohm $= \frac{1\text{volt}}{1\text{Amp}} = \frac{10^8\text{ emu of potential}}{10^{-1}\text{ emu of current}} = 10^9$ emu of resistance. It's dimension is $[ML^2T^{-3}A^{-2}]$

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Dependence of Resistance : Resistance of a conductor depends upon the following factors.

(i) Length of the conductor : Resistance of a conductor is directly proportional to it's length i.e $R \propto l$

(ii) Inversely proportional to it's area of cross section i.e., $R \propto \frac{1}{A}$

(iii) Nature of material of the conductor $R = \frac{\rho \ell}{A}$

(iv) Temperature For a conductor

Resistance $\propto$ Temperature.

If R_0 = resistance of conductor at 0^0 C

R_t = resistance of conductor at t^0 C

and α, β = temperature co-efficient of resistance then $R_t = R_0(1 + \alpha t + \beta t^2)$ for $t > 300°$ C and $R_t = R_0$

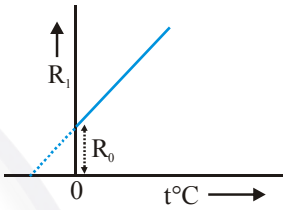
$(1 + \alpha t)$ for $1 \leq 300°$ C or $\alpha = \frac{R_t - R_0}{R_0 \times t}$

If R_1 and R_2 are the resistance at t_1 °C and t_2 °C respectively then $\frac{R_1}{R_2} = \frac{1+\alpha t_1}{1+\alpha t_2}$

The value of α is different at different temperature rage t_1 °C to t_2 °C is given by $\alpha = \frac{R_2 - R_1}{R_1(t_2 - t_1)}$ which given

$R_2 = R_1[1+ \alpha(t_2 - t_1)]$. This formula gives an approximate value.

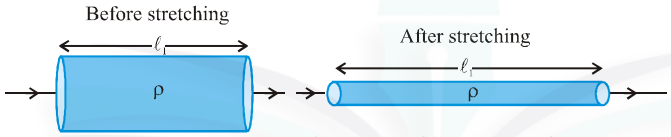
(v) Resistance of the conductor decreases linearly with decrease in temperature and becomes zero at a specific temperature. This temperature is called critical temperature. A this temperature conductor becomes a superconductor.



(vi) **Stretching of wire :** If a conducting wire stretches, it's length increases, area of cross-section decreases so resistance increases but volume remain constant.

Suppose for a conducting wire before stretching it's length = ℓ_1, area of cross-section = A_1 radius = r_1

diameter = d_1, and resistance $R_1 = \rho\frac{\ell_1}{A_1}$



Volume remains constant i.e., $A_1\ell_1 =$

After stretching length ℓ_2 area of cross-section = A_2 radius diameter = d_2 and resistance = $R_2 = \rho\frac{\ell_2}{A_2}$

Ratio of resistance before and after stretching

$$\frac{R_1}{R_2} = \frac{\ell_1}{\ell_2} \times \frac{A_2}{A_1} = \left(\frac{\ell_1}{\ell_2}\right)^2 = \left(\frac{r_2}{r_1}\right)^4 = \left(\frac{d_2}{d_1}\right)^4$$

(a) If length is given by $R \propto \ell^2 \Rightarrow \frac{R_1}{R_2} = \left(\frac{\ell_1}{\ell_2}\right)^2$

(b) If radius is given then $R \propto \frac{1}{r_4} \Rightarrow \frac{R_1}{R_2} = \left(\frac{r_2}{r_1}\right)^4$

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Resistivity (ρ), Conductivity (σ) and Conductance (c)

1. Resistivity : From $R = \rho\frac{1}{A}$; If $l = 1m$, $A = l\ m^2$ then $R = \rho$ i.e,. resistivity is numerically equal to the resistance of a substance having unit area of cross-section and unit length.

(i) Unit and dimension : It's S.I. unit ohm × m and dimension is $[ML^3T^{-3}A^{-2}]$

(ii) It's formula : $\rho = \frac{m}{ne^2\tau}$

(iii) Resistivity is the intrinsic property of the substance. It is independence of shape and size of the body (i.e., l and A).

(iv) Resistivity depends on the temperature. For metal $\rho_t = \rho_0(1 + \alpha\Delta t)$ i.e., resistivity increases with temperature.

(v) Resistivity increases with impurity and mechanical stress.

(vi) Magnetic field increases the resistivity of all metal except iron, cobalt and nickel.

(vii) Resistivity of certain substance like selenium, cadmium, sulphide is inversely proportional to intensity of light falling upon them.

2. **Conductivity :** Reciprocal of resistivity is called conductivity i.e., $s = \frac{1}{\rho}$ with unit mho/m and dimensions $[M^{-1}L^3T^{-3}A^2]$

3. **Conductance :** Reciprocal of resistance is known as conductance. $C = \frac{1}{R}$. It's unit is $\frac{1}{\Omega}$ or Ω^{-1} or "siemen".

(i) 1 ampere of current means the flow of 6.25×10^{18} electrons per second through any cross section of conductor.

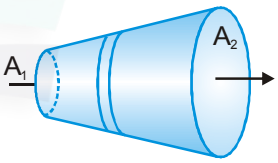
(ii) Current is a scalar quantity but current density is a vector quantity.

(iii) Order of free electron density in conductors = 10^{28} electrons/m^3

(iv)

Terms	Thermal speed v_T	Mean free path	Relaxation time	Drift speed v_d
Order	10^5 m/s	10 Å	10^{-14} m/s	10^{-4} m/s

(v) If a steady current flows in a metallic conductor of non uniform cross section.



(a) Along the wire I is same.

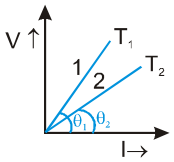
(b) Current density and drift velocity depends on area

$I_1 = I_2, A_1 < A_2 \Rightarrow J_1 > J_2, E_1 > E_2, v_{d_1} > v_{d_2}$

(vi) If the temperature of the conductor increases, the amplitude of the vibrations of the positive ions in the conductor also increase. Due to this, the free electrons collide more frequently with the vibrating ions and as a result, the average relaxation time decreases.

(vii) At different temperatures V–I curves are different.

Here $\tan\theta_1 > \tan\theta_2$ So $R_1 > R_2$ i.e. $T_1 > T_2$



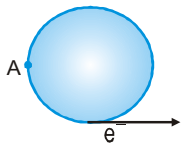
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Ex. What will be the number of electron passing through a heater wire in one minute, if it carries a current of 8 A.

Sol. $I = \frac{Ne}{t} \Rightarrow N = \frac{It}{e} = \frac{8 \times 60}{1.6 \times 10^{-19}} = 3 \times 10^{21}$ electrons

Ex. An electron moves in a circle of radius 10 cm with a constant speed of 4×10^6 m/s. Find the electric current at a point on the circle.

Sol. Consider a point A on the circle. The electron crosses this point once in every revolution. The number of revolutions made by electron in one second is $n = \frac{v}{2\pi r} = \frac{4 \times 10^6}{2\pi \times 10 \times 10^{-2}} = \frac{2}{\pi} \times 10^7$ rot/s.



$\therefore$ Current $I = \frac{ne}{t} = \frac{2}{\pi} \times 10^7 \times 1.6 \times 10^{-19}$ ($\because$ t = 1 s.) $= \frac{3.2}{\pi} \times 10^{-12} \cong 1 \times 10^{-12}$ A

Ex. A current of 1.34 A exists in a copper wire of cross–section 1.0 mm^2. Assuming each copper atom contributes one free electron. Calculate the drift speed of the free electrons in the wire. The density of copper is 8990 kg/m^3 and atomic mass =63.50.

Sol. Mass of $1m^3$ volume of the copper is = 8990 kg = 8990×10^3 g

Number of moles in $1m^3 = \frac{8990 \times 10^3}{63.5} = 1.4 \times 10^5$

Since each mole contains 6×10^{23} atoms therefore number of atoms in $1m^3$

$n = (1.4 \times 10^5) \times (6 \times 10^{23}) = 8.4 \times 10^{28}$

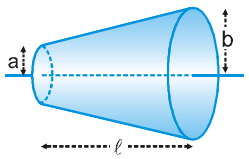
$\because I = neAv_d$ $\therefore v_d = \frac{I}{neA} = \frac{1.34}{8.4 \times 10^{28} \times 1.6 \times 10^{-19} \times 10^{-6}} = 10^{-4}$ m/s = 0.1 mm/s ($\because$ 1 $mm^2 = 10^{-6}$ m^2)

Ex. The current through a wire depends on time as i =(2 +3t)A. Calculate the charge crossed through a cross section of the wire in 10 s.

Sol. $I = \frac{dq}{dt} \Rightarrow dq = (2 + 3t)dt \Rightarrow \int_0^{10} dq = \int_0^{10} (2 + 3t)\, dt \Rightarrow q = \left(2t + \frac{3t^2}{2}\right)_0^{10}$

$q = 2t + \frac{3}{2} \times 100 = 20 + 150 = 170$ C

Ex. Figure shows a conductor of length ℓ carrying current I and having a circular cross – section. The radius of cross section varies linearly from a to b. Assuming that (b – a) << ℓ. Calculate current density at distance x from left end.



Sol. Since radius at left end is a and that of right end is b, therefore increase in radius over length ℓ is (b – a).

Hence rate of increase of radius per unit length = $\left(\frac{b-a}{\ell}\right)$ Increase in radius over length x = $\left(\frac{b-a}{\ell}\right)$x

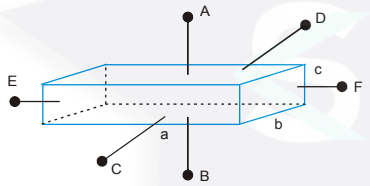
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Since radius at left end is a so radius at distance x, $r = a + \left(\frac{b-a}{\ell}\right)x$

Area at this particular section $A = \pi r^2 = \pi\left[a + \left(\frac{b-a}{\ell}\right)x\right]^2$

Hence current density $J = \frac{I}{A} = \frac{I}{\pi r^2} = \frac{I}{\pi\left[a + \frac{x(b-a)}{\ell}\right]^2}$

Ex. The dimensions of a conductor of specific resistance ρ are shown below. Find the resistance of the conductor across AB, CD and EF.



Sol. For a condition

$$R = \frac{\rho\ell}{A} = \frac{\text{Resistivity} \times \text{length}}{\text{Area of cross section}}$$

$$R_{AB} = \frac{\rho c}{ab}, R_{CD} = \frac{\rho b}{ac}, R_{EF} = \frac{\rho a}{bc}$$

Ex. If a wire is stretched to double its length, find the new resistance if original resistance of the wire was R.

Sol. As we know that $R = \frac{\rho\ell}{A}$

in case $R' = \frac{\rho\ell'}{A'} \Rightarrow \ell' = 2\ell$

$A'\ell' = A\ell$ (volume of the wire remains constant)

$A' = \frac{A}{2} \Rightarrow R' = \frac{\rho \times 2\ell}{A/2} = 4\frac{\rho\ell}{A} = 4R$

Ex. The wire is stretched to increase the length by 1% find the percentage change in the Resistance.

Sol. As we known that

$\therefore R = \frac{\rho\ell}{A} \Rightarrow \frac{\Delta R}{R} = \frac{\Delta\rho}{\rho} + \frac{\Delta\ell}{\ell} \frac{\Delta A}{A}$ and $\frac{\Delta\ell}{\ell} = \frac{\Delta A}{A}$

$\frac{\Delta R}{R} = O + 1 + 1 = 2$

Hence percentage increase in the Resistance = 2%

Ex. The resistance of a thin silver wire is 1.0 Ω at 20°C. The wire is placed in liquid bath and its resistance rises to 1.2 Ω. What is the temperature of the bath ? (Here $\alpha = 10^{-2}$ /°C)

Sol. Here change in resistance is small so we can apply

$R = R_0(1 + \alpha\Delta\theta)$

$\Rightarrow 1.2 = 1 \times (1 + 10^{-2}\Delta\theta) \Rightarrow \Delta\theta = 20°C$

$\Rightarrow \theta - 20 = 20 \Rightarrow \theta = 40°\,C$ **Ans.**

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Ex. A conductive wire has resistance of 10 ohm at 0ºC, and α is $\frac{1}{273}$ /ºC, then determine its resistance at 273ºC.

Sol. In such a problem, term $\alpha \Delta T$ will have a larger value so could not be used directly in $R = R_0 (1 + \alpha \Delta T)$. We need to go for basics as

As we know that $\alpha = \frac{dR}{RdT}$

$$\Rightarrow \quad \int \frac{dR}{R} = \int \alpha dT \qquad \Rightarrow \quad \ell n \frac{R_2}{R_1} = \alpha(T_2 - T_1)$$

$$\Rightarrow \quad R_2 = R_1 e^{\alpha(T_2 - T_1)} \qquad \Rightarrow \quad R_2 = 10e^1$$

$$\Rightarrow \quad R_2 = 10\, e\, \Omega \qquad \textbf{Ans.}$$

ELECTRIC CURRENT IN RESISTANCE



In a resistor current flows from high potential to low potential

High potential is represented by positive (+) sign and low potential is represented by negative (–) sign.

$$V_A - V_B = iR$$

If $V_1 > V_2$

then current will flow from A to B

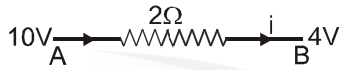


and $i = \frac{V_1 - V_2}{R}$

If $V_1 < V_2$

then current will go from B to A and $i = \frac{V_2 - V_1}{R}$

Ex. Calculate current **(i)** flowing in part of the circuit shown in figure?



Sol. $V_A - V_B = i \times R \quad \Rightarrow \quad i = \frac{6}{2} = 3A$

Specific use of conducting materials

(i) The **heating element** of devices like heater, geyser, press etc are made of **microhm** because it has high resistivity and high melting point. It does not react with air and acquires steady state when red hot at 800°C.

(ii) **Fuse wire** is made of **tin lead alloy** because it has low melting point and low resistivity. The fuse is used in series, and melts to produce open circuit when current exceeds the safety limit.

(iii) **Resistances** of resistance box are made of **manganin** or **constantan** because they have moderate resistivity and very small temperature coefficient of resistance. The resistivity is nearly independent of temperature.

(iv) The **filament of bulb** is made up of **tungsten** because it has low resistivity, high melting point of 3300 K and gives light at 2400 K. The bulb is filled with inert gas because at high temperature it reacts with air forming oxide.

(v) The **connection wires** are made of **copper** because it has low resistance and resistivity.

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Colour Coding of Resistance

To know the value of resistance colour code is used. These code are printed in form of set of rings or strips. By reading the values of colour bands, we can estimate the value of resistance.

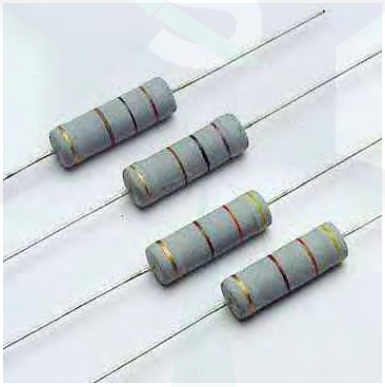
The carbon resistance has normally four coloured rings or bands say A, B, C and D as shown in following figure.

Colour band A and B : Indicate the first two significant figures of resistance in ohm.

Band C : Indicates the decimal multiplier i.e, the number of zeros that follows the two significant figures A and B.

Band D : Indicates the tolerance in percent about the indicated value or in other words it represents the percentage accuracy of the indicated value.

The tolerance in the case of gold is ±5% and silver is ±10%. If only three bands are marked on carbon resistance, then it indicate a tolerance of 20%.



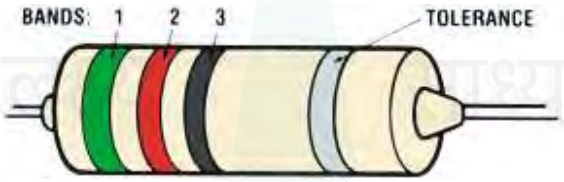


TABLE : COLOUR CODING FOR CARBON RESISTORS

Colour	Strip A	Strip B	Strip C	Strip D (Tolerance)
Black	0	0	10^0	
Brown	1	1	10^1	
Red	2	2	10^2	
Orange	3	3	10^3	
Yellow	4	4	10^4	
Green	5	5	10^5	
Blue	6	6	10^6	
Violet	7	7	10^7	
Grey	8	8	10^8	
White	9	9	10^9	
Gold	-	-	10^{-1}	± 5 %
Silver	-	-	10^{-2}	± 10 %
No colour	-	-	-	± 20 %

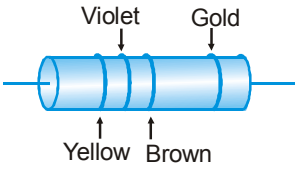
May be remembered as
BBROY
Great Britain
Very Good Wife.

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Ex. Draw a colour code for 42 k Ω ± 10% carbon resistance.

Sol. According to colour code colour for digit 4 is yellow, for digit 2 it is red, for 3 colour is orange and 10% tolerance is represented by silver colour. So colour code should be yellow, red, orange and silver.

Ex. What is resistance of following resistor.



Sol. Number for yellow is 4, Number of violet is 7

Brown colour gives multiplier 10^1, Gold gives a tolerance of ± 5%

So resistance of resistor is $47 \times 10^1\ \Omega \pm 5\% = 470 \pm 5\%\ \Omega$.

ELECTRICAL POWER :

Energy liberated per second in a device is called its power. The electrical power P delivered or consumed by an electrical device is given by P = VI, where V = Potential difference across the device and

I = Current.

If the current enters the higher potential point of the device then electric power is consumed by it (i.e. acts as load). If the current enters the lower potential point then the device supplies power (i.e. acts as source).

$$\text{Power} = \frac{V.dq}{dt}$$



$$= VI$$

$$\mathbf{P = V I}$$

If power is constant then energy = P t

If power is variable then

$$\text{Energy} = \int pdt$$

Power consumed by a resistor

$$P = I^2R = VI = \frac{V^2}{R}.$$

When a current is passed through a resistor energy is wasted in overcoming the resistance of the wire. This energy is converted into heat.

$$W = VIt = I^2Rt = \frac{V^2}{R}t$$

The heat generated (in joules) when a current of I ampere flows through a resistance of R ohm for t second is given by:

$$H = I^2Rt \text{ Joule} = \frac{I^2Rt}{4.2} \text{ Calorie}$$

1 unit of electrical energy = 1 Kilowatt hour = 1 KWh = 3.6×10^6 Joule.

Ex. If bulb rating is 100 watt and 220 V then determine

(a) Resistance of filament

(b) Current through filament

(c) If bulb operate at 110 volt power supply then find power consumed by bulb.

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Sol. Bulb rating is 100 W and 220 V bulb means when 220 V potential difference is applied between the two ends then the power consumed is 100 W

Here V = 220 Volt

P = 100 W

$\frac{V^2}{R} = 100$ So R = 484 Ω

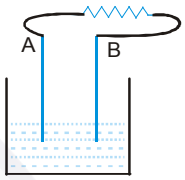
Since Resistance depends only on material hence it is constant for bulb

$$I = \frac{V}{R} = \frac{220}{22 \times 22} = \frac{5}{11} \text{ Amp.}$$

power consumed at 110 V

$$\therefore \text{ power consumed} = \frac{110 \times 110}{484} = 25 \text{ W}$$

Battery (Cell)



A battery is a device which maintains a potential difference across its two terminals A and B. Dry cells, secondary cells, generator and thermocouple are the devices used for producing potential difference in an electric circuit. Arrangement of cell or battery is shown in figure. Electrolyte provides continuity for current.

It is often prepared by putting two rods or plates of different metals in a chemical solution. Some internal mechanism exerts force $(\vec{F}_n)$ on the ions (positive and negative) of the solution. This force drives positive ions towards positive terminal and negative ions towards negative terminal. As positive charge accumulates on anode and negative charge on cathode a potential difference and hence an electric field $\vec{E}$ is developed from anode to cathode. This electric field exerts an electrostatic force $\vec{F} = q\vec{E}$ on the ions. This force is opposite to that of $\vec{F}_n$. In equilibrium (steady state)

$F_n = F_e$ and no further accumulation of charge takes place.

When the terminals of the battery are connected by a conducting wire, an electric field is developed in the wire. The free electrons in the wire move in the opposite direction and enter the battery at positive terminal. Some electrons are withdrawn from the negative terminal. Thus, potential difference and hence, F_e decreases in magnitude while F_n remains the same. Thus, there is a net force on the positive charge towards the positive terminal. With this the positive charge rush towards positive terminal and negative charge rush towards negative terminal. Thus, the potential difference between positive and negative terminal is maintained.

Internal Resistance (R)

The potential difference across a real source in a circuit is not equal to the emf of the cell. The reason is that charge moving through the electrolyte of the cell encounters resistance. We call this the internal resistance of the source.

* The internal resistance of a cell depends on the distance between electrodes ($r \propto d$), area of electrodes ($r \propto \frac{1}{s}$) and nature, concentration ($r \propto c$) and temperature of electrolyte ($r \propto \frac{1}{\text{Temp.}}$).

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Ex. What is the meaning of 10 Amp. hr ?

Sol. It means if the 10 A current is withdrawn then the battery will work for 1 hour.

10 Amp ⟶ 1 hr

1 Amp ⟶ 10 hr

½ Amp ⟶ 20 hr

Electromotive Force : (E.M.F.)

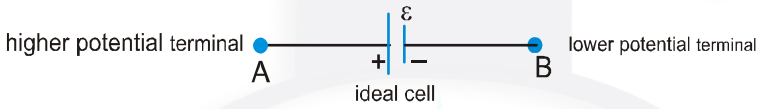
Definition I : Electromotive force is the capability of the system to make the charge flow.

Definition II : It is the work done by the battery for the flow of 1 coulomb charge from lower potential terminal to higher potential terminal inside the battery.

Representation for Battery :

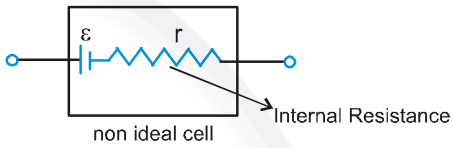
(a) Ideal cell :

Cell in which there is no heating effect.



(b) Non Ideal Cell :

Cell in which there is heating effect inside due to opposition to the current flow internally



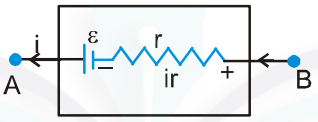
Case I : Battery Acting as a Source (or Battery is Discharging)

$V_A - V_B = \varepsilon - ir$

$V_A - V_B$

⇒ it is also called terminal voltage.

The rate at which the chemical energy of the cell is consumed = εi



The rate at which heat is generated inside the battery or cell = i^2r

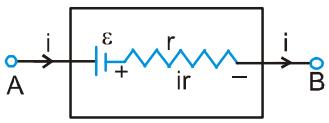
electric power output = $\varepsilon i - i^2r$

$= (\varepsilon - ir)\, i$

Case II : Battery Acting as a Load (or Battery Charging)

$V_A - V_B = \varepsilon + ir$

the rate at which chemical energy stored in the cell = εi



thermal power inside the cell = i^2r

electric power input = $\varepsilon i + i^2r = (\varepsilon + ir)\, i = (V_A - V_B)\, i$

Definition III :

Electromotive force of a cell is equal to potential difference between its terminals when no current is passing through the circuit.

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Case III :

When cell is in open circuit

i = 0 as resistance of open circuit is infinite (∞).

So V = ε, so open circuit terminal voltage difference is equal to emf of the cell.

Case IV :

Short circuiting : Two points in an electric circuit directly connected by a conducting wire are called short circuited, under such condition both points are at same potential.

When cell is short circuited

$i = \frac{\varepsilon}{r}$ and V = 0, short circuit current of a cell is maximum.

- The potential at all points of a wire of zero resistance will be same.

Earthing : If some point of circuit is earthed then its potential is assumed to be zero.

Relative Potential

While solving an electric circuit it is convenient to chose a reference point and assigning its voltage as zero, then all other potentials are measured with respect to this point. This point is also called the common point.

Ex. In the given electric circuit find

(a) current

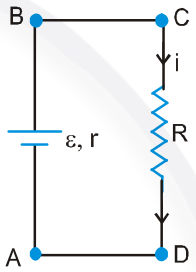
(b) power output

(c) relation between r and R so that the electric power output (that means power given to R) is maximum.

(d) value of maximum power output.

(e) plot graph between power and resistance of load

(f) From graph we see that for a given power output there exists two values of external resistance, prove that the product of these resistances equals r^2.



(g) what is the efficiency of the cell when it is used to supply maximum power.

Sol. **(a)** In the circuit shown if we assume that potential at A is zero then potential at B is $\varepsilon - ir$. Now since the connecting wires are of zero resistance

$\therefore \quad V_D = V_A = 0 \quad \Rightarrow \quad V_C = V_B = \varepsilon - ir$

Now current through CD is also i

($\because$ it's in series with the cell).

$\therefore \quad i = \frac{V_C - V_D}{R} = \frac{(\varepsilon - ir) - 0}{R}$ Current $i = \frac{\varepsilon}{r+R}$

- After learning the concept of series combination we will be able to calculate the current directly

(b) Power output $P = i^2 R = \frac{\varepsilon^2}{(r+R)^2} \cdot R$

(c) $\frac{dP}{dR} = \frac{\varepsilon^2}{(r+R)^2} - \frac{2\varepsilon^2 R}{(r+R)^3} = \frac{\varepsilon^2}{(R+r)^3}[R+r-2R]$

for maximum power supply

$\frac{dP}{dR} = 0 \quad \Rightarrow \quad r + R - 2R = 0 \quad \Rightarrow \quad r = R$

Here for maximum power output outer resistance should be equal to internal resistance

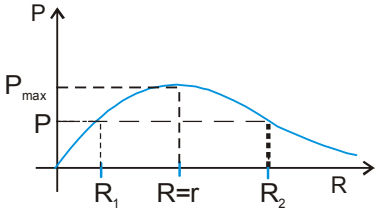
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(d) $P_{max} = \frac{\varepsilon^2}{4r}$

(e) Graph between 'P' and R

maximum power output at R = r

$$P_{max} = \frac{\varepsilon^2}{4r} \Rightarrow i = \frac{\varepsilon}{r+R}$$



(f) Power output

$$P = \frac{\varepsilon^2 R}{(r+R)^2}$$

$$P(r^2 + 2rR + R^2) = \varepsilon^2 R$$

$$R^2 + (2r - \frac{\varepsilon^2}{P})R + r^2 = 0$$

above quadratic equation in R has two roots R_1 and R_2 for given values of ε, P and r such that

$\therefore$ $R_1R_2 = r^2$ (product of roots) $\Rightarrow$ $r^2 = R_1R_2$

(g) Power of battery spent

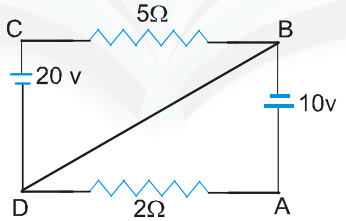
$$= \frac{\varepsilon^2}{(r+r)^2}.2r = \frac{\varepsilon^2}{2r}$$

power (output)

$$= \left(\frac{\varepsilon}{r+r}\right)^2 \times r = \frac{\varepsilon^2}{4r}$$

$$\text{Efficiency} = \frac{\text{power output}}{\text{total power spent by cell}} = \frac{\frac{\varepsilon^2}{4r} \times 100}{\frac{\varepsilon^2}{2r}} = \frac{1}{2} \times 100 = 50\%$$

Ex. In the figure given beside find out the current in the wire BD



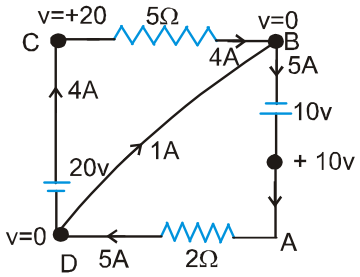
Sol. Let at point D potential = 0 and write the potential of other points then

current in wire AD = $\frac{10}{2}$ = 5 A from A to D current in wire CB = $\frac{20}{5}$ = 4A

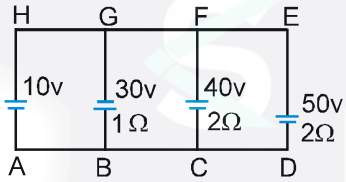
from C to F

$\therefore$ current in wire BD = 1 A from D to B

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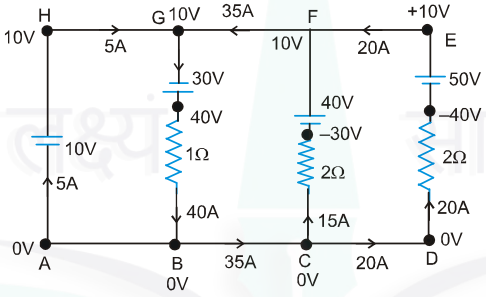
Ex. Find the current in each wire



Sol. Let potential at point A is 0 volt then potential of other points is shown in figure.

current in BG = $\frac{40-0}{1}$ = 40 A from G to B

current in FC = $\frac{0-(-30)}{2}$ = 15 A from C to F



current in DE = $\frac{0-(-40)}{2}$ = 20 A from D to E

current in wire AH = 40 – 35 = 5 A from A to H

KIRCHHOFF'S LAWS

1. Kirchhoff's Current Law (Junction law)

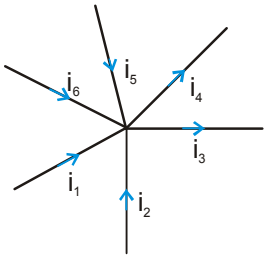
This law is based on law of conservation of charge. It states that " The algebraic sum of the currents meeting at a point of the circuit is zero " or total currents entering a junction equals total current leaving the junction.

$$\Sigma I_{in} = \Sigma I_{out}.$$

It is also known as KCL (Kirchhoff's current law).

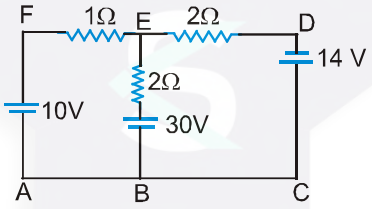
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Ex. Find relation in between current i_1, i_2, i_3, i_4, i_5 and i_6 .

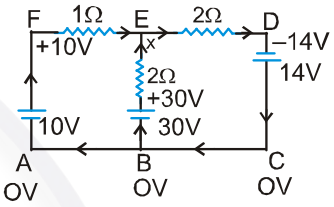


Sol. $i_1 + i_2 - i_3 - i_4 + i_5 + i_6 = 0$

Ex. Find the current in each wire



Sol. Let potential at point B = 0. Then potential at other points are mentioned.



$\therefore$ Potential at E is not known numerically.

Let potential at E = x

Now applying kirchhoff's current law at junction E. (This can be applied at any other junction also).

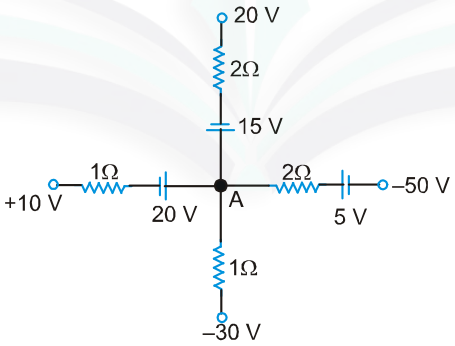
$$\frac{x-10}{1}+\frac{x-30}{2}+\frac{x+14}{2}=0 \Rightarrow 4x = 36 \Rightarrow x = 9$$

Current in EF = $\frac{10-9}{1}$ = 1 A from F to E

Current in BE = $\frac{30-9}{2} = 10.5\,A$ from B to E

Current in DE = $\frac{9-(-14)}{2} = 11.5\,A$ from E to D

Ex. Find the potential at point A



Sol. Let potential at A = x, applying kirchhoff current law at junction A

$$\frac{x-20-10}{1}+\frac{x-15-20}{2}+\frac{x+45}{2}+\frac{x+30}{1}=0 \Rightarrow \frac{2x-60+x-35+x+45+2x+60}{2}=0$$

$$\Rightarrow \quad 6x + 10 = 0 \quad \Rightarrow \quad x = -5/3 \quad \Rightarrow \quad \text{Potential at } A = \frac{-5}{3}\text{ V}$$

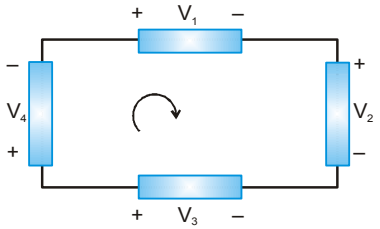
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2. Kirchhoff's Voltage Law (LOOP LAW)

"The algebraic sum of all the potential differences along a closed loop is zero.

So IR + Σ EMF = 0".

The closed loop can be traversed in any direction. While traversing a loop if potential increases, put a positive sign in expression and if potential decreases put a negative sign. (Assume sign convention)

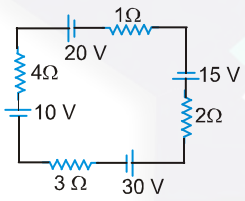


$-V_1 - V_2 + V_3 - V_4 = 0.$

Boxes may contain resistor or battery or any other element (linear or nonlinear).

It is also known as **KVL**

Ex. Find current in the circuit



Sol. all the elements are connected in series

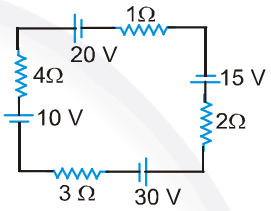
current is all of them will be same

let current = i

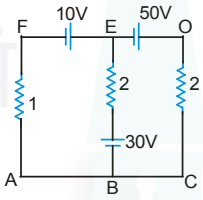
Applying kirchhoff voltage law in ABCDA loop

$10 + 4i - 20 + i + 15 + 2i - 30 + 3i = 0$

$10\ i = 25 \Rightarrow i = 2.5$ A



Ex. Find the current in each wire applying only kirchhoff voltage law



Sol. Applying kirchhoff voltage law in loop ABEFA

$i_1 + 30 + 2(i_1 + i_2) - 10 = 0$

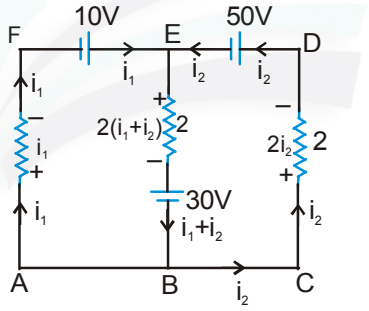
$3i_1 + 2i_2 + 20 = 0$ ..... **(i)**

Applying kirchoff voltage law in BEDCB

$+ 30 + 2(i_1 + i_2) + 50 + 2i_2 = 0$

$4i_2 + 2i_1 + 80 = 0$

$2i_2 + i_1 + 40 = 0$ ..... **(ii)**



Solving **(i)** and **(ii)**

$3[-40 - 2i_2] + 2i_2 + 20 = 0$

$-120 - 4i_2 + 20 = 0$

$i_2 = -25$ A

and $i_1 = 10$ A

$\therefore$ $i_1 + i_2 = -15$ A

current in wire AF = 10 A from A to F

current in wire EB = 15 A from B to E

current in wire DE = 25 A from E to D.

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(i) If a wire is stretched to n times of it's original length, its new resistance will be n^2 times.

(ii) If a wire is stretched such that it's radius is reduced to $\frac{1}{n}$th of it's original values, then resistance will increases n^4 times similarly resistance will decrease n^4 time if radius is increased n times by contraction.

(iii) To get maximum resistance, resistance must be connected in series and in series the resultant is greater than largest individual.

(iv) To get minimum resistance, resistance must be connected in parallel and the equivalent resistance of parallel combination is lower than the value of lowest resistance in the combination.

(v) Ohm's law is not a fundamental law of nature. As it is possible that for an element :–

- **(i)** V depends on I non linearly (e.g. vacuum tubes)
- **(ii)** Relation between V and I depends on the sign of V for the same value [Forward and reverse Bias in diode]
- **(iii)** The relation between V and I is non unique. That is for the same I there is more then one value of V.

(vi) In general

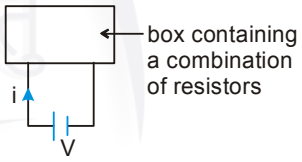
- **(i)** Resistivity of alloys is greater than their metals.
- **(ii)** Temperature coefficient of alloys is lower than pure metals.
- **(iii)** Resistance of most of non metals decreases with increase in temperature. (e.g.carbon)
- **(iv)** The resistivity of an insulator (e.g. amber) is greater then the metal by a factor of 10^{22}

(vii) Temperature coefficient (α) of semi conductor including carbon (graphite), insulator and electroytes is negative.

Combination of Resistances

A number of resistances can be connected and all the complicated combinations can be reduced to two different types, namely series and parallel.

The equivalent resistance of a combination is defined as $R_{eq} = \frac{V}{i}$



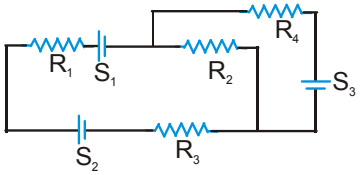
Resistances in Series :

When the resistances (or any type of elements) are connected end to end then they are said to be in series. The current through each element is same.



Resistances in series carry equal current but reverse may not be true.

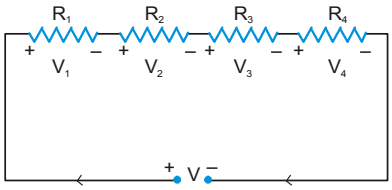
Ex. Which electrical elements are connected in series.



Sol. Here S_1, S_2, R_1, R_3 connected in one series and R_4, S_3 connected in different series

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Equivalent of Resistors



The effective resistance appearing across the battery (or between the terminals A and B) is

$R = R_1 + R_2 + R_3 + \ldots\ldots\ldots\ldots + R_n$ (this means R_{eq} is greater then any resistor)

and $V = V_1 + V_2 + V_3 + \ldots\ldots\ldots\ldots + V_n$

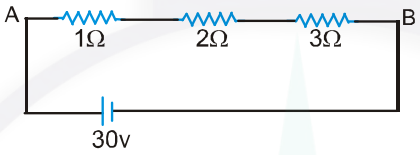
The potential difference across a resistor is proportional to the resistance. Power in each resistor is also proportional to the resistance

$\because \quad V = IR$ and $P = I^2R$

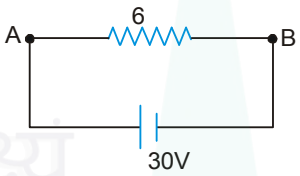
where I is same through any of the resistor.

$$V_1 = \frac{R_1}{R_1 + R_2 + \ldots\ldots\ldots + R_n} V \; ; \; V_2 = \frac{R_2}{R_1 + R_2 + \ldots\ldots\ldots + R_n} V \quad ; \quad \text{etc}$$

Ex. Find the current in the circuit

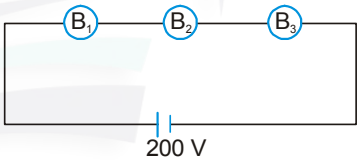


Sol. $R_{eq} = 1 + 2 + 3 = 6\ \Omega$ the given circuit is equivalent to



current $i = \frac{v}{R_{eq}} = \frac{30}{6} = 5\ A$ **Ans.**

Ex. In the figure shown B_1, B_2 and B_3 are three bulbs rated as (200V, 50 W), (200V, 100W) and (200 V, 25W) respectively. Find the current through each bulb and which bulb will give more light?



Sol. $R_1 = \frac{(200)^2}{50}$;

$$R_2 = \frac{(200)^2}{100} \; ; \quad R_3 = \frac{(200)^2}{25}$$

the current following through each bulb is

$$= \frac{200}{R_1 + R_2 + R_3} = \frac{200}{(200)^2\left[\frac{2+1+4}{100}\right]} = \frac{100}{200 \times 7} = \frac{1}{14}\ A$$

Since $R_3 > R_1 > R_2$

$\therefore$ Power consumed by bulb = i^2R

$\therefore$ if the resistance is of higher value then it will give more light.

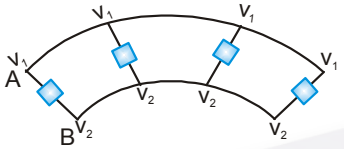
$\therefore$ Here Bulb B_3 will give more light.

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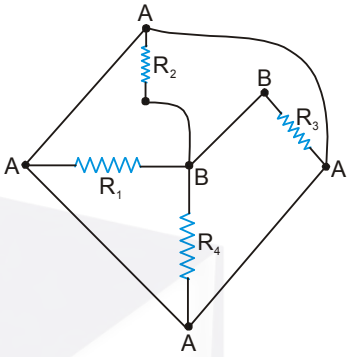
Resistances in Parallel

A parallel circuit of resistors is one in which the same voltage is applied across all the components in a parallel grouping of resistors R_1, R_2, R_3,....., R_n.

(a)

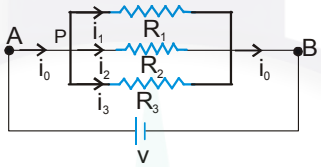


(b)



In the figure (a) and (b) all the resistors are connected between points A and B so they are in parallel.

Equivalent resistance



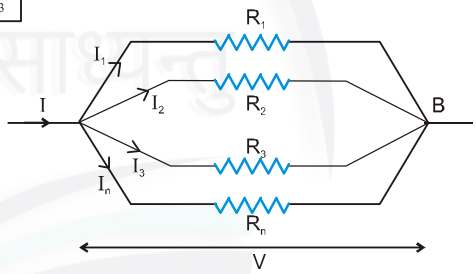
Applying kirchhoff's junction law at point P

$$i_0 = i_1 + i_2 + i_3$$

Therefore, $\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$ $\boxed{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$

in general,

$$\boxed{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots\ldots\ldots + \frac{1}{R_n}}$$



Conclusions: (about parallel combination)

(a) Potential difference across each resistor is same.

(b) $I = I_1 + I_2 + I_3 + \ldots\ldots\ldots I_n$.

(c) Effective resistance (R) then $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots\ldots + \frac{1}{R_n}$.

(R is less than each resistor).

(d) Current in different resistors is inversely proportional to the resistance.

$$I_1 : I_2 : \ldots\ldots\ldots I_n = \frac{1}{R_1} : \frac{1}{R_2} : \frac{1}{R_3} : \ldots\ldots\ldots : \frac{1}{R_n} .$$

$$I_1 = \frac{G_1}{G_1 + G_2 + \ldots\ldots\ldots + G_n} \cdot I, \; I_2 = \frac{G_2}{G_1 + G_2 + \ldots\ldots\ldots + G_n} I, \text{ etc.}$$

where $G = \frac{1}{R}$ = Conductance of a resistor. [Its unit is Ω^{-1} or $\mho$ (mho)]

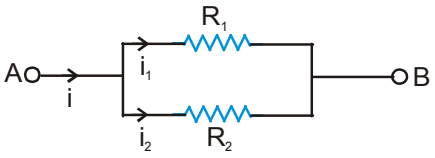
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Ex. When two resistors are in parallel combination then determine i_1 and i_2, if the combination carries a current i?

Sol. $\therefore \quad i_1R_1 = i_2R_2$

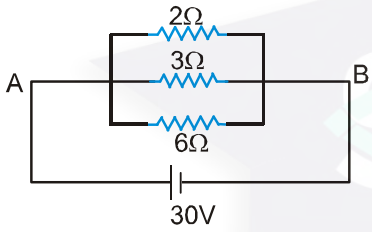
or $\quad \frac{i_1}{i_2} = \frac{R_2}{R_1}$

$$i_1 = \frac{R_2 i}{R_1 + R_2} \quad \Rightarrow \quad i_2 = \frac{R_1 i}{R_1 + R_2},$$



- Remember this law of $i \propto \frac{1}{R}$ in the resistors connected in parallel. It can be used in problems.

Ex. Find current passing through the battery and each resistor.



Sol. **Method (I)**

It is easy to see that potential difference across each resistor is 30 V.

$\therefore$ current is each resistors are $\frac{30}{2} = 15$ A, $\frac{30}{3} = 10\ A$ and $\frac{30}{6} = 5\ A$

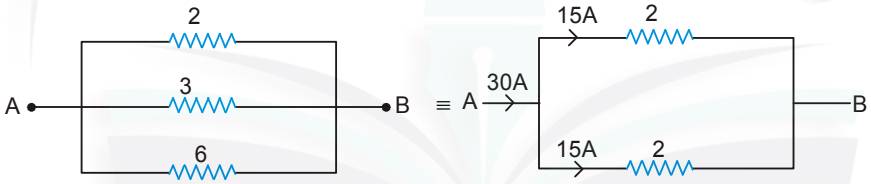
$\therefore$ Current through battery is = 15 + 10 + 5 =30 A.

Method (II)

By ohm's law $\quad i = \frac{V}{R_{eq}} \quad \Rightarrow \quad \frac{1}{R_{eq}} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6} \quad = 1\Omega$

$$R_{eq} = 1\ \Omega \quad \Rightarrow \quad i = \frac{30}{1} = 30\ A$$

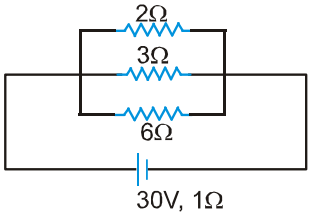
Now distribute this current in the resistors in their inverse ratio.



Current total in 3 Ω and 6 Ω is 15 A it will be divided as 10 A and 5 A.

- The method (I) is better. But you will not find such an easy case every where.

Ex. Find current which is passing through battery.



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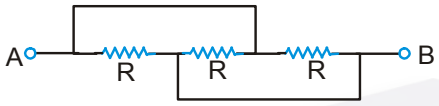
Sol. Here potential difference across each resistor is not 30 V

∵ battery has internal resistance. Here the concept of combination of resistors is useful.

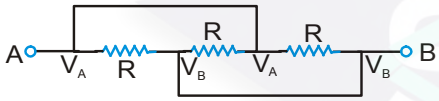
$R_{eq} = 1 + 1 = 2\ \Omega$

$i = \frac{30}{2} = 15$ A.

Ex. Find equivalent Resistance



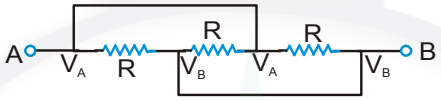
Sol.



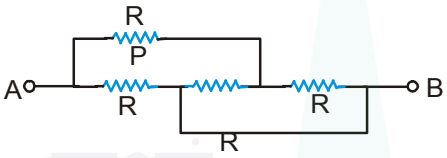
Here all the Resistance are connected between the terminals A and B

Modified circuit is

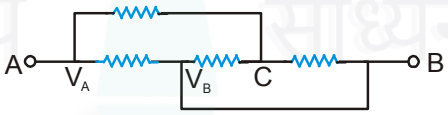
So $R_{eq} = \frac{R}{3}$



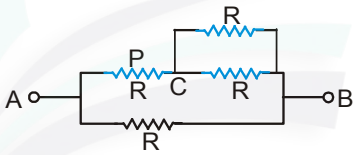
Ex. Find the current in Resistance P if voltage supply between A and B is V volts



Sol $R_{eq} = \frac{3R}{5}$

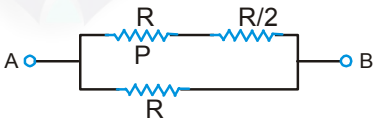


$I = \frac{5V}{3R}$ Modified circuit

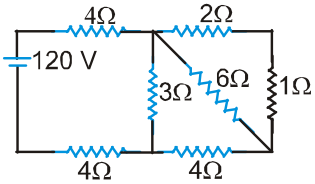


Current in P $= \frac{R \times \frac{5V}{3R}}{1.5R + R}$

$= \frac{2V}{3R}$



Ex. Find the current in 2Ω resistance



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Sol. 2Ω, 1Ω in series = 3Ω

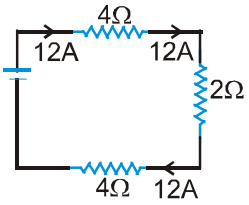
3Ω, 6Ω in parallel = $\frac{18}{9}$ =2Ω

2Ω, 4Ω in series = 6Ω

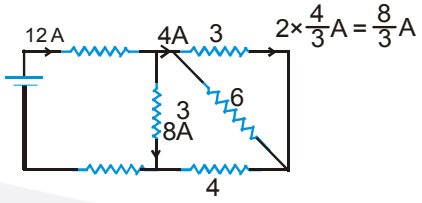
6Ω, 3Ω in parallel = 2Ω

R_{eq} = 4 + 4 + 2 = 10Ω

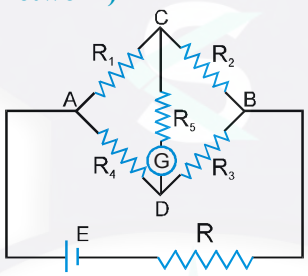
$i = \frac{120}{10}$ = 12A



So current in 2Ω Resistance = $\frac{8}{3}$ A

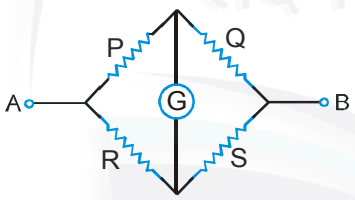


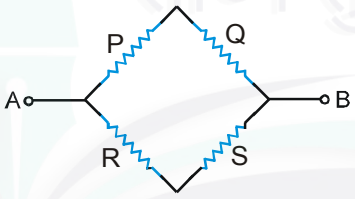
Wheatstone Network : (4 terminal network)



The arrangement as shown in figure, is known as Wheat stone bridge
Here there are four terminals in which except two all are connected to each other through resistive elements.
In this circuit if $R_1 R_3 = R_2 R_4$ then $V_C = V_D$ and current in $R_5 = 0$ this is called balance point or null point

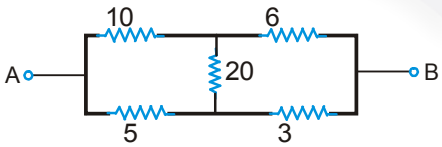
When current through the galvanometer is zero (null point or balance point) $\frac{P}{Q}=\frac{R}{S}$, then PS = QR $\Rightarrow$ Here in this case products of opposite arms are equal. Potential difference between C and D at null point is zero. The null point is not affected by resistance R_5, E and R. It is not affected even if the positions of Galvanometer and battery (E) are interchanged.
hence, here the circuit can be assumed to be following,





or

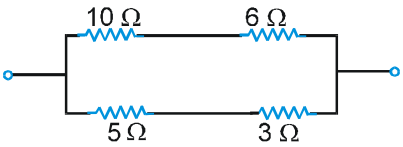
Ex. Find equivalent resistance of the circuit between the terminals A and B.



Sol. Since the given circuit is wheat stone bridge and it is in balance condition.

$\because$ $10\times3 = 30 = 6\times5$

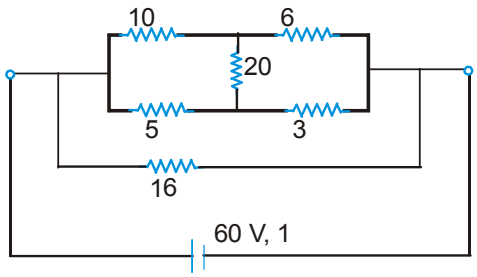
hence this is equivalent to



$R_{eq} = \frac{16\times8}{16+8} = \frac{16}{3}\Omega$

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Ex.



Find **(a)** Equivalent resistance **(b)** and current in each resistance

Sol. **(a)** $R_{eq} = \left(\frac{1}{16}+\frac{1}{8}+\frac{1}{16}\right)^{-1} + 1 = 5\,\Omega$

(b) $i = \frac{60}{4+1} = 12\ A$

Hence 12 A will flow through the cell.

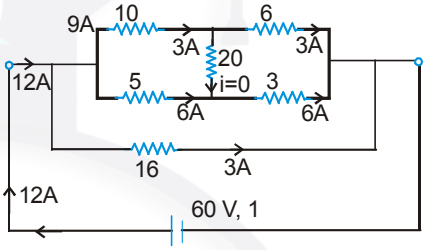
By using current distribution law.

Current in resistance 10Ω and 6Ω = 3A

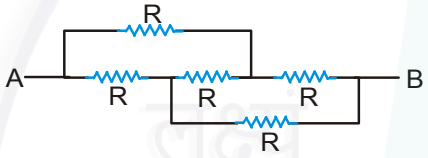
Current in resistance 5Ω and 3Ω = 6A

Current in resistance 20Ω = 0

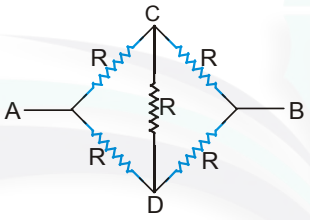
Current in resistance 16Ω = 3A



Ex. Find the equivalent resistance between A and B

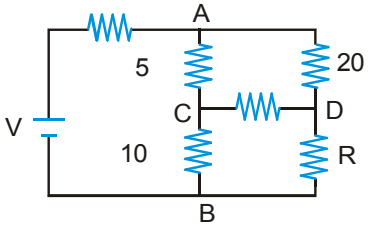


Sol This arrangement can be modified as shown in figure since it is balanced wheat stone bridge



$R_{eq} = \frac{2R \times 2R}{2R+2R} = R$

Ex. Determine the value of R in the circuit shown in figure, when the current is zero in the branch CD.



Sol The current in the branch CD is zero, if the potential difference across CD is zero.

That means, voltage at point C = voltage at point D.

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Since no current is flowing, the branch CD is open circuited. So the same voltage is applied across ACB and ADB

$$V_{10} = V \times \frac{10}{15} \quad \Rightarrow \quad V_R = V \times \frac{R}{20+R}$$

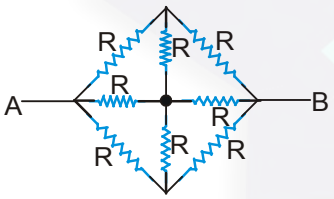
$$\therefore \quad V_{10} = V_R \text{ and } \quad V \times \frac{10}{15} = V \times \frac{R}{20+R}$$

$$\therefore \quad R = 40 \quad \Omega$$

Symmetrical Circuits

Some circuits can be modified to have simpler solution by using symmetry if they are solved by traditional method of KVL and KCL then it would take much time.

Ex. Find the equivalent Resistance between A and B

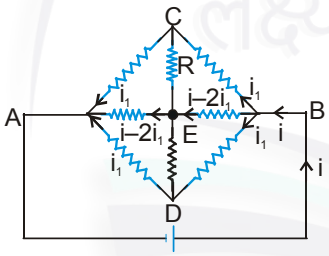


Sol **I Method :**

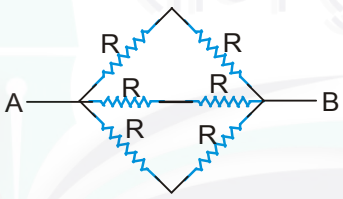
Here no two resistors appear to be in series or parallel no Wheatstone bridge here. This circuit will be solved by using $R_{eq} = \frac{V}{I}$. The branches AC and AD are symmetrical

$\therefore$ current through them will be same.

The circuit is also similar from left side and right side current distribution while entering through B and an exiting from A will be same. Using all these facts the currents are as shown in the figure. It is clear that current in resistor between C and E is 0 and also in ED is 0. It's equivalent as shown in figure (b)



(fig. a)



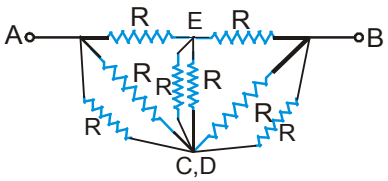
(fig. b)

$$R_{eq} = \frac{2R}{3}$$

II Method

$\because$ The potential difference in R between (B, C) and between (B.D.) is same $V_C = V_D$

Hence the point C and D are same hence circuit can be simplified as this called folding.

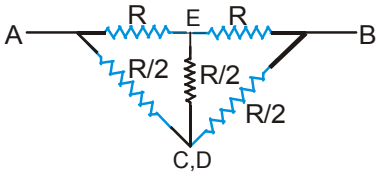


Now, it is Balanced Wheatstone bridge

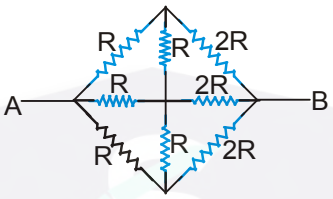
$$R_{eq} = \frac{2R \times R}{2R + R} = \frac{2R}{3}$$

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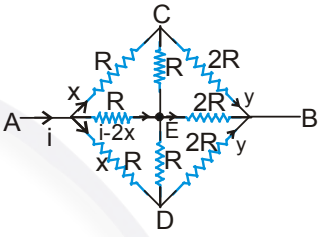
- In II Method it is not necessary to know the currents in CA and DA.



Ex. Find the equivalent Resistance between A and B

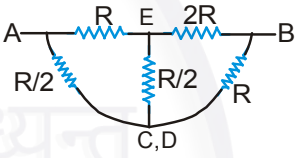


Sol. In this case the circuit has symmetry in the two branches AC and AD at the input
$\therefore$ current in them are same but from input and from exit the circuit is not similar
($\because$ on left R and on right 2R)
$\therefore$ on both sides the distribution of current will not be similar.
Here $V_c = V_d$
hence C and D are same point
the circuit can be simplified that as shown
Now it is balanced wheat stone bridge

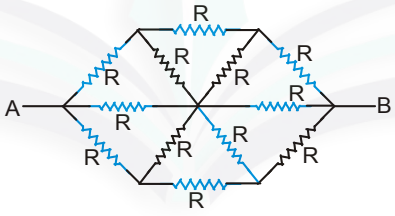


$$R_{eq} = \frac{3R \times \frac{3R}{2}}{3R + \frac{3R}{2}}$$

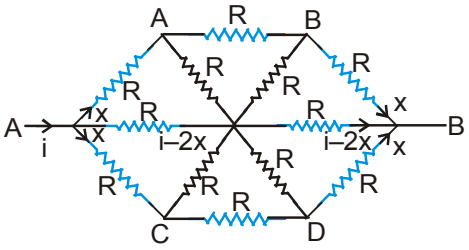
$$= \frac{\frac{9}{2}R}{\frac{9}{2}} = R.$$



Ex. Find the equivalent Resistance between A and B



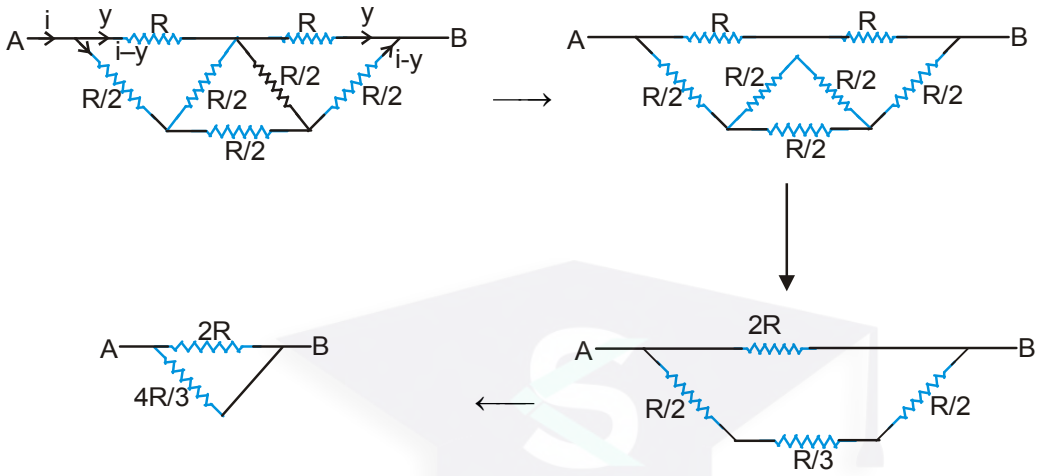
Sol.



Here $V_A = V_C$ and $V_B = V_D$

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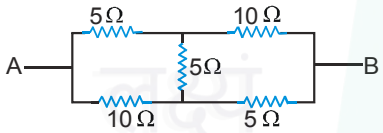
Here the circuit can be simplified as
this circuit can be simplified as



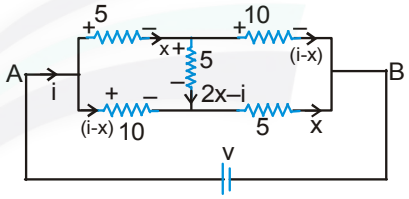
$$R_{eq} = \frac{2R \times \frac{4R}{3}}{\frac{10R}{3}}$$

$$= \frac{4R}{5}$$ **Ans.**

Ex. Find the equivalent Resistance between A and B



Sol. It is wheat stone bridge but not balanced. No series parallel connections. But similar values on input side and output. Here we see that even after using symmetry the circuit does not reduce to series parallel combination as in previous examples.



∴ applying kirchoff voltage law

$v - 10(i - x) - 5x = 0$

$v - 10i + 5x = 0$ .....(1)

$10(i - x) - 5(2x - i) - 5x = 0$

$10i - 10x - 10x + 5i - 5x = 0$

$15i - 25x = 0$

$x = \frac{15}{25} i$ $\quad 5x = 3i$ .....(2)

Using (2) and (1)

$\therefore v - 10i + 3i = 0$

$\frac{v}{i} = 7\Omega$

$R_{eq} = 7\Omega$

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Combination of Cells

1. Cells in Series



Equivalent EMF

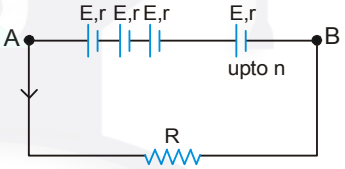
$$E_{eq} = E_1 + E_2 + ... + E_n$$ [write EMF's with polarity]

Equivalent internal resistance

$$r_{eq} = r_1 + r_2 + r_3 + r_4 + ... + r_n$$

If n cells each of emf E, arranged in series and if r is internal resistance of each cell, then total emf = n E so current in the circuit

$$I = \frac{nE}{R + nr}$$



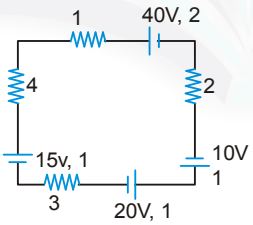
If nr << R then $I = \frac{nE}{R}$ ⟶ Series combination is advantageous.

If nr >> R then $I = \frac{E}{r}$ ⟶ Series combination is not advantageous.

(i) If polarity of m cells is reversed, then equivalent emf = (n-2m)E while the equivalent resistance is still nr+R, so current in R will be

$$i = \frac{(n-2m)E}{nr+R}.$$

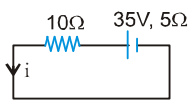
Ex. Find the current in the loop.



Sol. The given circuit can be simplified as

$$i = \frac{35}{10+5} = \frac{35}{15}$$

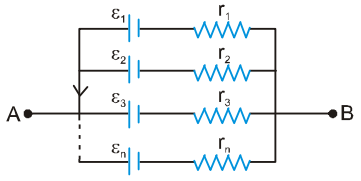
$$= \frac{7}{3}\text{ A} \quad \Rightarrow \quad I = \frac{7}{3}\text{ A}$$



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2. Cells in Parallel

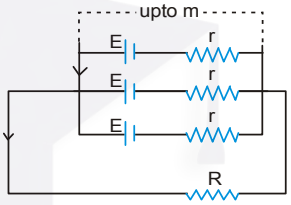
$$E_{eq} = \frac{\varepsilon_1/r_1 + \varepsilon_2/r_2 + ... + \varepsilon_n/r_n}{1/r_1 + 1/r_2 + ... + 1/r_n}$$ [Use emf's with polarity]



$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + ... + \frac{1}{r_n}$$

If m cells each of emf E and internal resistance r be connected in parallel and if this combination is connected to an external resistance then equivalent emf of the circuit = E.

Internal resistance of the circuit = $\frac{r}{m}$.



and $I = \frac{E}{R + \frac{r}{m}} = \frac{mE}{mR + r}$.

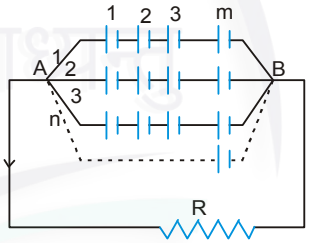
If mR << r ; $I = \frac{mE}{r}$ ⟶ Parallel combination is advantageous.

If mR >> r ; $I = \frac{E}{R}$ ⟶ Parallel combination is not advantageous.

3. Cells in Multiple Arc

mn = number of identical cells.
n = number of rows
m = number of cells in each row.
The combination of cells is equivalent to single cell of
emf = mE

and internal resistance = $\frac{mr}{n}$



Current $I = \frac{mE}{R + \frac{mr}{n}}$

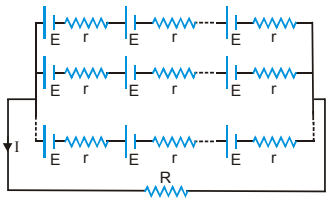
For maximum current nR = mr

or $R = \frac{mr}{n}$ = internal resistance of the equivalent battery.

$I_{max} = \frac{nE}{2r} = \frac{mE}{2R}$.

4. Mixed Combination

If n cells connected in series and their are m such branches in the circuit then total number of identical cell in this circuit is nm. The internal resistance of the cells connected in a row = nr . Since there are such m rows,



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Total internal resistance of the circuit $r_{net} = \frac{nr}{m}$

Total e.m.f. of the circuit = total e.m.f. of the cells connected in a row $E_{net} = nE$

Current in the circuit $I = \frac{E_{net}}{R + r_{net}} = \frac{nE}{R + \frac{nr}{m}}$

Current in the circuit is maximum when external resistance in the circuit is equal to the total internal resistance of the cells $R = \frac{nr}{m}$

(i) At the time of charging a cell when current is supplied to the cell, the terminal voltage is greater than the e.m.f. E, $V = E + Ir$

(ii) Series combination is useful when internal resistance is less than external resistance of the cell.

(iii) Parallel combination is useful when internal resistance is greater than external resistance of the cell.

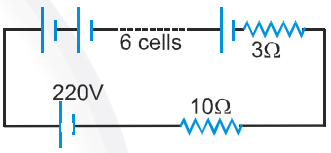
(iv) Power in R (given resistance) is maximum, if its value is equal to net resistance of remaining circuit.

(v) Internal resistance of ideal cell = 0

(vi) If external resistance is zero than current given by circuit is maximum.

Ex. A battery of six cells each of e.m.f. 2 V and internal resistance 0.5 Ω is being charged by D. C. mains of e.m.f. 220 V by using an external resistance of 10 Ω. What will be the charging current.

Sol. Net e.m.f of the battery = 12V and total internal resistance = 3Ω



Total resistance of the circuit = 3 + 10 = 13 Ω

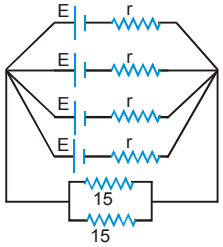
Charging current $I = \frac{\text{Net e.m.f.}}{\text{total resis tan ce}} = \frac{220 - 12}{13} = 16\ A$

Ex. A battery of six cells each of e.m.f. 2 V and internal resistance 0.5 Ω is being charged by D. C. mains of e.m.f. 220 V by using an external resistance of 10 Ω. What is the potential difference across the battery ?

Sol. In case of charging of battery, terminal potential $V = E + Ir = 12 + 16 \times 3 = 60$ volt.

Ex. Four identical cells each of e.m.f. 2V are joined in parallel providing supply of current to external circuit consisting of two 15Ω resistors joined in parallel. The terminal voltage of the equivalent cell as read by an ideal voltmeter is 1.6V calculate the internal resistance of each cell.

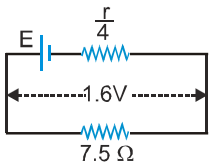
Sol. Total internal resistance of the combination $r_{eq} = \frac{r}{4}$



Total e.m.f. $E_{eq} = 2V$

Total external resistance $R = \frac{15 \times 15}{15 + 15} = \frac{15}{2} = 7.5\Omega$

Current drawn from equivalent cell $I = \frac{\text{terminal potential}}{\text{external resistance}} = \frac{1.6}{7.5} A$



$\because\ E - I\left(\frac{r}{4}\right) = 1.6 \qquad \therefore\ 2 - \frac{1.6}{7.5}\left(\frac{r}{4}\right) = 1.6 \Rightarrow r = 7.5\ \Omega$

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Ex. The e.m.f. of a primary cell is 2 V, when it is shorted then it gives a current of 4 A. Calculate internal resistance of primary cell.

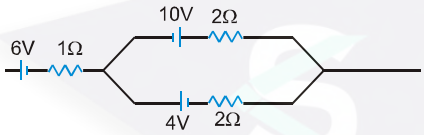
Sol. $I = \frac{E}{r+R}$, If cell is shorted then $R = 0$, $I = \frac{E}{r}$ $\therefore\ r = \frac{E}{I} = \frac{2}{4} = 0.5\ \Omega$

Ex. n rows each containing m cells in series, are joined in parallel. Maximum current is taken from this combination in a 3 Ω resistance. If the total number of cells used is 24 and internal resistance of each cell is 0.5 Ω , find the value of m and n.

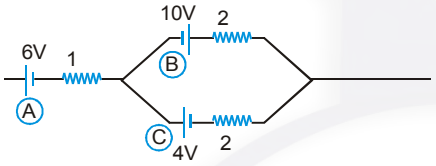
Sol. Total number of cell $mn = 24$, For maximum current $\frac{mr}{n} = R \Rightarrow 0.5\,m = 3\,n,\ m = \frac{3n}{0.5} = 6n$

$\therefore 6n \times n = 24 \Rightarrow n = 2$ and $m \times 2 = 24 \Rightarrow m = 12$

Ex. Find the emf and internal resistance of a single battery which is equivalent to a combination of three batteries as shown in figure.



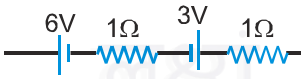
Sol.



Battery (B) and (C) are in parallel combination with opposite polarity. So, their equivalent

$$\varepsilon_{BC} = \frac{\frac{10}{2} + \frac{-4}{2}}{\frac{1}{2} + \frac{1}{2}} = \frac{5-2}{1} = 3V \quad \Rightarrow \quad r_{BC} = 1\Omega.$$

Now,



$\varepsilon_{ABC} = 6 - 3 = 3V \Rightarrow r_{ABC} = 2\Omega.$ **Ans.**

1. Galvanometer

Galvanometer is represented as follow :



It consists of a pivoted coil placed in the magnetic field of a permanent magnet. Attached to the coil is a spring. In the equilibrium position, with no current in the coil, the pointer is at zero and spring is relaxed. When there is a current in the coil, the magnetic field exerts a torque on the coil that is proportional to current. As the coil turns, the spring exerts a restoring torque that is proportional to the angular displacement. Thus, the angular deflection of the coil and pointer is directly proportional to the coil current and the device can be calibrated to measure current.

When coil rotates the spring is twisted and it exerts an opposing torque on the coil.

There is a resistive torque also against motion to damp the motion. Finally in equilibrium

$$\tau_{magnetic} = \tau_{spring} \quad \Rightarrow \quad BINA \sin\theta = C\phi$$

But by making the magnetic field radial $\theta = 90^\circ$.

$\therefore$ $BINA = C\phi$

$I \propto \phi$

here B = magnetic field, A = Area of the coil, I = Current, C = torsional constant, N = Number of turns, ϕ = angle rotate by coil.

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- **Current Sensitivity**

The ratio of deflection to the current i.e. deflection per unit current is called current sensitivity (C.S.) of the galvanometer $CS = \frac{\phi}{I} = \frac{BNA}{C}$

Shunt

The small resistance connected in parallel to galvanometer coil, in order to control current flowing through the galvanometer, is known as shunt.

- **Merits of shunt**

(i) To protect the galvanometer coil from burning.

(ii) Any galvanometer can be converted into ammeter of desired range with the help of shunt.

(iii) The range an ammeter can be changed by using shunt resistance of different values.

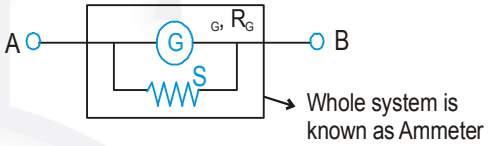
- **Demerits of shunt**

Shunt resistance decreases the sensitivity of galvanometer.

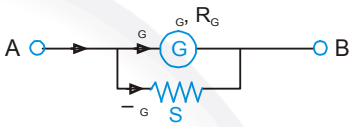
2. Ammeter

A shunt (small resistance) is connected in parallel with galvanometer to convert it into ammeter; An ideal ammeter has zero resistance

Ammeter is represented as follow -







If maximum value of current to be measured by ammeter is I then

$I_G \cdot R_G = (I - I_G)S$

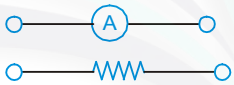
$$S = \frac{I_G . R_G}{I - I_G}$$

$$S = \frac{I_G \times R_G}{I} \quad \text{when} \quad I >> I_G.$$

where I = Maximum current that can be measured using the given ammeter.

For measuring the current the ammeter is connected is series.

In calculation it is simply a resistance



Resistance of ammeter

$$R_A = \frac{R_G . S}{R_G + S}$$

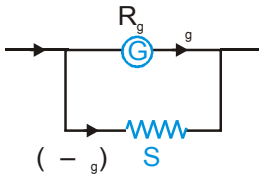
for $S << R_G \Rightarrow R_A = S$

Ex. What is the value of shunt which passes 10% of the main current through a galvanometer of 99 ohm ?

Sol. As in figure $R_g I_g = (I - I_g)S$

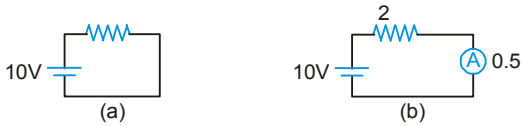
$$\Rightarrow \quad 99 \times \frac{I}{10} = \left(I - \frac{I}{10}\right) \times S$$

$$\Rightarrow \quad S = 11\ \Omega.$$



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Ex. Find the current in the circuit (a) & (b) and also determine percentage error in measuring the current through an ammeter.



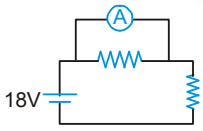
Sol. In A $I = \frac{10}{2} = 5A$

In B $I = \frac{10}{2.5} = 4A$

Percentage error is $= \frac{i - i'}{i} \times 100 = 20\%$ **Ans.**

Here we see that due to ammeter the current has reduced. A good ammeter has very low resistance as compared with other resistors, so that due to its presence in the circuit the current is not affected.

Ex. Find the reading of ammeter ? Is this the current through 6 Ω ?



Sol. $R_{eq} = \frac{3 \times 6}{3+6} + 1 = 3\ \Omega$

Current through battery

$$I = \frac{18}{3} = 6\ A$$

So, current through ammeter

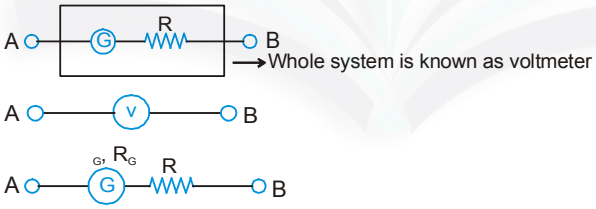
$$= 6 \times \frac{6}{9} = 4\ A$$

No, it is not the current through the 6 Ω resistor.

- Ideal ammeter is equivalent to zero resistance wire for calculation potential difference across it is zero.

3. Voltmeter

A high resistance is put in series with galvanometer. It is used to measure potential difference across a resistor in a circuit.



For maximum potential difference

$$V = I_G \cdot R + I_G R_G \qquad R = \frac{V}{I_G} - R_G$$

$$\text{If } R_G << R \quad \Rightarrow \quad R_S \approx \frac{V}{I_G}$$

For measuring the potential difference a voltmeter is connected across that element. (parallel to that element it measures the potential difference that appears between terminals 'A' and 'B'.)

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For calculation it is simply a resistance



Resistance of voltmeter $R_V = R_G + R \approx R$

$I_g = \frac{V_o}{R_g + R}$. $R \to \infty \Rightarrow$ Ideal voltmeter.

A good voltmeter has high value of resistance.
Ideal voltmeter $\to$ which has high value of resistance.

- For calculation purposes the current through the ideal voltmeter is zero.
- Percentage error in measuring the potential difference by a voltmeter is $= \frac{V - V'}{V} \times 100$

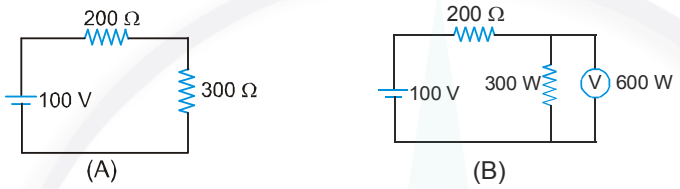
Ex. A galvanometer has a resistance of G ohm and range of V volt. Calculate the resistance to be used in series with it to extend its range to nV volt.

Sol. Full scale current $i_g = \frac{V}{G}$

to change its range

$$V_1 = (G + R_s)i_g \quad \Rightarrow \quad nV = (G + R_s)\frac{V}{G} \quad \Rightarrow \quad R_s = G(n-1) \quad \textbf{Ans.}$$

Ex. Find potential difference across the resistance 300 Ω in A and B.



Sol. In (A) : Potential difference $= \frac{100}{200+300} \times 300 = 60$ volt

In (B) : Potential difference $= \frac{100}{200 + \frac{300 \times 600}{300+600}} \times \frac{300 \times 600}{300+600} = 50$ volt

We see that by connecting voltmeter the voltage which was to be measured has changed. Such voltmeters are not good. If its resistance had been very large than 300 Ω then it would not have affected the voltage by much amount.

Current sensitivity

The ratio of deflection to the current i.e. deflection per unit current is called current sensitivity (C.S.) of the galvanometer $CS = \frac{\theta}{I}$

- Shunting a galvanometer decreases its current sensitivity.

Ex. A galvanometer with a scale divided into 100 equal divisions, has a current sensitivity of 10 division per mA and voltage sensitivity of 2 division per mV. What adoptions are required to use it (a) to read 5A full scale and (b) 1 division per volt ?

Sol. Full scale deflection current $i_g = \frac{\theta}{cs} = \frac{100}{10}$ mA = 10 mA

Full scale deflection voltage $V_g = \frac{\theta}{vs} = \frac{100}{2}$ mv = 50 mv

So galvanometer resistance $G = \frac{V_g}{i_g} = \frac{50mV}{10mA} = 5\ \Omega$

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(a) to convert the galvanometer into an ammeter of range 5A, a resistance of value SΩ is connected in parallel with it such that

$$(I - i_g)\, S = i_g\, G$$
$$(5 - 0.01)\, S = 0.01 \times 5$$
$$S = \frac{5}{499} \cong 0.01\ \Omega \qquad \textbf{Ans.}$$

(b) To convert the galvanometer into a voltmeter which reads 1 division per volt, i.e. of range 100 V,

$V = i_g (R + G)$

$$100 = 10 \times 10^{-3} (R + 5)$$
$$R = 10000 - 5$$
$$R = 9995\ \Omega \cong 9.995\ k\Omega \qquad \textbf{Ans.}$$

4. POTENTIOMETER

(i) Necessity of potentiometer

Practically voltameter has a finite resistance. (ideally it should be ∞) in other words it draws some current from the circuit . To overcome this problem potentiometer is used because at the instant of measurement , it draws no current from the circuit. It means its effective resistance is infinite.

(ii) Working principle of potentiometer

Any unknown potential difference is balanced on a known potential difference which is uniformly distributed over entire length of potentiometer wire. This process is named as zero deflection or null deflection method.

(iii) Potentiometer wire

Made up of alloys of manganin, constantan, Eureka. Specific properties of these alloys are high specific resistance, negligible temperature co–efficient of resistance (α). Invariability of resistance of potentiometer wire over a long period.

Circuits of Potentiometer

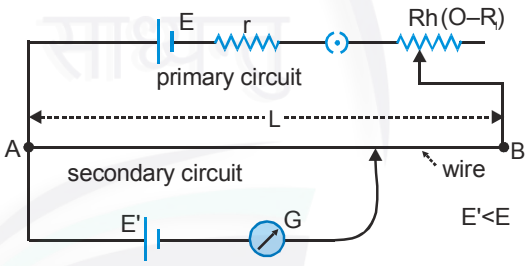
(a) Primary circuit contains constant source of voltage rheostat or Resistance Box

(b) Secondary, Unknown or galvanometer circuit

Let ρ = Resistance per unit length of potentiometer wire

(c) Potential gradient (x) (V/m)

The fall of potential per unit length of potentiometer wire is called potential gradient.



$$x = \frac{V}{L} = \frac{\text{current} \times \text{resitance of potentiometer wire}}{\text{length of potentiometer wire}} = I\left(\frac{R}{L}\right)$$

The potential gradient depends only on primary circuit and is independent of secondary circuit.

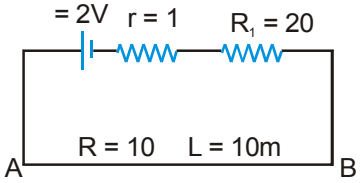
Ex. Primary circuit of potentiometer is shown in figure determine :

(A) current in primary circuit

(B) potential drop across potentiometer wire AB

(C) potential gradient (means potential drop per unit length of potentiometer wire)

(D) maximum potential which we can measure above potentiometer



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Sol. **(a)** $i = \frac{\varepsilon}{r + R_1 + R} = \frac{2}{1 + 20 + 10} \Rightarrow i = \frac{2}{31}$ A

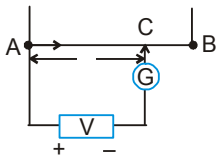
(b) $V_{AB} = iR = \frac{2}{31} \times 10 \Rightarrow v_{AB} = \frac{20}{31}$ volt

(c) $x = \frac{V_{AB}}{L} = \frac{2}{31}$ volt/m

(d) Maximum potential which we can measure by it = potential drop across wire AB = $\frac{20}{31}$ volt

Ex. How to measure an unknown voltage using potentiometer.

Sol. The unknown voltage V is connected across the potentiometer wire as shown in figure. The positive terminal of the unknown voltage is kept on the same side as of the source of the top most battery. When reading of galvanometer is zero then we say that the meter is balanced. In that condition $V = x\ell$.



Application of Potentiometer

(a) To find emf of unknown cell and compare emf of two cells.

In Case I,

In figure, **(2)** is joint to **(1)** then balance length = ℓ_1

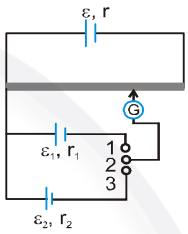
$\varepsilon_1 = x\ell_1$ ....**(1)**

In Case II,

In figure, **(3)** is joint to **(2)** then balance length = ℓ_2

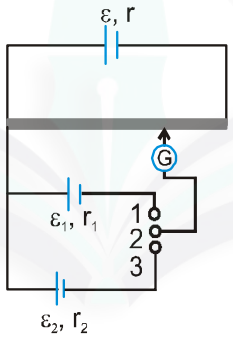
$\varepsilon_2 = x\ell_2$ ....**(2)**

$\frac{\varepsilon_1}{\varepsilon_2} = \frac{\ell_1}{\ell_2}$



If any one of ε_1 or ε_2 is known the other can be found. If x is known then both ε_1 and ε_2 can be found

Ex. In an experiment to determine the em*f* of an unknown cell, its emf is compared with a standard cell of known emf $\varepsilon_1 = 1.12$ V. The balance point is obtained at 56cm with standard cell and 80 cm with the unknown cell. Determine the emf of the unknown cell.



Sol. Here, $\varepsilon_1 = 1.12$ V; $\ell_1 = 56$ cm; $\ell_2 = 80$ cm

Using equation

$\varepsilon_1 = x\ell_1$ ....**(1)**

$\varepsilon_2 = x\ell_2$ ....**(2)**

we get $\frac{\varepsilon_1}{\varepsilon_2} = \frac{\ell_1}{\ell_2} \Rightarrow \varepsilon_2 = \varepsilon_1\left(\frac{\ell_2}{\ell_1}\right)$

or $\varepsilon_2 = 1.12\left(\frac{80}{56}\right) = 1.6$ V Ans

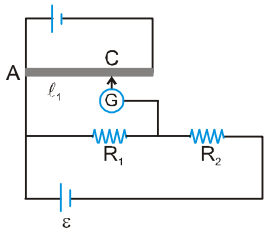
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(b) To find current if resistance is known

$V_A - V_C = x\ell_1$

$IR_1 = x\ell_1$

$$I = \frac{x\ell_1}{R_1}$$



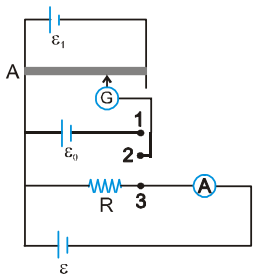
Similarly, we can find the value of R_2 also.

Potentiometer is ideal voltmeter because it does not draw any current from circuit, at the balance point.

Ex. A standard cell of emf $\varepsilon_0 = 1.11$ V is balanced against 72 cm length of a potentiometer. The same potentiometer is used to measure the potential difference across the standard resistance R = 120 Ω. When the ammeter shows a current of 7.8 mA, a balanced length of 60 cm is obtained on the potentiometer.

(i) Determine the current flowing through the resistor.

(ii) Estimate the error in measurement of the ammeter.



Sol. Here, $\ell_0 = 72$ cm ; $\ell = 60$ cm; $R = 120\ \Omega$ and $\varepsilon_0 = 1.11$ V

(i) By using equation $\varepsilon_0 = x\ell_0$ .....(i)

$V = IR = x\ell$ .....(ii)

From equation (i) and (ii)

$$I = \frac{\varepsilon_0}{R}\left(\frac{\ell}{\ell_0}\right) \quad \therefore \quad I = \frac{1.11}{120}\left(\frac{60}{72}\right) = 7.7\ \text{mA}$$

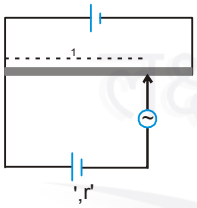
(ii) Since the measured reading 7.8 mA (> 7.7 mA) therefore, the instrument has a positive error.

$\Delta I = 7.8 - 7.7 = 0.1$ mA,

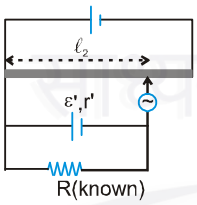
$$\frac{\Delta I}{I} = \frac{0.1}{7.7} \times 100 = 1.3\ \%$$

(c) To find the internal resistance of cell.

I[st] arrangement



2[nd] arrangement



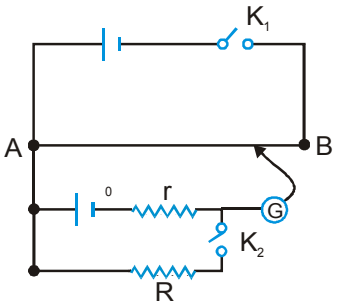
by first arrangement $\varepsilon' = x\ell_1$ ...(1)

by second arrangement $IR = x\ell_2$

$$I = \frac{x\ell_2}{R},$$

Also $$I = \frac{\varepsilon'}{r'+R} \Rightarrow \frac{\varepsilon'}{r'+R} = \frac{x\ell_2}{R} \Rightarrow \frac{x\ell_1}{r'+R} = \frac{x\ell_2}{R} \Rightarrow r' = \left[\frac{\ell_1 - \ell_2}{\ell_2}\right]R$$

Ex. The internal resistance of a cell is determined by using a potentiometer. In an experiment, an external resistance of 60Ω is used across the given cell. When the key is closed, the balance length on the potentiometer decreases from 72 cm to 60 cm. calculate the internal resistance of the cell.



Sol. According to equation $\varepsilon_0 = x\ell_0$ ....(i)

$V = IR = x\ell$ ....(ii)

$$I = \frac{\varepsilon_0}{R+r}$$ .....(iii)

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From equation **(i)**, **(ii)** and **(iii)** we get

$$r = R\left(\frac{\ell_0}{\ell} - 1\right)$$

Here $\ell_0 = 72$ cm; $\ell = 60$ cm; $R = 60\ \Omega$ $\therefore$ $r = (60)\left(\frac{72}{60} - 1\right)$ or $r = 12\ \Omega$.

Applications of Potentiometer

(i) To measure potential difference across a resistance.
(ii) To find out emf of a cell.
(iii) Comparision of two emfs E_1/E_2
(iv) To find out internal resistance of a primary cell.
(v) Comparision of two resistance.
(vi) To find out an unknown resistance which is connected series with the given resistance.
(vii) To find out current in a given circuit.
(viii) Callibration of an ammeter or to have a check on reading of (A).
(ix) Callibration of an voltmeter or to have a check on reading of (V).
(x) To find out thermocouple emf (e) (mV or mV)

Difference between potentiometer and voltmeter

Potentiometer	Voltmeter
(a) It measures the unknown emf very accurately	It measures the unknown emf approximately.
(b) While measuring emf it does not draw any current from the driving source of know emf.	While measuring emf it draws some current from the source of emf.
(c) While measuring unknown potential difference the resistance of potentiometer becomes infinite.	While measuring unknown potential difference the resistance of voltmeter is high but finite.
(d) It is based on zero deflection method.	It is based on deflection method.
(e) It has a high sensitivity.	Its sensitivity is low.
(f) it is used for various applications like measurement of internal resistance of cell, calibration of ammeter and voltmeter, measurement of thermo emf, comparison of emf's etc.	It is only used to measured emf or unknown potential difference.

5. Metre Bridge (Use to measure unknown resistance)

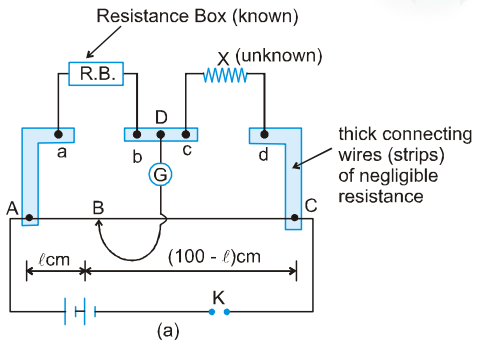
If $AB = \ell$ cm, then $BC = (100 - \ell)$ cm.

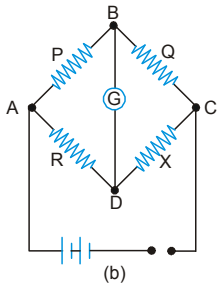
Resistance of the wire between A and B $R \propto \ell$

[$\because$ Specific resistance ρ and cross-sectional area A are same for whole of the wire]

or $R = \sigma\ell$ ...**(1)**

where σ is resistance per cm of wire.





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Similarly, if Q is resistance of the wire between B and C, then

$$Q \propto 100 - \ell$$

$$\therefore \quad Q = \sigma(100 - \ell) \qquad \text{....(2)}$$

Dividing (1) by (2), $\frac{P}{Q} = \frac{\ell}{100 - \ell}$

Applying the condition for balanced Wheatstone bridge, we get

$$R\ Q = P\ X$$

$$\therefore \quad x = R\frac{Q}{P} \qquad \text{or} \qquad X = \frac{100 - \ell}{\ell} R$$

Since R and ℓ are known, therefore, the value of X can be calculated.

- For better accuracy, R is so adjusted that ℓ lies between 40 cm and 60 cm.

Ex. In a meter bridge experiment, the value of unknown resistance is 2Ω. To get the balancing point at 40cm distance from the same end, the resistance in the resistance box will be :

(A) 0.5 Ω **(B)** 3 Ω **(C)** 20 Ω **(D)** 80 Ω

Sol. Apply condition for balance wheat stone bridge,

$$\frac{P}{Q} = \frac{\ell}{100 - \ell} = \frac{P}{2} = \frac{100 - 40}{40}$$

$P = 3\Omega$.

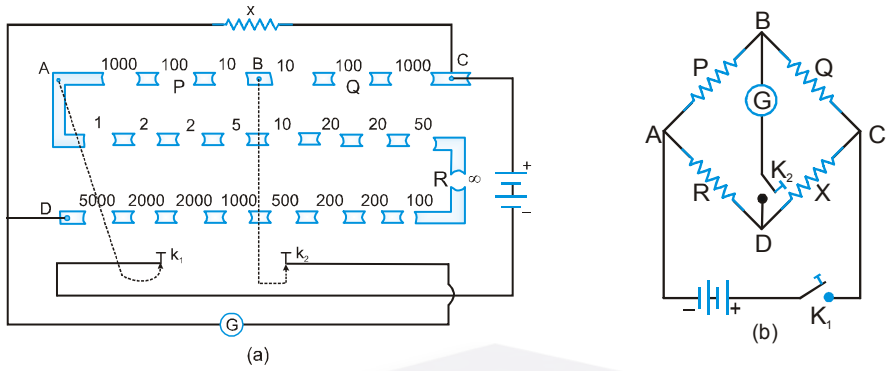
6. Post-office Box

Introduction. It is so named because its shape is like a box and it was originally designed to determine the resistances of electric cables and telegraph wires. It was used in post offices to determine the resistance of transmission lines.

Construction. A post office box is a compact form of Wheatstone bridge with the help of which we can measure the value of the unknown resistance correctly up to 2nd decimal place, i.e., up to 1/100th of an ohm correctly. Two types of post office box are available - plug type and dial type. In the plug-type instrument shown in figure (a), each of the arms AB and BC contains three resistances of 10, 100 and 1000 ohm. These arms are called the ratio arms. While the resistance P can be introduced in the arm AB, the resistance Q can be introduced in the arm BC. The third arm AD, called the resistance arm, is a complete resistance box containing resistances from 1 Ω to 5,000 Ω. In this arm, the resistance R is introduced by taking out plugs of suitable values. The unknown resistance X constitutes the fourth arm CD. Thus, the four arms AB, BC, CD and AD are infect the four arms of the Wheatstone bridge (figure (b)). Two tap keys K_1 and K_2 are also provided. While K_1 is connected internally to the terminal A, K_2 is connected internally to B. These internal connections are shown by dotted lines in figure (a).

A battery is connected between C and key K_1 (battery key). A galvanometer is connected between D and key K_2 (galvanometer key). Thus, the circuit is exactly the same as that shown in figure (b). It is always the battery key which is pressed first and then the galvanometer key. This is because a self-induced current is always set up in the circuit whenever the battery key is pressed or released. If we first press the galvanometer key, the balance point will be disturbed on account of induced current. If the battery key is pressed first, then the induced current becomes zero by the time the galvanometer key is pressed. So, the balance point is not affected.

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Working : The working of the post office box involves broadly the following four steps :

I. Keeping R zero, each of the resistances P and Q are made equal to 10 ohm by taking out suitable plugs from the arms AB and BC respectively. After pressing the battery key first and then the galvanometer key, the direction of deflection of the galvanometer coil is noted. Now, making R infinity, the direction of deflection is again noted. If the direction is opposite to that in the first case, then the connections are correct.

II. Keeping both P and Q equal to 10Ω, the value of R is adjusted, beginning from 1Ω, till 1 Ω increase reverses the direction of deflection. The 'unknown' resistance clearly lies somewhere between the two final values of R. $\left[X = R\frac{Q}{P} = R\frac{10}{10} = R\right]$

As an illustration, suppose with 3Ω resistance in the arm AD, the deflection is towards left and with 4Ω, it is towards right. The unknown resistance lies between 3Ω and 4Ω.

III. Making P 100 Ω and keeping Q 10 Ω, we again find those values of R between which direction of deflection is reversed. Clearly, the resistance in the arm AD will be 10 times the resistance X of the wire.

$$\left[X = R\frac{Q}{P} = R\frac{10}{100} = \frac{R}{10}\right]$$

In the illustration considered in step II, the resistance in the arm AD will now lie between 30 Ω, and 40 Ω. So, in this step, we have to start adjusting R from 30 Ω onwards. If 32 Ω and 33 Ω are the two values of R which give opposite deflections, then the unknown resistance lies between 3.2 Ω and 3.3 Ω.

IV. Now, P is made 1000 Ω and Q is kept at 10 Ω. The resistance in the arm AD will now be 100 times the 'unknown' resistance.

$$\left[X = R\frac{10}{1000} = \frac{R}{100}\right]$$

In the illustration under consideration, the resistance in the arm AD will lie between 320 Ω and 330Ω. Suppose the deflection is to the right for 326 ohm, towards left for 324 ohm and zero deflection for 325Ω Then, the unknown resistance is 3.25 Ω.

The post office box method is a less accurate method for the determination of unknown resistance as compared to a metre bridge. This is due to the fact that it is not always possible to arrange resistance in the four arms to be of the same order. When the arms ratio is large, large resistance are required to be introduced in the arm R.

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(i) To increase the range of an ammeter a shunt is connected in parallel with the galvanometer.

(ii) To convert an ammeter of range I ampere and resistance $R_g\ \Omega$ into an ammeter of range nI ampere, the value of resistance to be connected in parallel will be $R_g(n-1)$

(iii) To increase the range of a voltmeter a high resistance is connected in series with it.

(iv) To convert a voltmeter of resistance $R_g\ \Omega$ and range V volt into a voltmeter of range nV volt, the value of resistance to be connected in series will be $(n-1)R_g$.

(v) Resistance of ideal ammeter is zero & resistance of ideal voltmeter is infinite.

(vi) The bridge is most sensitive when the resistance in all the four branches of the bridge is of same order.

Ex. The post office box works on the principle of :

(A) Potentiometer **(B)** Wheatstone bridge

(C) Matter waves **(D)** Ampere's law **Ans. : (B)**

Ex. While using a post office box the keys should be switched on in the following order :

(A) first cell key the and then galvanometer key.

(B) first the galvanometer key and then cell key.

(C) both the keys simultaneously.

(D) any key first and then the other key. **Ans. : (A)**

Ex. In a post office box if the position of the cell and the galvanometer are interchanged, then the :

(A) null point will not change **(B)** null point will change

(C) post office box will not work **(D)** Nothing can be said. **Ans. : (A)**

Heating effect of current

Cause of heating

The potential difference applied across the two ends of conductor sets up electric field. Under the effect of electric field, electrons accelerate and as they move, they collide against the ions and atoms in the conductor, the energy of electrons transferred to the atoms and ions appears as heat.

- **Joules's Law of Heating**

When a current I is made to flow through a passive or ohmic resistance R for time t, heat Q is produced such that

$$Q = I^2 R t = P \times t = V I t = \frac{V^2}{R} t$$

Heat produced in conductor does not depend upon the direction of current.

• **SI unit** : joule ;

$1\text{kWh} = 3.6 \times 10^6 \text{ joule} = 1 \text{ unit}$

Practical Units : 1 kilowatt hour (kWh)

1 BTU (British Thermal Unit) = 1055 J

• **Power :** $P = V I = \frac{V^2}{R} = I^2R$

• **SI unit :** Watt

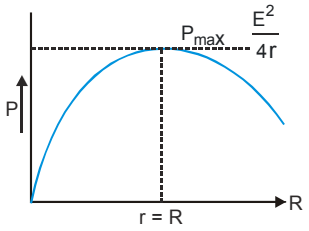
The watt–hour meter placed on the premises of every consumer records the electrical energy consumed.

- **Power transferred to load by cell :**

$$P = I^2R = \frac{E^2R}{(r+R)^2} \quad \Rightarrow \quad P = P_{max} \quad \text{if} \quad \frac{dP}{dR} = 0 \quad \Rightarrow \quad r = R$$

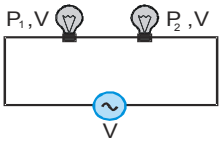
Power transferred by cell to load is maximum when

$$r = R \text{ and } P_{max} = \frac{E^2}{4r} = \frac{E^2}{4R}$$



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- **Series combination of resistors (bulbs)**

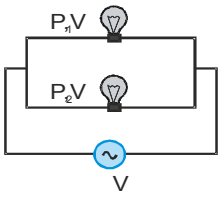


Total power consumed $P_{total} = \frac{P_1P_2}{P_1 + P_2}$ If n bulbs are identical $P_{total} = \frac{P}{n}$

In series combination of bulbs Brightness $\propto$ Power consumed by bulb $\propto V \propto R \propto \frac{1}{P_{rated}}$

Bulb of lesser wattage will shine more. For same current $P = I^2R$ $P \propto R$ $R\uparrow \Rightarrow P\uparrow$

- **Parallel combination of resistors (bulbs)**



Total power consumed $P_{total} = P_1 + P_2$ If n bulbs are identical $P_{total} = nP$

In parallel combination of bulbs

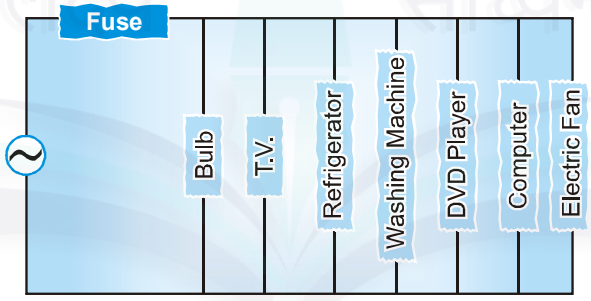
Brightness $\propto$ Power consumed by bulb $\propto I \propto \frac{1}{R}$ Bulb of greater wattage will shine more.

For same V more power will be consumed in smaller resistance $P \propto \frac{1}{R}$

- Two identical heater coils gives total heat H_S when connected in series and H_p when connected in parallel than $\frac{H_P}{H_S} = 4$ [In this, it is assumed that supply voltage is same]
- If a heater boils m kg water in time T_1 and another heater boils the same water in T_2, then both connected in series will boil the same water in time $T_s = T_1 + T_2$ and in parallel $T_P = \frac{T_1T_2}{T_1 + T_2}$ [Use time taken $\propto$ Resistance]
- Instruments based on heating effect of current, works on both A.C. and D.C. Equal value of A.C. (RMS) and D.C. produces, equal heating effect. That why brightness of bulb is same whether it is operated by A.C. or same value D.C.

Fuse wire

The fuse wire for an electric circuit is chosen keeping in view the value of safe current through the circuit.



(i) The fuse wire should have high resistance per unit length and low melting point.

(ii) However the melting point of the material of fuse wire should be above the temperature that will be reached on the passage of the current through the circuit

(iii) A fuse wire is made of alloys of lead (Pb) and tin (Sn).

(iv) Length of fuse wire is immaterial.

(v) The material of the filament of a heater should have high resistivity and high melting point.

(vi) The temperature of the wire increases to such a value at which, the heat produced per second equals heat lost per second due to radiation from the surface of wire $I^2\left(\frac{\rho\ell}{\pi r^2}\right) = H \times 2\pi r\ell$ $I^2 \propto r^3$

H = heat lost per second per unit area due to radiation.

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Ex. An electric heater and an electric bulb are rated 500 W, 220 V and 100 W, 220 V respectively. Both are connected in series to a 220 V a.c. mains. Calculate power consumed by **(i)** heater **(ii)** bulb.

Sol. $P = \frac{V^2}{R}$ or $R = \frac{V^2}{P}$, For heater. Resistance $R_h = \frac{(220)^2}{500} = 96.8\ \Omega$, For bulb resistance $R_L = \frac{(220)^2}{100} = 484\ \Omega$

Current in the circuit when both are connected in series $I = \frac{V}{R_L + R_h} = \frac{220}{484 + 96.8} = 0.38\ A$

(i) Power consumed by heater $= I^2R_h = (0.38)^2 \times 96.8 = 13.98\ W$

(ii) Power consumed by bulb $= I^2R_L = (0.38)^2 \times 484 = 69.89\ W$

Ex. A heater coil is rated 100 W, 200 V. It is cut into two identical parts. Both parts are connected together in parallel, to the same source of 200 V. Calculate the energy liberated per second in the new combination.

Sol. $\because P = \frac{V^2}{R}$ $\therefore R = \frac{V^2}{P} = \frac{(220)^2}{100} = 400\ \Omega$

Resistance of half piece $= \frac{400}{2} = 200\ \Omega$

Resistance of pieces connected in parallel $= \frac{200}{2} = 100\ \Omega$

Energy liberated/second $P = \frac{V^2}{R} = \frac{200 \times 200}{100} = 400\ W$

Ex. The power of a heater is 500W at 800°C. What will be its power at 200°C. If $\alpha = 4 \times 10^{-4}$ per °C ?

Sol. $P = \frac{V^2}{R}$ $\therefore$ $\frac{P_{200}}{P_{800}} = \frac{R_{800}}{R_{200}} = \frac{R_0(1 + 4 \times 10^{-4} \times 800)}{R_0(1 + 4 \times 10^{-4} \times 200)}$ $\Rightarrow$ $P_{200} = \frac{500 \times 1.32}{1.08} = 611W$

Ex. When a battery sends current through a resistance R_1 for time t, the heat produced in the resistor is Q. When the same battery sends current through another resistance R_2 for time t, the heat produced in R_2 is again Q. Determine the internal resistance of battery.

Sol. $\left[\frac{E}{R_1 + r}\right]^2 R_1 = \left[\frac{E}{R_2 + r}\right]^2 R_2 \Rightarrow r = \sqrt{R_1R_2}$

Ex. A fuse with a circular cross-sectional radius of 0.15 mm blows at 15A. What is the radius of a fuse, made of the same material which will blow at 120 A?

Sol. For fuse wire $I \propto r^{3/2}$

So $\frac{r_2}{r_1} = \left(\frac{I_2}{I_1}\right)^{2/3} = \left(\frac{120}{15}\right)^{2/3} = (8)^{2/3} = 4 \Rightarrow r_2 = 4r_1 = 0.60\ mm$

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TIPS& FORMULAS

1. Electric Current :

Electric charges in motion constitute an electric current.Any medium having practically free electric charges, free to migrate is a conductor of electricity. The electric charge flows from higher potential energy state to lower potential energy state. Positive charge flows from higer to lower potential and negative charge flows from lower to higher. Metals such as gold, copper, aluminium etc. are good conductors.

2. Electric Current in a Conductor :

In absence of potential difference across a conductor, no net current flows through a cross section. When a potential difference is applied across a conductor the charge carries (electrons in case of metallic conductors) flow in a definite direction which constitutes a net current in it. These electrons are accelerated by electric field in the conductor produced by potential difference across the conductor. They move with a constant drift velocity. The direction of current is along the flow of positive charge (or opposite to flow of negative charge). $i = nv_d eA$, where v_d = drift velocity.

3. Charge Current and Current Density

The strength of the current i is the rate at which the electir charges are flowing. If a charge Q coulomb passes through a given cross section of the conductor in t second the current I through the conductor is given by

$$I = \frac{Q \text{ coulomb}}{t \text{ second}} = \text{ampere}$$

Ampere is the unit of current. If i is not constant then $i = \frac{dq}{dt}$, where dq is net charge transported at a section in time dt. In a current carrying conductor we can define a vector which gives the direction as current per unit normal, cross sectional area & is known as current density.

Thus $\vec{J} = \frac{I}{S}\hat{n}$ or $I = \vec{J}.\vec{S}$

Where $\hat{n}$ is the unit vector in the direction of the flow of current.

For random J or S, we use $I = \int \vec{J}.\vec{ds}$

4. Relation in J, E and V_D :

In conductors drift velocity of electrons is proportional to the electric field inside the conductor as; $V_d = \mu E$ where μ is the mobility of electrons

current density is given as $J = \frac{I}{A}$ $ne V_d = ne(\mu E) = \sigma E$

where $\sigma = ne\mu$ is called conductivity of material and we can also write

$\rho = \frac{1}{\sigma} \rightarrow$ resistivity of material.

Thus $E = \rho . J$. It is called as differential form of Ohm`s Law.

5. Sources of Potential Difference & Electromotive Force :

Dry cells, secondary cells, generator and thermo couple are the devices used for producing potential difference in an electric circuit. The potential difference between the **"Electromotive force"** or **"EMF"** of the source. The unit of potential difference is volt.

1 volt = 1 Ampere × 1 Ohm.

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6. Electircal Resistance :

The property of a substance which opposes the flow of electric current through it, is termed as electrical resistance. Electrical resistance depends on the size, geometery, temperature and internal structure of the conductor.

7. Law of Resistance

The resistance R offered by a conductor depends on the following factors :

$R \propto \ell$ (length of the conductor) ; $R \propto \frac{1}{A}$ (cross section area of the conductor) at a given temperature $R = \rho\frac{\ell}{A}$.

where ρ is the resistivity of the material of the conductor at the given temperature. It is also known as **specific resistance** of the material & it depends upon nature of conductor.

8. Dependence of Resistance on Temperature :

The resistance of most conductors and all pure metals increases with temperature, but there are a few in which resistance decreases with temperature.

If R_o & R be there are few in which resistance of a conductor at 0 °C and θ °C, then it is found that $R = R_o (1 + \alpha\theta)$. Here we assume that the dimensions of resistance do not change with temperature if expension coefficient of material is considerable. Then instead of resistance we use same property for resistivity as $\rho = \rho_o (1 + \alpha\theta)$. The material for which resistance decreases with temperature, the temperature coefficient of resistance is negative.

Where α is called the temperature co-efficient of resistance. The unit of α is K^{-1} or $^oC^{-1}$. Resiprocal of resistivity is called conductivity and reciprocal of resistance is called conductance (G). S.I. unit of G is mho.

**9. Ohm`s Law :** Ohm`s law is the most fundamental law of all the laws in electricity. It says that the current through the cross section of the conductor is proportional to the applied potential difference under the given physical condition. V = RI. Ohm`s law is applicable to only metallic conductors.

10. KRICHHOFF'S LAW'S :

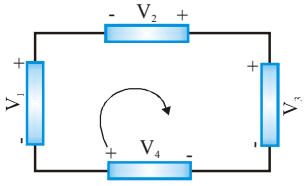
(a) I - Law (Junction law or Nodal Analysis) : This law is based on law of conservation of charge. It states that "The algebric sum of the currents meeting at a point is zero" or total currents entering a junction equal s total current leaving the junction.

$$\sum I_{in} = \sum I_{out}$$

It is also known as KCL (Kirchoff's current law).

(b) II - Law (Loop analysis) : The algebric sum of all the voltages in closed circuit is zero.

$\sum IR = \sum EMF = 0$ in a closed loop. The closed loop can be traversed in any direction. While traversing a loop if higher potential point is entered, put a +ve sign in expression or if lower potential point is entered put a negative sign.



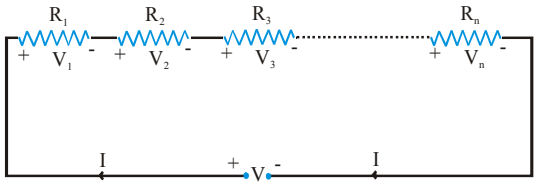
$-V_1 - V_2 + V_3 - V_4 = 0$. Boxes may contain resistor or battery or any other element (linear or non-linear).

It is also known as **KVL (Kirchoff's voltage law)**.

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11. COMBINATION OF RESISTANCES :

A number of resistance can be connected and all the complited combinations can be reduced to two different types, namely series and parallel.



(a) Resistance in Series :

When the resistance are connected end to end then they are said to be in series. The current through each resistor is same the effective resistance appearing across the battery.

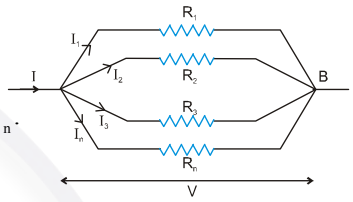
$R = R_1 + R_2 + R_3 + ...+ R_n$ and $V = V_1 + V_2 + V_3 + ...+ V_n$

The voltage across a resistor is proportion to the resistance

$$V_1 = \frac{R_1}{R_1 + R_2 + ...+ R_n} V \; ; \; V_2 = \frac{R_2}{R_1 + R_2 + ...+ R_n} V \; ; \text{ etc}$$

(b) Resistance in Parallel :

A parallel circuit of resistors is one, in which the same voltage is applie across all the components in a parallel grouping of resistors R_1, R_2, R_3, ...R_n.



12. Conclusion :

(a) Potential difference across each resistor is same.

(b) $I = I_1 + I_2 + I_3 + ...I_n$

(c) Effective resistance (R) then $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...+ \frac{1}{R_n}$

(d) Current in different resistors is inversally proportional to the resistance.

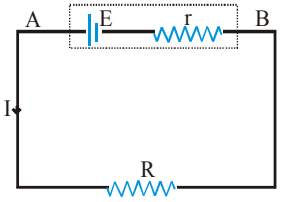
$$I_1 : I_2 : ..... I_n = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...+ \frac{1}{R_n}$$

$$I_1 = \frac{G_1}{G_1 + G_2 + ...G_n} I \; , \; I_2 = \frac{G_2}{G_1 + G_2 + ...G_n} I \text{ , etc.}$$

where $G = \frac{I}{R}$ = Conducatance of a resistor.

13. EMF of a Cell & its Internal Resistance :

If a cell emf E and internal resistance r be connected with a resistance R the total resistance of the circuit is (R + r).



$$I = \frac{E}{R + r} \; ; \; V_{AB} = \frac{E}{R + r}$$

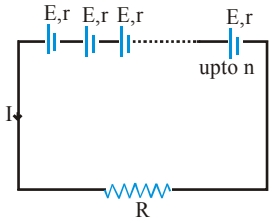
where V_{AB} = Terminal voltage of the battery.

If $r \to 0$, cell is Ideal & $V \to E$ & $r = R\left(\frac{E}{V} - 1\right)$

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14. Grouping of Cells :

(a) Cells in Series : Let there be n cells each of emf E, arranged in series. Let r be the internal resistance of each cell. The total emf = n E. Current in the circuit $I = \frac{nE}{R + nr}$.

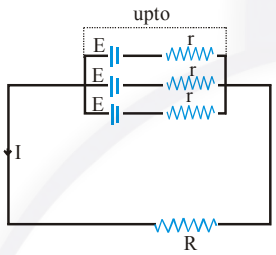


If nr << R then $I = \frac{nE}{R}$ → Series combination should be used

If nr >> R then $I = \frac{E}{R}$ → Series combination should not be used.

(b) Cells in Parallel : If m cells each of emf E & internal resistance r be connected in parallel and if this combination be connected to an external resistance then the emf of the circuit = E.

Internal resistance of the circuit = $\frac{r}{m}$.



$$I = \frac{E}{R + \frac{r}{m}} = \frac{mE}{mR + r}$$

If mR << r then $I = \frac{mE}{r}$ → Parallel combination should be used.

If mR >> r then $I = \frac{E}{R}$ → Parallel combination should be used.

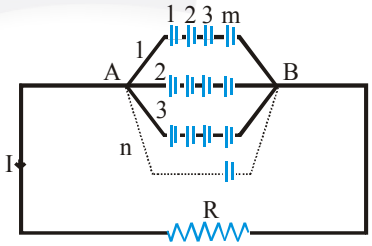
(c) Cells in Multiple Arc :

mn = number of identical cells.

n = number of rows

m = number of cells in each rows.

The combination of cells in each equivalent to single cell of :



(a) emf = mE & **(b)** internal resistance = $\frac{mr}{n}$

Current $I = \frac{mE}{R + \frac{mr}{n}}$

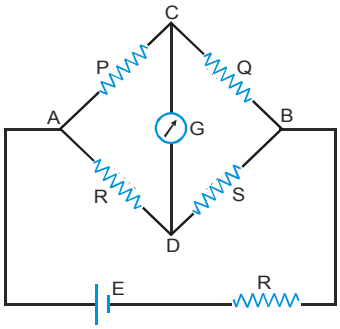
For maximum current

nR = mr or $R = \frac{mr}{n}$ so $I_{max} = \frac{nE}{2r} = \frac{mE}{2R}$

For a cell to deliver maximum power across the load internal resistance = load resistance

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15. Wheat Stone Network :



When current through the galvanometer is zero

(null point or balance point) $\frac{P}{Q}=\frac{R}{S}$.

When

$PS > QR, V_C < V_D$ & $PS < QR, V_C > V_D$

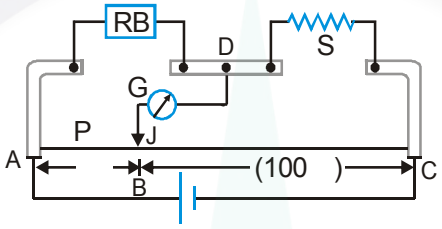
or $PS = QR \Rightarrow$ product of opposite arms are equal. Potential difference between

C & D at null point is zero. The null point is not affected by resistance of G & E. It is not affected even if the position of G & E are intercharged.

$$I_{CD} \propto (QR - PS)$$

16. Metre Bridge

At balance condition : $\frac{P}{Q}=\frac{R}{S} \Rightarrow \frac{r\ell}{r(100-\ell)}=\frac{R}{S} \Rightarrow S=\frac{(100-\ell)}{\ell}R$

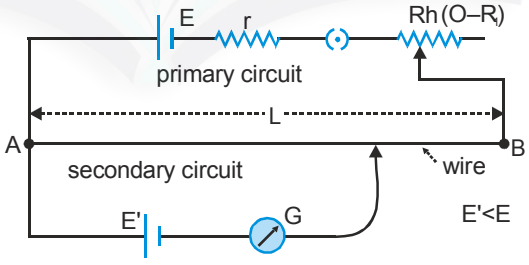


17. Potentiometer :

A potentiometer is a linear conductor of uniform cross-section with a steady current set up in it. This maintains a uniform potential gradient along the length of the wire. Any potential difference which is less than the potential difference maintained across the potentiometer wire can be measured using this. The potentiometer equation is

$\frac{E_1}{E_2}=\frac{\ell_1}{\ell_2}$.

Circuits of potentiometer :



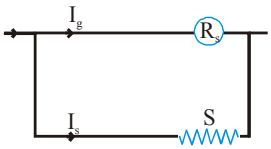
$$x=\frac{V}{L}=\frac{\text{current} \times \text{resistance of potentiometer wire}}{\text{length of potentiometer wire}}=I\left(\frac{R}{L}\right)$$

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18. Ammeter :

It is a modified form of suspended coil galvanometer, it is used to measure current. A shunt (small resistance) is connected in parallel with galvanometer to convert into ammeter.

$$S = \frac{I_g R_g}{I - I_g}$$



where

R_g = galvanometer resistance

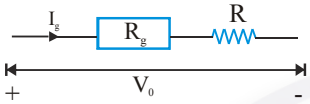
I_g = Maximum current that can flow through the galvanometer.

I = Maximum current that can be measured using the given ammeter.

An ideal ammeter has zero resistance

19. Voltmeter :

A high resistance is put in series with galvanometer. It is used to measure potential difference.



$$I_g = \frac{V_o}{R_g + R}; R \to \infty \text{ , Ideal voltmeter}$$

20. Electrical Power :

The energy librated per second in a device is given by P = VI, where V = potential difference across device & I = current enters the higher potential point difference across device then power is consumed by it (i.e. acts as load). If the current enters the lower potential point then the device supplies power (i.e., acts as source)

Power consumed by a resistor $P = I^2R = VI = \frac{V^2}{R}$

21. Heating Effect of Electric Current :

When a current is passed through a resistor energy is wasted in over coming the resistance of the wire. The energy is converted into heat

$$W = VIt = I^2Rt = \frac{V^2}{R}t$$

22. Joules Law of Electric Heating :

The heat generated (in joules) when a current of I ampere flows through a resistance of R ohm for T second is given by :

$$H = I^2RT \text{ joule} = \frac{I^2Rt}{4.2} \text{ calories.}$$

If current is variable passing through the conductor then we use for heat produced in resistance in time 0 to T is :

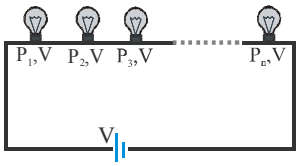
$$H = \int_0^T I^2 R dt$$

23. Unit of Electrical Energy Consumption :

1 unit of electrical energy = kilowatt hour = 1 kWh = 3.6×10^6 joules

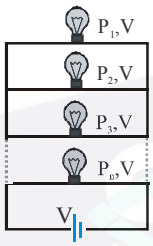
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(a) Series combination of Bulbs



$$\frac{1}{P_{total}} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3} + ...$$

(b) Parallel combination of Bulbs



$$P_{total} = P_1 + P_2 + P_3 + ...$$

24. A current flows through a conductor only when there is an electric field within the conductor because the drift velocity of electrons is directly proportional to the applied electric field.

25. Electric field outside the conducting wire which carries a constant current is zero beacuse net charge on a current carrying conductor is zero.

26. A metal has a resistance and gets often heated by flow of current because when free electrons drift through a metal, they make occasional collisions with the lattice. These collisions are inelastic and transfer energy to the lattice as internal energy.

27. Ohm's law holds only for small current in metallic wire, not for high currents because resistance increased with increase in temperature.

28. Potentiometer is an ideal instrument to measure the potential difference because potential gradient along the potentiometer wire can be made very small.

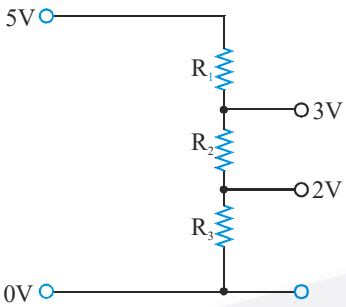
29. An ammeter is always connected in series whereas a voltmeter is connected in parallel becuase an ammeter is a low-resistance galvanometer while a voltmeter is a high-resistance galvanometer.

30. Current is passed through a metallic wires, heating it red, when cold water is poured over half of the portion, rest of the portion becomes more hot because resistance decreases due to decrease in temperature so current through wire increases.

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SOLVED EXAMPLE

Ex. 1 A potential divider is used to give outputs of 2V and 3V from a 5V source, as shown in figure. Which combination of resistances, R_1, R_2 and R_3 gives the correct voltages?



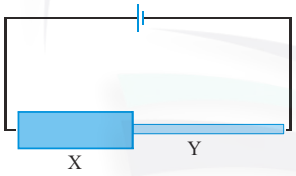
	R_1	R_2	R_3
(A)	1 kΩ	1 kΩ	2 kΩ
(B)	2 kΩ	1 kΩ	2 kΩ
(C)	3 kΩ	2 kΩ	2 kΩ
(D)	3 kΩ	2 kΩ	3 kΩ

Sol. For resistors in series connection, current (I) is the same through the resistors. In other words, ratio of the voltage drop across each resistor with its resistance is the same.

That is $I = \frac{5-3}{R_1} = \frac{3-2}{R_2} = \frac{2}{R_3}$

i.e., $R_1 : R_2 : R_3 = 2 : 1 : 2$.

Ex. 2 Figure shows a thick copper rod X and a thin copper wire Y, joined in series. They carry a current which is sufficient to make Y much hotter than X. Which one of the following is correct?



	Density of conduction electrons	Mean time between collisions of the electrons
(A)	Same in X and Y	Less in X than Y
(B)	Same in X and Y	Same in X and Y
(C)	Same in X and Y	More in X than Y
(D)	More in X than Y	less in X than Y

Sol. The number density n of conduction electrons in the copper is a characteristic of the copper and is about 10^{29} at room temperature for both the copper rod X and the thin copper wire Y.

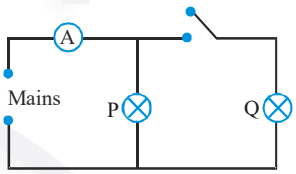
Both X and Y carry the same current I since they are joined in series.

From $I = neAv_d$

We may conclude that rod X has a lower drift velocity of electrons compared to wire Y since rod X has larger cross-sectional area. This is so because the electrons in X collide more often with one another and with the copper ions when drifting towards the positive end. Thus, the mean time between collisions of the electrons is more in X and than in Y.

Ex. 3 How will the reading in the ammeter A of figure be affected if another identical bulb Q is connected in parallel to P as shown. The voltage in the mains is maintained at a constant value.

(A) The reading will be reduced to one-half



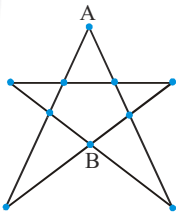
(B) The reading will not be affected

(C) The reading will be doubled of the previous one

(D) The reading will be increased four-fold

Sol. Resistance is halved . Current is doubled.

Ex. 4 The resistance of all the wires between any two adjacent dots is R. The equivalent resistance between A and B as shown in figure is



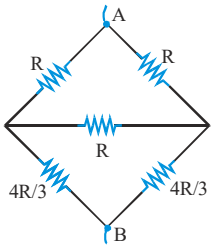
(A) $\frac{7}{3}R$

(B) $\frac{7}{6}R$

(C) $\frac{14}{8}R$

(D) None of these

Sol. Given circuit can be reduce to

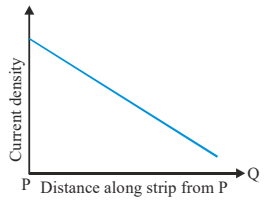


$R_{AB} = \frac{7}{6}R$

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Ex. 5 An electric current flows along an insulated strip PQ of a metallic conductor. The current density in the strip varies as shown in the graph. Which one of the following statements could explain this variation?

(A) The strip is narrower at P than at Q



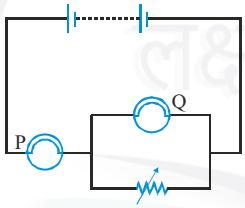
(B) The strip is narrower at Q than at P

(C) The potential gradient along the strip is uniform

(D) The resistance per unit length of the strip is constant

Sol. The current density at P is higher than at Q. For the same current flowing through the metallic conductor PQ, the cross-sectional area at P is narrower than at Q. The resistance per unit length r is given by $r = \frac{\rho}{A}$ where ρ is the resistivity and A is the cross-sectional area of the conductor PQ. Thus, r is inversely proportional to the cross-sectional area A of the conductor.

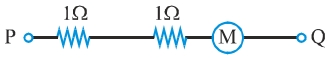
Ex. 6 The circuit shown in figure, contains a battery, a rheostat and two identical lamps. What will happen to the brightness of the lamps if the resistance of the rheostat is increased?

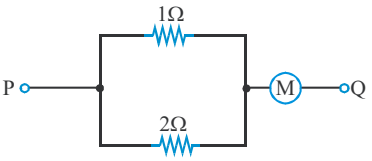


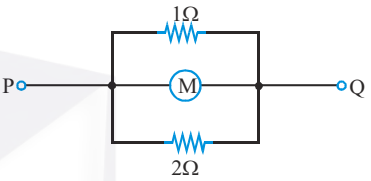
	Lamp P	Lamp Q
(A)	Less brighter	Brighter
(B)	Less brighter	Less brighter
(C)	Brighter	Less brighter
(D)	No change	Brighter

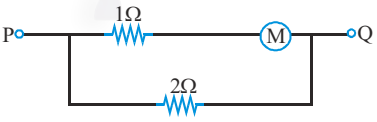
Sol. Consider two extreme cases. **(i)** When the resistance of the rheostat is zero, the current through Q is zero since Q is short-circuited. The circuit is then essentially a battery in series with lamp P. **(ii)** When the resistance of the rheostat is very large, almost no current flows through it. So, the currents through P and Q are almost equal. The circuit is essentially a battery in series with lamps P and Q.

Ex. 7 In which one of the following arrangements of resistors does the ammeter M, which has a resistance of 2Ω, give the largest reading when the same potential difference is applied between points P and Q?

(A)


(B)


(C)


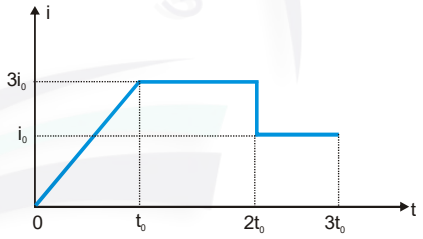
(D)


Sol. Let $V_{PQ} = E$

For **(A)** : $I = \frac{E}{4}$ For **(B)** : $I = \frac{E}{\frac{2}{3}+2} = \frac{E}{\frac{8}{3}}$

For **(C)** : $I = \frac{E}{2}$ For **(D)** : $I = \frac{E}{3}$

Ex. 8 A time varying current i is passed through a resistance R as shown in figure. The total heat generated in the resistance is



(A) $11i_0^2Rt_0$ **(B)** $13i_0^2Rt_0$

(C) $17i_0^2Rt_0$ **(D)** $15i_0^2Rt_0$

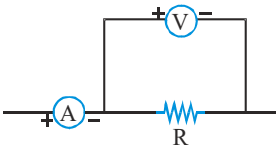
Sol. Total heat produced =

$$\int_0^{t_0}\left(\frac{3i_0}{t_0}t\right)^2 Rdt + (3i_0)^2 R(2t_0 - t_0) + i_0^2R(3t_0 - 2t_0)$$

$$= 3i_0^2Rt_0 + 9i_0^2Rt_0 + i_0^2Rt_0 = 13i_0^2Rt_0$$

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Ex. 9 A candidate connects a moving coil voltmeter V, a moving coil ammeter A and a resistance R as shown in figure. If the voltmeter reads 20 V and the ammeter reads 4A, R is



(A) equal to 5Ω

(B) greater than 5Ω

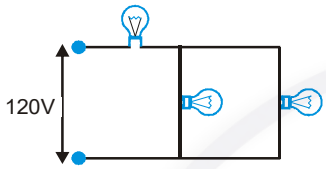
(C) less than 5Ω

(D) greater or less than 5Ω depending upon its material

Sol. Let a current of x ampere passes through the voltmeter, then (4–x) ampere passes through the resistance R. Therefore, voltmeter reading

$$20 = (40 - x)\,R \;\therefore\; R = \frac{20}{4-x}, \text{ i.e., } R > 5\Omega$$

Ex. 10 Three 60W, 120V light bulbs are connected across a 120 V power source. If resistance of each bulb does not change with current then find out total power delivered to the three bulbs.



(A) 180 W **(B)** 20 W

(C) 40 W **(D)** 60 W

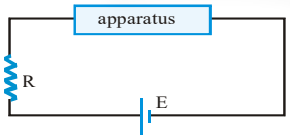
Sol.



Here $R = \frac{V^2}{P}$, Total power supplied

$$= \frac{V^2}{3/2R} = \left(\frac{2}{3}\right)\left(\frac{V^2}{R}\right) = \frac{2}{3} \times 60 = 40W$$

Ex. 11 An apparatus is connected to an ideal battery as shown in figure. For what value of current, power delivered to the apparatus will be maximum?

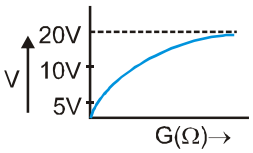


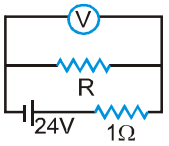
(A) $\frac{E}{R}$ **(B)** $\frac{E}{2R}$

(C) $\frac{E}{4R}$ **(D)** information insufficient

Sol. For maximum power $R_{ext} = R_{int} = R \;\therefore$ current $= \frac{E}{2R}$

Ex. 12 A cell of internal resistance 1Ω is connected across a resistor. A voltmeter having variable resistance is used to measure potential difference across resistor. The plot of voltmeter reading V against G is shown. What is value of external resistor R ? (G = Resistance of galvanometer)





(A) 5 Ω **(B)** 4 Ω

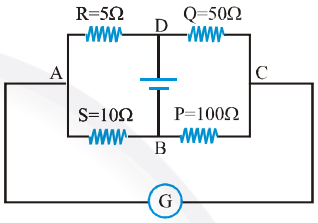
(C) 3 Ω **(D)** can't be determined

Sol. When galvanometer resistance tends to infinity $G \to \infty$,

Potential difference across R is 20V $\Rightarrow 20 = 24 - i \times 1$

$\Rightarrow i = 4\,A$ also $20 = 4 \times R \Rightarrow R = 5\Omega$.

Ex. 13 Figure shows a balanced Wheatstone's bridge



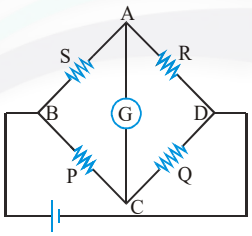
(A) If P is slightly increased, the current in the galvanometer flows from C to A

(B) If P is slightly increased, the current in the galvanometer flows from A to C

(C) If Q is slightly increased, the current in the galvanometer flows from C to A

(D) If Q is slightly increased, the current in the galvanometer flows from A to C

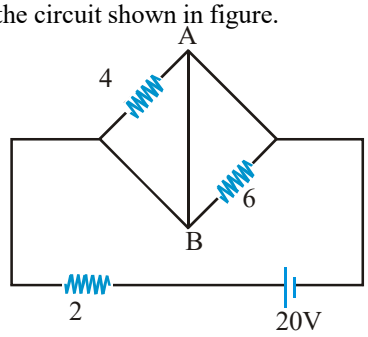
Sol.



If P is slightly increased, potential of C will decrease. Hence current will from A to C. If Q is slightly increased, potential of C will increases, hence current will flow from C to A.

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Ex. 14 In the circuit shown in figure.



(A) power supplied by the battery is 200W

(B) current flowing in the circuit is 5A

(C) potential difference across the 4Ω resistance is equal to the potential difference across the 6Ω resistance

(D) current in wire AB is zero.

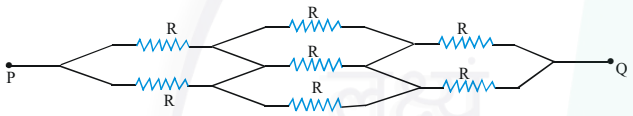
Sol. **(ACD)**

4Ω and 6Ω resistor are short-circuited. Therefore, no current will flow through these resistances. Current passing through the battery is I = (20/2) = 10A. This is also the current passing in wire AB from B to A.

Power supplied by the battery P = EI = (20) (10) = 200W

Potential difference across the 4Ω resistance = potential difference across the 6Ω resistance.

Ex. 15 Equivalent resistance for the given figure between P and Q is NR/3. Find value of N.

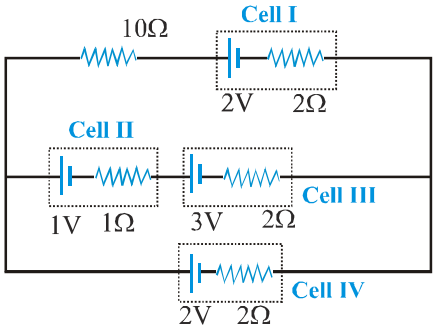


Sol.



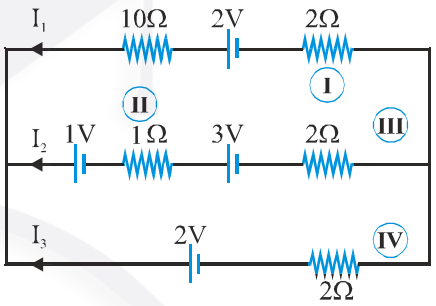
$$R_{net} = \frac{4R}{3} \Rightarrow N = 4$$

Ex. 16 For the circuit shown in figure, 4 cells are arranged. In column I, the cell number is given while in column II, some statements related to cells are given. Match the entries of column I with the entries of column II.



Column I	Column II
(A) Cell I	**(P)** Chemical energy of cell is decreasing.
(B) Cell II	**(Q)** Chemical energy of cell is increasing.
(C) Cell III	**(R)** Work done by cell is positive.
(D) Cell IV	**(S)** Thermal energy developed in cell is positive.
	(T) None of these

Sol. We have, $I_1 = -\frac{2}{33}A, I_2 = \frac{14}{33}A, I_3 = -\frac{12}{33}A$



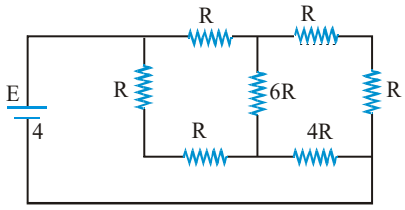
In each cell thermal energy will be dissipated due to internal resistance whether the chemical energy of the cell is increasing or decreasing.

(i) Cell I is getting charged, hence its chemical energy increases.

(ii) Cell II and III both are getting discharged, hence their chemical energy is decreasing. So, work done by both of them is positive.

(iv) Cell IV is getting charged, hence its chemical energy increases.

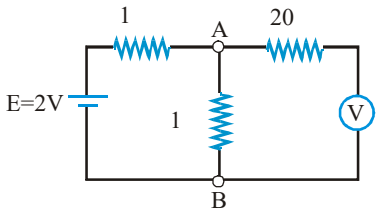
Ex. 17 A battery of internal resistance 4Ω is connected to the network of resistances as shown in figure. In order that the maximum power can be delivered to the network, the value of R in Ω should be



Sol. For maximum power, external resistance is equal to internal resistance. Therefore, 2R = 4 or R =2

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Ex. 18 In the given circuit, the voltmeter and the electric cell are ideal. Find the reading of the voltmeter (in volt)



Sol. The electric current through ideal voltmeter is zero.

According to loop rule, $E - 1 \times I - 1 \times I = 0$

$$\Rightarrow I = \frac{E}{2} = \frac{2}{2} = 1A$$

Reading of the voltmeter $= V_A - V_B = [1 \times I] = [1 \times 1] = 1V$

Ex. 19 A wire of length L and 3 identical cells of negligible internal resistances are connected in series. Due to the current, the temperature of the wire is raised by ΔT in a time t. A number N of similar cells is now connected in series with a wire of the same material and cross-section but of length 2L. The temperature of the wire is raised by the same amount ΔT in the same time t, the value of N is

Sol. Let R be the resistance of wire. Let R' be the resistance of another wire so R'=2R ($\because$ Length is twice)

In case **(i)** Energy released in t second $= \frac{(3V)^2}{R} \times t$

In case **(ii)** $\therefore$ Energy released in t-seconds $= \frac{(N^2V^2)}{2R} \times t$

But $Q = mc\Delta T$ $\quad \therefore \; mc\Delta T = \frac{(9V^2)}{R} \times t$ ...**(i)**

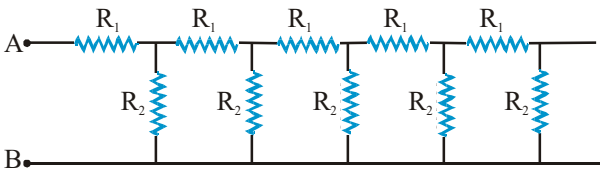
Applying $Q' = m'c\Delta T \Rightarrow 2mc\Delta T = \frac{(N^2V^2)}{2R} \times t$...**(ii)**

Dividing equation **(ii)** by equation **(i)**

$$\frac{mc\Delta T}{2mc\Delta T} = \frac{9V^2 \times t/R}{N^2V^2 \times t/2R} \quad \therefore \quad \frac{1}{2} = \frac{9 \times 2}{N^2}$$

$\Rightarrow N^2 = 18 \times 2 \quad \therefore \; N = 6$

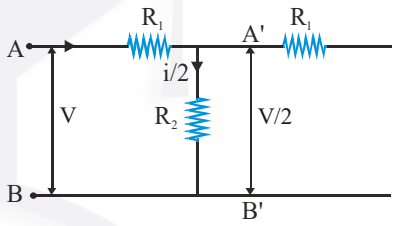
Ex. 20 Consider an infinite ladder of network shown in figure. A voltage is applied between points A and B. If the voltage is halved after each section, find the ratio of $\frac{R_2}{R_1}$.



Sol. Voltage across AB = V, Voltage across A'B' = $\frac{V}{2}$

i.e., Voltage across $R_2 = \frac{V}{2}$

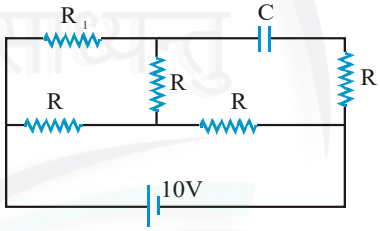
Now from Kirchhoff's law it is obvious that voltage across $R_1 = V - \frac{V}{2} = \frac{V}{2}$



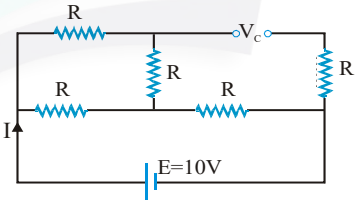
When the voltage is halved, current is also halved, i.e., current in R_2 is half of that in R_1.

So $R_1 i = R_2 \frac{i}{2} \Rightarrow \frac{R_2}{R_1} = 2$

Ex. 21 Find the potential difference across the capacitor in volts.



Sol.

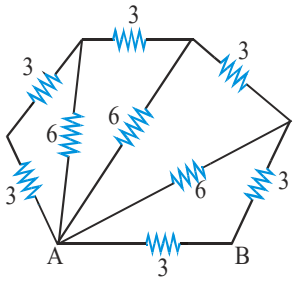


In steady state $I = \frac{E}{2R/3 + R} = \frac{3E}{5R}$;

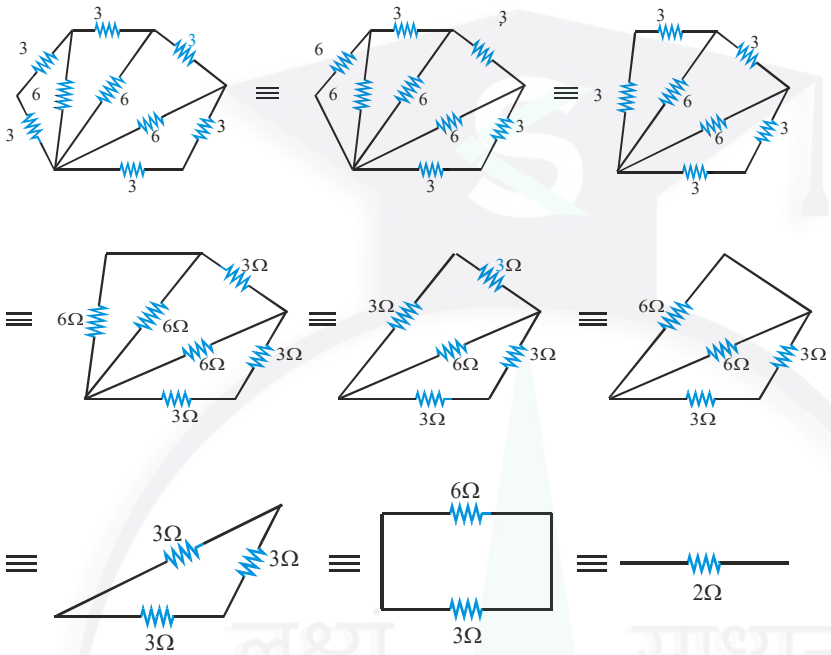
$$V_C = E - \frac{IR}{3} = E - \frac{E}{5} = \frac{4E}{5} = 8 \text{ Volts}$$

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Ex. 22 All resistances in the diagram below are in ohms. Find the effective resistance between the point A and B (in Ω).



Sol. The given system can be reduced as shown in figure.

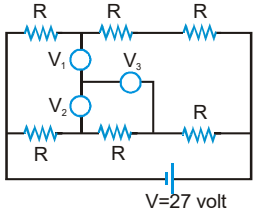


Ex. 23 How much time heater will take to increase the temperature of 100 g water by 50°C if resistance of heating coil is 484Ω and supply voltage is 220V a.c.

Sol. Heat given by heater = heat taken by water $\Rightarrow \frac{V^2}{R} t = ms J\Delta\theta \Rightarrow \frac{220 \times 220}{484}$

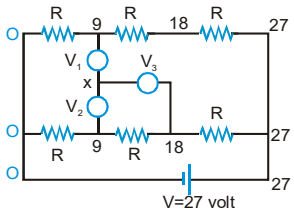
$t = (100 \times 10^{-3})(4.2 \times 10^{3})(50) \Rightarrow t = 210\ s$

Ex. 24 In the circuit shown below, all the voltmeter identical and have very high resistance. Each resistor has the same resistance. The voltage of the ideal battery shown is 27 V. Find the reading of voltmeter V_3 (in volts).



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Sol.

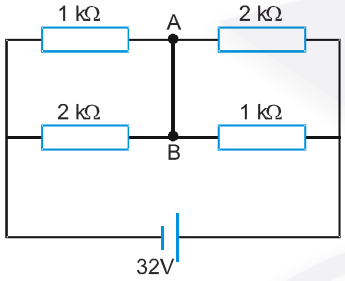


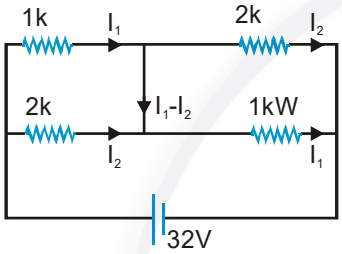
$$\frac{x-9}{R_V}+\frac{x-9}{R_V}+\frac{x-18}{R_V}=0$$

$\Rightarrow x=12 \quad \therefore V_3=6$ volt

Ex. 25 In the given circuit, find the current (in mA) in the wire between points A and B.

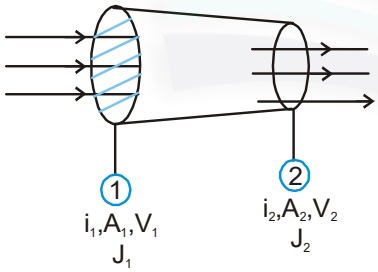
Sol.





$I_1=16$ mA; $I_2=8$mA $\Rightarrow I_1-I_2=8$mA

Ex. 26 Current is flowing from a conductor of non-uniform cross section area if $A_1 > A_2$ then find relation between



(A) i_1 and i_2

(B) j_1 and j_2

(C) v_1 and v_2 (drift velocity)

where i is current, j is current density and V is drift velocity.

Sol. **(A)** i = charge flowing through a cross-section per unit time.

$\therefore \quad i_1=i_2$

(B) $j=\frac{i}{A}$ as $A_1>A_2$ then $j_1<j_2$

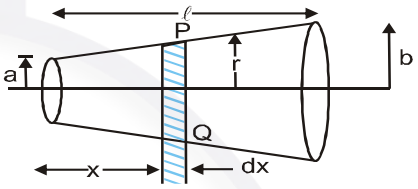
(C) $j=nev_d \quad \Rightarrow v_d=\frac{j}{ne}$ as $j_1<j_2$

then, $v_1<v_2$

Ex. 27 Figure shows a conductor of length ℓ having a circular cross-section. The radius of cross-section varies linearly from a to b. The resistivity of the material is ρ. Find the resistance of the conductor.



Sol. In this problem cross–section area is variable so we



can't apply formula $\left(R=\frac{\rho\ell}{A}\right)$ directly.

So we assume elementary strip 'PQ' of thickness dx

and radius r resistance of this strip is : $dR=\frac{\rho dx}{\pi r^2}$

By geometry $=\frac{r-a}{x}=\frac{b-a}{\ell}$

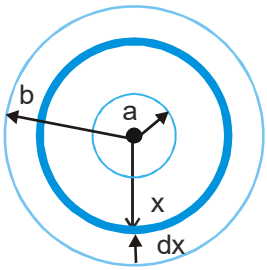
$\Rightarrow r=\frac{b-a}{\ell}x+a$

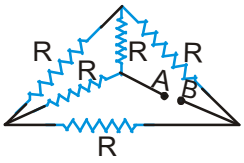
resistance of conductor is

$$R=\int_0^{\ell}\frac{\rho dx}{\pi\left\{\frac{b-a}{\ell}x+a\right\}^2} \Rightarrow R=\frac{\rho\ell}{\pi ab}$$ **Ans.**

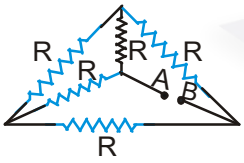
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Ex. 28. Find the equivalent Resistance between A and B

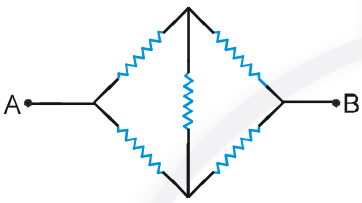


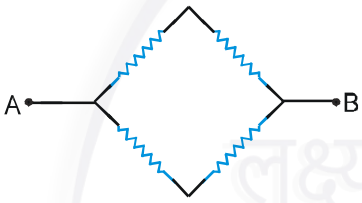


Sol.



Putting A out of the structure in the same plane





$R_{eq} = \frac{2R \times 2R}{2R + 2R} = R$ **Ans. : Req = R**

Ex. 29 A cylindrical tube of length ℓ has inner radius a while outer radius b. What is the resistance of the tube between **(A)** its ends **(B)** its inner and outer surfaces ? (the resistivity of its material is ρ)

Sol. **(A)** $A = \pi(b^2 - a^2)$



$$R = \frac{\rho\ell}{\pi(b^2 - a^2)}$$

(B) $d_R = \frac{\rho dx}{2\pi x \ell}$ for a section taken at distance x from centre.

$$d_R = \frac{\rho}{2\pi\ell} \cdot \frac{dx}{x}$$

$$\Rightarrow R = \int dR = \frac{\rho}{2\pi\ell} \int_a^b \frac{dx}{x} = \frac{\rho}{2\pi\ell} \ell n \frac{b}{a}$$

Ex. 30 How can we convert a galvanometer with $R_g = 20\ \Omega$ and $i_g = 1.0$ mA into a voltmeter with a maximum range of 10 V ?

Sol. $v = i_g R_S + i_g R_g$

$10 = 1 \times 10^{-3} \times R_s + 1 \times 10^{-3} \times 20$

$$R_S = \frac{10 - 0.02}{1 \times 10^{-3}} = \frac{9.98}{10^{-3}} = \mathbf{9980\ \Omega}$$

Ex. 31 What shunt resistance is required to convert the 1.0 mA, 20Ω galvanometer into an ammeter with a range of 0 to 50mA ?

Sol. $i_g R_g = (i - i_g)S$

$i_g = 1.0 \times 10^{-3}$ A , $G = 20\Omega$

$i = 50 \times 10^{-3}$ A

$$S = \frac{i_g R_g}{i - v_g} = \frac{1 \times 10^{-3} \times 20}{49 \times 10^{-3}} = 0.408\ \Omega$$

Ex. 32 A Potentiometer wire of 10 m length and having 10 ohm resistance, emf 2 volts and a rheostat. If the potential gradient is 1 micro volt/mm, the value of resistance in rheostat in ohms will be :

(A) 1.99 **(B)** 19.9

(C) 199 **(D)** 1990

Sol. d = 10 m , R = 10Ω ,

E = 2volts , $\frac{dv}{d\ell} = 1\mu$ v/mm

$$\frac{dv}{d\ell} = \frac{1 \times 10^{-6}}{1 \times 10^{-3}} \text{ v/m} = 1 \times 10^{-3} \text{ v/m}$$

Across wire potential drop ,

$$\frac{dv}{d\ell} \times \ell = 1 \times 10^{-3} \times 10 = 0.01 \text{ volts}$$

$$i = \frac{0.01}{10} = 0.001$$

$$= \frac{E}{R + R'} \quad (R' = \text{resistance of rheostat})$$

$$R' = \frac{E}{0.001} - R = \frac{2}{0.001} - 10$$

$= 2000 - 10 = 1990\ \Omega$

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Exercise # 1 SINGLE OBJECTIVE NEET LEVEL

1. Current of 4.8 amperes is flowing through a conductor. The number of electrons per second will be

(A) 3×10^{19} **(B)** 7.68×10^{21}

(C) 7.68×10^{20} **(D)** 3×10^{20}

2. When the current i is flowing through a conductor, the drift velocity is ν. If $2i$ current is flowed through the same metal but having double the area of cross-section, then the drift velocity will be

(A) $v/4$ **(B)** $v/2$

(C) ν **(D)** 4ν

3. When current flows through a conductor, then the order of drift velocity of electrons will be

(A) 10^{10} m / sec **(B)** 10^{-2} cm / sec

(C) 10^{4} cm / sec **(D)** 10^{-1} cm / sec

4. Every atom makes one free electron in copper. If 1.1 ampere current is flowing in the wire of copper having 1 mm diameter, then the drift velocity (approx.) will be (Density of copper $=9\times10^{3}$ kg m^{-3} and atomic weight = 63)

(A) 0.3 mm / sec **(B)** 0.1 mm / sec

(C) 0.2 mm / sec **(D)** 0.2 cm / sec

5. Which one is not the correct statement

(A) 1 volt × 1 coulomb = 1 joule

(B) 1 volt × 1 ampere = 1 joule / second

(C) 1 volt × 1 watt = 1 H.P.

(D) Watt-hour can be expressed in eV

6. If a 0.1 % increase in length due to stretching, the percentage increase in its resistance will be

(A) 0.2 % **(B)** 2 %

(C) 1 % **(D)** 0.1 %

7. The specific resistance of manganin is 50×10^{-8} ohm × m. The resistance of a cube of length 50 cm will be

(A) 10^{-6} ohm **(B)** 2.5×10^{-5} ohm

(C) 10^{-8} ohm **(D)** 5×10^{-4} ohm

8. The resistivity of iron is 1×10^{-7} *ohm* $-m$. The resistance of a iron wire of particular length and thickness is 1 *ohm*. If the length and the diameter of wire both are doubled, then the resistivity in *ohm* $-m$ will be

(A) 1×10^{-7} **(B)** 2×10^{-7}

(C) 4×10^{-7} **(D)** 8×10^{-7}

9. The temperature coefficient of resistance for a wire is $0.00125\ /°C$. At $300K$ its resistance is 1 *ohm*. The temperature at which the resistance becomes 2 *ohm* is

(A) 1154 K **(B)** 1100 K

(C) 1400 K **(D)** 1127 K

10. When the length and area of cross-section both are doubled, then its resistance

(A) Will become half

(B) Will be doubled

(C) Will remain the same

(D) Will become four times

11. The resistance of a wire is 20 *ohms*. It is so stretched that the length becomes three times, then the new resistance of the wire will be

(A) 6.67 *ohms* **(B)** 60.0 *ohms*

(C) 120 *ohms* **(D)** 180.0 *ohms*

12. The resistivity of a wire

(A) Increases with the length of the wire

(B) Decreases with the area of cross-section

(C) Decreases with the length and increases with the cross-section of wire

(D) None of the above statement is correct

13. *Ohm*'s law is true

(A) For metallic conductors at low temperature

(B) For metallic conductors at high temperature

(C) For electrolytes when current passes through them

(D) For diode when current flows

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14. The example for non-*ohm*ic resistance is

(A) Copper wire **(B)** Carbon resistance

(C) Diode **(D)** Tungston wire

15. Drift velocity v_d varies with the intensity of electric field as per the relation

(A) $v_d \propto E$ **(B)** $v_d \propto \frac{1}{E}$

(C) v_d = constant **(D)** $v_d \propto E^2$

16. On increasing the temperature of a conductor, its resistance increases because

(A) Relaxation time decreases

(B) Mass of the electrons increases

(C) Electron density decreases

(D) None of the above

17. In a conductor 4 *coulombs* of charge flows for 2 *seconds*. The value of electric current will be

(A) 4 *volts* **(B)** 4 *amperes*

(C) 2 *amperes* **(D)** 2 *volts*

18. The specific resistance of a wire is ρ, its volume is 3 m^3 and its resistance is 3 *ohms*, then its length will be

(A) $\sqrt{\frac{1}{\rho}}$ **(B)** $\frac{3}{\sqrt{\rho}}$

(C) $\frac{1}{\rho}\sqrt{3}$ **(D)** $\rho\sqrt{\frac{1}{3}}$

19. 62.5×10^{18} electrons per second are flowing through a wire of area of cross-section $0.1\ m^2$, the value of current flowing will be

(A) 1 A **(B)** 0.1 A

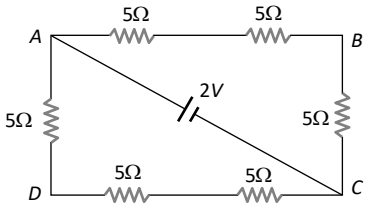
(C) 10 A **(D)** 0.11 A

20. A piece of wire of resistance 4 *ohms* is bent through $180°$ at its mid point and the two halves are twisted together, then the resistance is

(A) 8 *ohms* **(B)** 1 *ohm*

(C) 2 *ohms* **(D)** 5 *ohms*

21. The potential difference between points A and B of adjoining figure is



(A) $\frac{2}{3}V$ **(B)** $\frac{8}{9}V$

(C) $\frac{4}{3}V$ **(D)** $2\ V$

22. Two resistors of resistance R_1 and R_2 having $R_1 > R_2$ are connected in parallel. For equivalent resistance R, the correct statement is

(A) $R > R_1 + R_2$ **(B)** $R_1 < R < R_2$

(C) $R_2 < R < (R_1 + R_2)$ **(D)** $R < R_1$

23. A wire of resistance R is divided in 10 equal parts. These parts are connected in parallel, the equivalent resistance of such connection will be

(A) $0.01\ R$ **(B)** $0.1\ R$

(C) $10\ R$ **(D)** $100\ R$

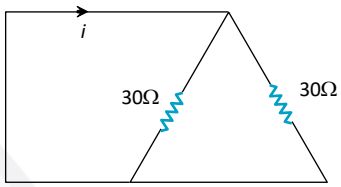
24. The current in the adjoining circuit will be

(A) $\frac{1}{45}$ *ampere*

(B) $\frac{1}{15}$ *ampere*

(C) $\frac{1}{10}$ *ampere*

(D) $\frac{1}{5}$ *ampere*



25. There are 8 equal resistances R. Two are connected in parallel, such four groups are connected in series, the total resistance of the system will be

(A) $R/2$ **(B)** $2\ R$

(C) $4\ R$ **(D)** $8\ R$

26. Three resistances of one *ohm* each are connected in parallel. Such connection is again connected with $2/3\ \Omega$ resistor in series. The resultant resistance will be

(A) $\frac{5}{3}\Omega$ **(B)** $\frac{3}{2}\Omega$

(C) $1\ \Omega$ **(D)** $\frac{2}{3}\Omega$

27. The lowest resistance which can be obtained by connecting 10 resistors each of 1/10 *ohm* is

(A) $1/250\ \Omega$ **(B)** $1/200\ \Omega$

(C) $1/100\ \Omega$ **(D)** $1/10\ \Omega$

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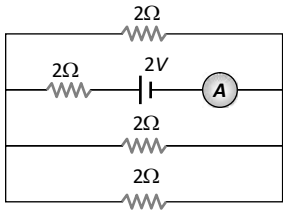
28. The reading of the ammeter as per figure shown is

(A) $\frac{1}{8}A$

(B) $\frac{3}{4}A$

(C) $\frac{1}{2}A$

(D) 2A



29. Three resistors each of 2 *ohm* are connected together in a triangular shape. The resistance between any two vertices will be

(A) 4/3 *ohm* **(B)** 3/4 *ohm*

(C) 3 *ohm* **(D)** 6 *ohm*

30. There are n similar conductors each of resistance R. The resultant resistance comes out to be x when connected in parallel. If they are connected in series, the resistance comes out to be

(A) x / n^2 **(B)** n^2x

(C) x/n **(D)** nx

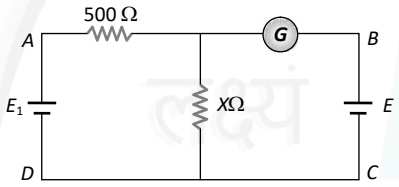
31. In the adjoining circuit, the battery E_1 has an *e.m.f.* of 12 *volt* and zero internal resistance while the battery E has an *e.m.f.* of 2 *volt*. If the galvanometer G reads zero, then the value of the resistance X in *ohm* is

(A) 10

(B) 100

(C) 500

(D) 200



32. The magnitude and direction of the current in the circuit shown will be

(A) $\frac{7}{3}A$ from *a* to *b* through *e*

(B) $\frac{7}{3}A$ from *b* to *a* through *e*

(C) 1*A* from *b* to *a* through *e*

(D) 1*A* from *a* to *b* through *e*

33. A cell of e.m.f. 1.5 V having a finite internal resistance is connected to a load resistance of 2Ω. For maximum power transfer the internal resistance of the cell should be

(A) 4 *ohm* **(B)** 0.5 *ohm*

(C) 2 *ohm* **(D)** None of these

34. By a cell a current of 0.9 A flows through 2 *ohm* resistor and 0.3 A through 7 *ohm* resistor. The internal resistance of the cell is

(A) 0.5 Ω **(B)** 1.0 Ω

(C) 1.2 Ω **(D)** 2.0 Ω

35. The e.m.f. of a cell is E volts and internal resistance is r *ohm*. The resistance in external circuit is also r *ohm*. The p.d. across the cell will be

(A) *E*/2 **(B)** 2*E*

(C) 4*E* **(D)** *E*/4

36. A cell of e.m.f. E is connected with an external resistance R, then p.d. across cell is V. The internal resistance of cell will be

(A) $\frac{(E-V)R}{E}$ **(B)** $\frac{(E-V)R}{V}$

(C) $\frac{(V-E)R}{V}$ **(D)** $\frac{(V-E)R}{E}$

37. Two cells, e.m.f. of each is E and internal resistance r are connected in parallel between the resistance R. The maximum energy given to the resistor will be, only when

(A) $R = r/2$ **(B)** $R = r$

(C) $R = 2r$ **(D)** $R = 0$

38. Kirchhoff's first law i.e. $\Sigma i = 0$ at a junction is based on the law of conservation of

(A) Charge **(B)** Energy

(C) Momentum **(D)** Angular momentum

39. Kirchhoff's second law is based on the law of conservation of

(A) Charge **(B)** Energy

(C) Momentum

(D) Sum of mass and energy

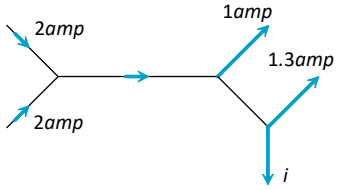
40. The figure below shows currents in a part of electric circuit. The current *i* is

(A) 1.7 *amp*

(B) 3.7 *amp*

(C) 1.3 *amp*

(D) 1 *amp*



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41. In meter bridge or Wheatstone bridge for measurement of resistance, the known and the unknown resistances are interchanged. The error so removed is

(A) End correction

(B) Index error

(C) Due to temperature effect

(D) Random error

42. A galvanometer can be converted into an ammeter by connecting

(A) Low resistance in series

(B) High resistance in parallel

(C) Low resistance in parallel

(D) High resistance in series

43. A cell of internal resistance $1.5\,\Omega$ and of e.m.f. 1.5 volt balances 500 *cm* on a potentiometer wire. If a wire of $15\,\Omega$ is connected between the balance point and the cell, then the balance point will shift

(A) To zero **(B)** By 500 *cm*

(C) By 750 *cm* **(D)** None of the above

44. 10^{-3} *amp* is flowing through a resistance of $1000\,\Omega$. To measure the correct potential difference, the voltmeter is to be used of which the resistance should be

(A) $0\,\Omega$ **(B)** $500\,\Omega$

(C) $1000\,\Omega$ **(D)** $>> 1000\,\Omega$

45. A galvanometer of $100\,\Omega$ resistance gives full scale deflection when 10 *mA* of current is passed. To convert it into 10 *A* range ammeter, the resistance of the shunt required will be

(A) $-10\,\Omega$ **(B)** $1\,\Omega$

(C) $0.1\,\Omega$ **(D)** $0.01\,\Omega$

46. $50\,\Omega$ and $100\,\Omega$ resistors are connected in series. This connection is connected with a battery of 2.4 *volts*. When a voltmeter of $100\,\Omega$ resistance is connected across $100\,\Omega$ resistor, then the reading of the voltmeter will be

(A) 1.6 *V* **(B)** 1.0 *V*

(C) 1.2 *V* **(D)** 2.0 *V*

47. A 2 *volt* battery, a $15\,\Omega$ resistor and a potentiometer of 100 cm length, all are connected in series. If the resistance of potentiometer wire $5\,\Omega$ is , then the potential gradient of the potentiometer wire is

(A) 0.005 *V/cm* **(B)** 0.05 *V/cm*

(C) 0.02 *V/cm* **(D)** 0.2 *V/cm*

48. An ammeter gives full scale deflection when current of 1.0 A is passed in it. To convert it into 10 A range ammeter, the ratio of its resistance and the shunt resistance will be

(A) 1 : 9 **(B)** 1 : 10

(C) 1 : 11 **(D)** 9 : 1

49. By ammeter, which of the following can be measured

(A) Electric potential **(B)** Potential difference

(C) Current **(D)** Resistance

50. The resistance of 1 *A* ammeter is $0.018\,\Omega$. To convert it into 10 *A* ammeter, the shunt resistance required will be

(A) $0.18\,\Omega$ **(B)** $0.0018\,\Omega$

(C) $0.002\,\Omega$ **(D)** $0.12\,\Omega$

51. One *kilowatt* hour is equal to

(A) 36×10^5 *joules* **(B)** 36×10^3 *joules*

(C) 10^3 *joules* **(D)** 10^5 *joules*

52. If R_1 and R_2 are respectively the filament resistances of a 200 *watt* bulb and 100 *watt* bulb designed to operate on the same voltage, then

(A) R_1 is two times R_2 **(B)** R_2 is two times R_1

(C) R_2 is four times R_1 **(D)** R_1 is four times R_2

53. Two electric bulbs, one of 200 *volt* 40 *watt* and the other 200 *volt* 100 *watt* are connected in a house wiring circuit

(A) They have equal currents through them

(B) The resistance of the filaments in both the bulbs is same

(C) The resistance of the filament in 40 *watt* bulb is more than the resistance in 100 *watt* bulb

(D) The resistance of the filament in 100 *watt* bulb is more than the resistance in 40 *watt* bulb

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54. The two bulbs as in the above question are connected in series to a 200 *volt* line. Then
(A) The potential drop across the two bulbs is the same
(B) The potential drop across the 40 *watt* bulb is greater than the potential drop across the 100 *watt* bulb
(C) The potential drop across the 100 *W* bulb is greater than the potential drop across the 40 *W* bulb
(D) The potential drop across both the bulb is 200 *volt*

55. Forty electric bulbs are connected in series across a 220 *V* supply. After one bulb is fused, the remaining 39 are connected again in series across the same supply. The illumination will be
(A) More with 40 bulbs than with 39
(B) More with 39 bulbs than with 40
(C) Equal in both the cases
(D) In the ratio of $49^2 : 39^2$

56. The material of fuse wire should have
(A) A high specific resistance and high melting point
(B) A low specific resistance and low melting point
(C) A high specific resistance and low melting point
(D) A low specific resistance and a high melting point

57. Two electric bulbs whose resistances are in the ratio of 1 : 2 are connected in parallel to a constant voltage source. The powers dissipated in them have the ratio
(A) 1 : 2 **(B)** 1 : 1
(C) 2 : 1 **(D)** 1 : 4

58. A heater coil is cut into two parts of equal length and one of them is used in the heater. The ratio of the heat produced by this half coil to that by the original coil is
(A) 2 : 1 **(B)** 1 : 2
(C) 1 : 4 **(D)** 4 : 1

59. Resistance of one carbon filament and one tungsten lamp are measured individually when the lamp are lit and compared with their respective resistances when cold. Which one of the following statements will be true
(A) Resistance of the carbon filament lamp will increase but that of the tungsten will diminish when hot
(B) Resistance of the tungsten filament lamp will increase but that of carbon will diminish when hot
(C) Resistances of both the lamps will increase when hot
(D) Resistances of both the lamps will decrease when hot

60. The mechanism of the heat produced in a conductor when an electric current flows through it, can be explained on the basis of
(A) Viscosity **(B)** Friction
(C) Free electron theory **(D)** Gauss's theorem

61. Two electric bulbs whose resistances are in the ratio of 1 : 2 are connected in series. The powers dissipated in them have the ratio
(A) 1 : 2 **(B)** 2 : 1
(C) 1 : 1 **(D)** 1 : 4

62. You are given a resistance wire of length 50 cm and a battery of negligible resistance. In which of the following cases is largest amount of heat generated
(A) When the wire is connected to the battery directly
(B) When the wire is divided into two parts and both the parts connected to the battery in parallel
(C) When the wire is divided into four parts and all the four connected to the battery in parallel
(D) When only half the wire is connected to the battery

63. What is immaterial for an electric fuse wire
(A) Its specific resistance
(B) Its radius
(C) Its length
(D) Current flowing through it

64. The electric bulbs have tungsten filaments of same length. If one of them gives 60 *watt* and other 100 *watt*, then
(A) 100 *watt* bulb has thicker filament
(B) 60 *watt* bulb has thicker filament
(C) Both filaments are of same thickness
(D) It is possible to get different wattage unless the lengths are different

65. Three equal resistors connected in series across a source of e.m.f. together dissipate 10 watt. If the same resistors are connected in parallel across the same e.m.f., then the power dissipated will be
(A) 10 *watt* **(B)** 30 *watt*
(C) 10/3 *watt* **(D)** 90 *watt*

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66. How much energy in kilowatt hour is consumed in operating ten 50 watt bulbs for 10 hours per day in a month (30 days).

(A) 1500 **(B)** 5,000

(C) 15 **(D)** 150

67. (1) The product of a volt and a coulomb is a joule.

(2) The product of a volt and an ampere is a joule/second.

(3) The product of volt and watt is horse power.

(4) Watt-hour can be measured in terms of electron volt.

State if

(A) All four are correct

(B) (1), (2) and (4) are correct

(C) (1) and (3) are correct

(D) (3) and (4) are correct

68. A 25 *W*, 220 *V* bulb and a 100 *W*, 220 *V* bulb are connected in parallel across a 440 *V* line

(A) Only 100 *watt* bulb will fuse

(B) Only 25 *watt* bulb will fuse

(C) Both bulbs will fuse

(D) None of the bulbs will fuse

69. Two electric lamps of 40 watt each are connected in parallel. The power consumed by the combination will be

(A) 20 *watt* **(B)** 60 *watt*

(C) 80 *watt* **(D)** 100 *watt*

70. Two heating coils, one of fine wire and the other of thick wire of the same material and of the same length are connected in series and in parallel. Which of the following statement is correct

(A) In series fine wire liberates more energy while in parallel thick wire will liberate more energy

(B) In series fine wire liberates less energy while in parallel thick wire will liberate more energy

(C) Both will liberate equally

(D) In series the thick wire will liberate more while in parallel it will liberate less energy

71. Water can not be made conducting by adding small amount of any of the following except

(A) Sodium chloride **(B)** Copper sulphate

(C) Ammonium chloride **(D)** Sugar

72. The electrochemical equivalent Z of any element can be obtained by multiplying the electrochemical equivalent of hydrogen with

(A) Atomic weight **(B)** Molecular weight

(C) Chemical equivalent **(D)** A constant

73. A silver and zinc voltameter are connected in series and a current *i* is passed through them for a time *t* liberating *W gm* of zinc. The weight of silver deposited is nearly

(A) *W* **(B)** 1.7 *W*

(C) 2.4 *W* **(D)** 3.5 *W*

74. To deposit one gm equivalent of an element at an electrode, the quantity of electricity needed is

(A) One *ampere* **(B)** 96000 *amperes*

(C) 96500 *farads* **(D)** 96500 *coulombs*

75. In an electrolysis experiment, a current *i* passes through two different cells in series, one containing a solution of $CuSO_4$ and the other a solution of $AgNO_3$. The rate of increase of the weight of the cathodes in the two cells will be

(A) In the ratio of the densities of *Cu* and *Ag*

(B) In the ratio of the at. weights of *Cu* and *Ag*

(C) In the ratio of half the atomic weight of *Cu* to the atomic weight of *Ag*

(D) In the ratio of half the atomic weight of *Cu* to half the atomic weight of *Ag*

76. To deposit one litre of hydrogen at 22.4 atmosphere from acidulaled water, the quantity of electricity that must pass through is

(A) 1 *coulomb* **(B)** 22.4 *coulomb*

(C) 96500 *coulomb* **(D)** 193000 *coulomb*

77. The amount of substance liberated on electrodes during electrolysis when 1 coulomb of electricity is passed, is

(A) Chemical equivalent

(B) Electrochemical equivalent

(C) Equivalent weight

(D) One mol

78. For goldplating on a copper chain, the substance required in the form of solution is

(A) Copper sulphate

(B) Copper chloride

(C) Potassium cyanide

(D) Potassium aurocyanide

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79. On passing the current in water voltameter, the hydrogen
(A) Liberated at anode
(B) Liberated at cathode
(C) Does not liberate
(D) Remains in the solution

80. In water voltameter, the electrolysis of ..... takes place
(A) H_2O **(B)** H_2SO_4
(C) H_2O and H_2SO_4 both **(D)** H_2 and O_2

81. The production of e.m.f. by maintaining a difference of temperature between the two junctions of two different metals is known as
(A) Joule effect **(B)** Seebeck effect
(C) Peltier effect **(D)** Thomson effect

82. When a current passes through the junction of two different metals, evolution or absorption of heat at the junction is known as
(A) Joule effect **(B)** Seebeck effect
(C) Peltier effect **(D)** Thomson effect

83. When a current passes through a wire whose different parts are maintained at different temperatures, evolution or absorption of heat all along the length of wire is known as
(A) Joule effect **(B)** Seebeck effect
(C) Peltier effect **(D)** Thomson effect

84. The thermocouple is based on the principle of
(A) Seebeck effect **(B)** Thomson effect
(C) Peltier effect **(D)** Joule effect

85. For a thermocouple, the neutral temperature is $270°C$ and the temperature of its cold junction is $20°C$. If there is no deflection in the galvanometer, the temperature of the hot junction should be
(A) $210°C$ **(B)** $540°C$
(C) $520°C$ **(D)** $209°C$

86. Thermocouple is a device for the measurement of
(A) Absolute temperature of a metal
(B) The temperature difference between two substances
(C) The couple acting on a wire
(D) Thermal conductivity of a substance

87. The true statement for thermo e.m.f. of a thermocouple
(A) Depends on the nature of metals
(B) Depends only on temperature of cold junction
(C) Depends only on temperature of hot junction
(D) Depends on the length of the wires used for thermocouple

88. The direction of current in an iron-copper thermocouple is
(A) From copper to iron at the hot junction
(B) From iron to copper at the hot junction
(C) From copper to iron at cold junction
(D) No current will flow

89. Peltier coefficient for the junction of a pair of metals is proportional to
(A) T absolute temperature of the junction
(B) Square of absolute temperature of the junction
(C) $\frac{1}{\text{Absolute temperature of the junction}}$
(D) $\frac{1}{\text{Square of absolute temperature of the junction}}$

90. If for a thermocouple T_n is the neutral temperature, T_c is the temperature of the cold junction and T_i is the temperature of inversion, then
(A) $T_i = 2T_n - T_c$ **(B)** $T_n = T_i - 2T_c$
(C) $T_i = T_n - T_c$ **(D)** None of these

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Exercise # 2 SINGLE OBJECTIVE AIIMS LEVEL

1. A current I flows through a uniform wire of diameter d when the mean electron drift velocity is v. The same current will flow through a wire of diameter d/2 made of the same material if the mean drift velocity of the electron is

(A) v/4 **(B)** v/2
(C) 2v **(D)** 4v

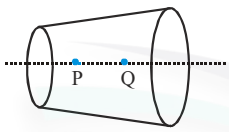
2. Two wires each of radius of cross section r but of different materials are connected together end to end (in series). If the densities of charge carries in the two wires are in the ratio 1:4, the drift velocity of electrons in the two wires will be in the ratio :

(A) 1:2 **(B)** 2:1
(C) 4:1 **(D)** 1:4

3. An insulating pipe of cross–section area 'A' contains an electrolyte which has two types of ions : their charges being –e and +2e. A potential difference applied between the ends of the pipe result in the drifting of the two types of ions, having drift speed = v (–ve ion) and v/4 (+ve ion). Both ions have the same number per unit volume = n. The current flowing through the pipe is

(A) nev A/2 **(B)** nev A/4
(C) 5nev A/2 **(D)** 3nev A/2

4. 45 A wire has a non–uniform cross–section as shown in figure. A steady current flows through it. The drift speed of electrons at points P and Q is v_P and v_Q



(A) $v_P = v_Q$ **(B)** $v_P < v_Q$
(C) $v_P > v_Q$ **(D)** data insufficient

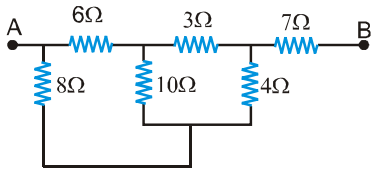
5. A wire of resistance R is stretched to double its length. Its new resistance is

(A) R **(B)** R/2
(C) 4R **(D)** R/4

6. Three copper wires have their lengths in the ratio 5 : 3 : 1 and their masses are in the ratio 1 : 3 : 5. Their electrical resistance will be in the ratio

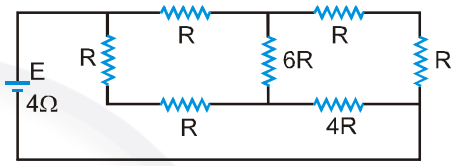
(A) 5 : 3 : 1 **(B)** 1 : 3 : 5
(C) 125 : 15 : 1 **(D)** 1 : 15 : 125.

7. The equivalent resistance between the points A and B is –



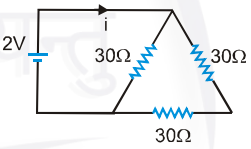
(A) $\frac{36}{7}\Omega$ **(B)** 10 Ω
(C) $\frac{85}{7}\Omega$ **(D)** none of these

8. A battery of internal resistance 4Ω is connected to the network of resistance as shown. In order that the maximum power can be delivered to the network, the value of R in Ω should be :–



(A) $\frac{4}{9}$ **(B)** 2
(C) $\frac{8}{3}$ **(D)** 18

9. The current i in the circuit (see figure) is :



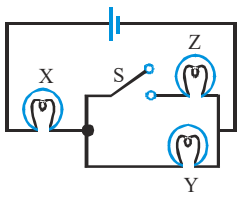
(A) $\frac{1}{45}$ A **(B)** $\frac{1}{15}$ A
(C) $\frac{1}{10}$ A **(D)** $\frac{1}{5}$ A

10. A battery of internal resistance 2Ω is connected to a variable resistor whose value can vary from 4Ω to 10 Ω. The resistance is initially set at 4Ω. If the resistance is now increased then –

(A) power consumed by it will decrease
(B) power consumed by it will increase
(C) power consumed by it may increase or may decrease
(D) power consumed will first increase then decrease

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11. If X, Y and Z in figure are identical lamps, which of the following changes to the brightness of the lamps occur when switch S is closed?



(A) X stays the same, Y decreases

(B) X increases, Y decreases

(C) X increases, Y stays the same

(D) X decreases, Y increases

12. Two heating coils, one of fine wire and the other of thick wire made of same material and of same length are connected in series and then in parallel. Which of the following statements is correct

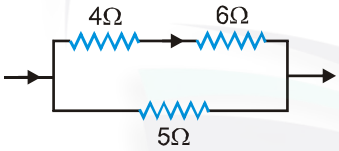
(A) In series fine wire liberates more energy while in parallel thick wire liberates more energy

(B) In series fine wire liberates less energy while in parallel thick wire liberates less energy

(C) In series thick wire liberates more energy while in parallel it liberates less energy

(D) Both wires liberates equal energies in series and in parallel

13. In the circuit shown in figure the heat produced in the 5Ω resistor due to the current flowing through it is 10 cal/s. The heat generated in the 4Ω resistor is :



(A) 1 cal/s **(B)** 2 cal/s

(C) 3 cal/s **(D)** 4 cal/s

14. A storage battery is connected to a charger for charging with a voltage of 12.5 volts. The internal resistance of the storage battery is 1Ω.When the charging current is 0.5 A, the emf of the storage battery is

(A) 13 volts **(B)** 12.5 volts

(C) 12 volts **(D)** 11.5 volts

15. A galvanometer has a resistance of 20Ω and reads full–scale when 0.2V is applied across it. To convert it into a 10A ammeter, the galvanometer coil should have a

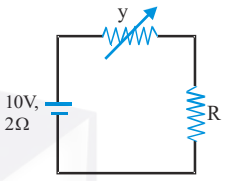
(A) 0.01 Ω resistor connected across it

(B) 0.02 Ω resistor connected across it

(C) 200 Ω resistor connected in series with it

(D) 2000 Ω resistor connected in series with it

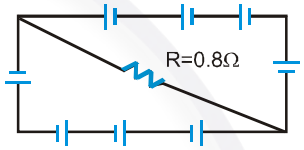
16. In the figure shown the power generated in y is maximum when y=5Ω then R is



(A) 2Ω **(B)** 6Ω

(C) 5Ω **(D)** 3Ω

17. A circuit is comprised of eight identical batteries and a resistor R = 0.8Ω. Each battery has an emf of 1.0 V and internal resistance of 0.2Ω. The voltage difference across any of the battery is



(A) 0.5 V **(B)** 1.0V

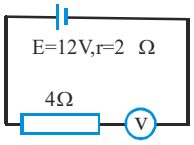
(C) 0V **(D)** 2V

18. A galvanometer coil has a resistance 90Ω and full scale deflection current 10mA. A 910 Ω resistance is connected in series with the galvanometer to make a voltmeter. If the least count of the voltmeter is 0.1V, the number of divisions on its scale is

(A) 90 **(B)** 91

(C) 100 **(D)** None

19. By error, a student places moving–coil voltmeter V (nearly ideal) in series with the resistance in a circuit in order to read the current, as shown. The voltmeter reading will be

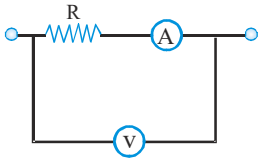


(A) 0 **(B)** 4V

(C) 6V **(D)** 12V

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20. In the circuit shown the resistance of voltmeter is 10,000 ohm and that of ammeter is 20 ohm. The ammeter reading is 0.10 Amp and voltmeter reading is 12 volt. Then R is equal to

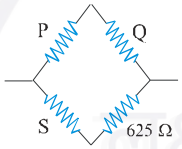


(A) 122 Ω **(B)** 140Ω
(C) 116 Ω **(D)** 100Ω

21. The length of a potentiometer wire is ℓ. A cell of emf E is balanced at a length $\ell/3$ from the positive end of the wire. If the length of the wire is increased by $\ell/2$ at what distance will the same cell give a balanced point

(A) $\frac{2\ell}{3}$ **(B)** $\frac{\ell}{2}$
(C) $\frac{\ell}{6}$ **(D)** $\frac{4\ell}{3}$

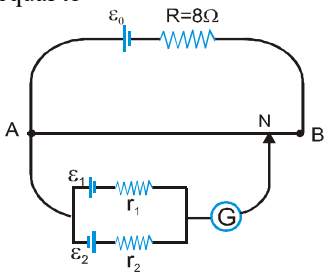
22. A Wheatstone's bridge is balanced with a resistance of 625Ω in the third arm, where P, Q and S are in the 1st, 2nd and 4th arm respectively. If P and Q are interchanged, the resistance in the third arm has to be increased by 51Ω to secure balance. The unknown resistance in the fourth arm is



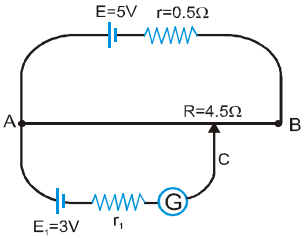
(A) 625 Ω **(B)** 650Ω
(C) 676Ω **(D)** 600Ω

23. A battery of emf E_0 =12V is connected across a 4m long uniform wire having resistance $\frac{4\Omega}{m}$. The cells of small emfs ε_1=2V and ε_2=4V having internal resistance 2Ω and 6Ω respectively, are connected as shown in the figure. If galvanometer shows no deflection at the point N, the distance of point N from the point A is equal to

(A) $\frac{1}{6}$m
(B) $\frac{1}{3}$m
(C) 25cm
(D) 50cm

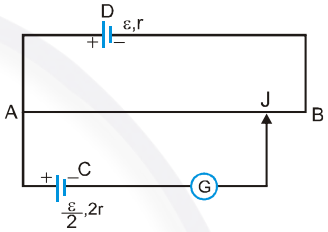


24. In the given potentiometer circuit length of the wire AB is 3m and resistance is R=4.5Ω. The length AC for no deflection in galvanometer is



(A) 2m **(B)** 1.8m
(C) dependent on r_1 **(D)** None of these

25. In the figure, the potentiometer wire AB of length L and resistance 9r is joined to the cell D of emf ε and internal resistance r. The cell C's emf is $\frac{\varepsilon}{2}$ and its internal resistance is 2r. The galvanometer G will show no deflection when the length AJ is



(A) $\frac{4L}{9}$ **(B)** $\frac{5L}{9}$
(C) $\frac{7L}{18}$ **(D)** $\frac{11L}{18}$

26. Two bulbs rated (25W– 220V) and (100W–220V) are connected in series to a 440 V line. Which one is likely to fuse?

(A) 25W bulb **(B)** 100 W bulb
(C) both bulbs **(D)** None

27. A constant voltage is applied between the two ends of a uniform metallic wire. Some heat is developed in it. The heat developed is doubled if

(A) both the length and the radius of the wire are halved

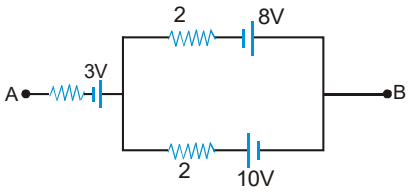
(B) both the length and the radius of the wire are doubled

(C) the radius of the wire is doubled

(D) the length of the wire is doubled

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28. The net emf and internal resistance of three batteries as shown in figure is :

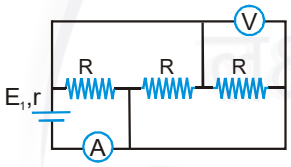


(A) 2V, 1Ω **(B)** 2V, 2Ω
(C) 2V, 1.5Ω **(D)** 4V, 2Ω

29. If the length of the filament of a heater is reduced by 10%, the power of the heater will
(A) increase by about 9%
(B) increase by about 11%
(C) increase by about 19%
(D) decrease by about 10%

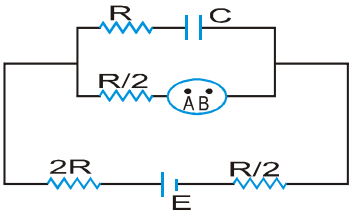
30. The equivalent resistance of a group of resistances is R. If another resistance is connected in parallel to the group, its new equivalent becomes R_1 and if it is connected in series to the group, it new equivalent becomes R_2 we have
(A) $R_1 > R$ or $R_2 > R$ **(B)** $R_1 < R$ or $R_2 > R$
(C) $R_1 > R$ or $R_2 < R$ **(D)** $R_1 < R$ or $R_2 < R$

31. In the circuit shown in figure, ammeter and voltmeter are ideal. If E = 4V, R = 9Ω and r = 1Ω, then readings of ammeter and voltmeter are



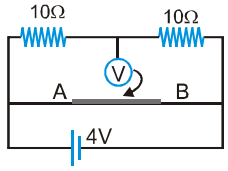
(A) 1A, 3V **(B)** 2A, 3V
(C) 3A, 4V **(D)** 4A, 4V

32. A conducting solid sphere is joined in an electrical circuit as shown in figure. Two imaginary points A and B are taken inside the sphere. For given conditions-



(A) $V_A > V_B$ **(B)** $V_A < V_B$
(C) $V_A = V_B$ **(D)** Data insufficient

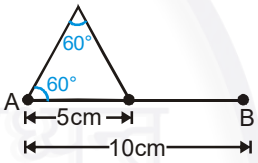
33. In the adjacent circuit, AB is a potentiometer wire of length 40 cm and resistance per unit length 50 Ω/m. As shown in the figure, the free end of an ideal voltmeter is touching the potentiometer wire. What should be the velocity of the jockey as a function of time so that reading in the voltmeter varies with time as (2 sin πt)?



(A) (10 π sin πt) cm/s **(B)** (10 π cos πt) cm/s
(C) (20π sin πt) cm/s **(D)** (20 π cos πt) cm/s

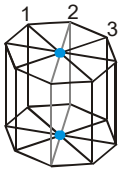
34. An electric bell has a resistance of 5Ω and requires a current of 0.25 A to work it. Assuming that the resistance of the bell wire is 1Ω per 15m and that the bell push is 90m distance from the bell. How many cells each of emf1.4V and internal resistance 2Ω, will be required to work the circuit-
(A) 3 **(B)** 4
(C) 5 **(D)** Can't be determined

35. A wire has resistance of 24 Ω is bent in the following shape. The effective resistance between A and B is-



(A) 24 Ω **(B)** 10 Ω
(C) $\frac{16}{3}\Omega$ **(D)** None of these

36. In the diagram shown, all the wires have resistance R. The equivalent resistance between the upper and lower dots shown in the diagram is



(A) R/8 **(B)** R
(C) 2R/5 **(D)** 3R/8

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Exercise # 3 PART - 1 MATRIX MATCH COLUMN

1. Match the statements in Column I with the current element in Column II

	Column - I		Column - II
(A)	Current always flows from higher potential to lower potential	(P)	A Resistor
(B)	Energy dissipated in an element is always zero	(Q)	Ideal cell/Battery
(C)	Current flow through the element is always zero	(R)	Non-Ideal cell/Battery
(D)	Potential difference may/will be zero	(S)	Short-circuited resistor

2. **Match the following :**

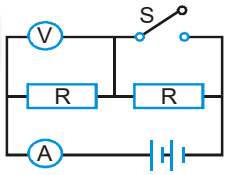
The following table gives the lengths of four copper rods at the same temperature, their diameters, and the potential differences between their ends.

Rod	Length	Diameter	Potential Difference
1	L	3d	V
2	2L	d	3V
3	3L	2d	2V
4	3L	d	V

Correctly match the physical quantities mentioned in the left column with the rods as marked.

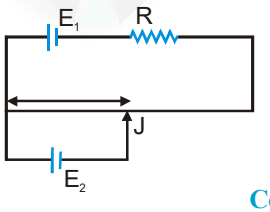
(A)	Greatest Drift speed of the electrons.	(P)	Rod 1
(B)	Greatest Current	(Q)	Rod 2
(C)	Greatest rate of thermal energy produced	(R)	Rod 3
(D)	Greatest Electric field	(S)	Rod 4

3. The diagram shows a circuit with two identical resistors. The battery has a negligible internal resistance.What will the effect on the ammeter and voltmeter be if the switch S is closed ?



	Column I		Column II
(A)	Ammeter reading	(P)	Increases
(B)	Voltmeter reading	(Q)	Decreases
(C)	Equivalent resistance of circuit	(R)	Does not change
(D)	Power dissipated across R in right branch	(S)	Becomes zero

4. In the potentiometer arrangement shown in figure, null point is obtained at length l.



	Column I		Column II
(A)	If E_1 is increased	(P)	l should increase
(B)	If R is increased	(Q)	l should decrease
(C)	If E_2 is increased	(R)	l should remain the same to

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Exercise # 3 PART - 2 ASSERTION & REASONING

These questions contains, Statement I (assertion) and Statement II (reason).

(A) If both assertion and reason are true and the reason is the correct explanation of the assertion.

(B) If both assertion and reason are true but reason is not the correct explanation of the assertion.

(C) If assertion is true but reason is false.

(D) If assertion is false but reason is true.

(E) If the assertion and reason both are false.

1. **Assertion :** The electric bulb glows immediately when switch is on.
Reason : The drift velocity of electrons in a metallic wire is very high.

2. **Assertion :** When an external resistor of resistance R (connected across a cell of internal resistance r) is varied, power consumed by resistance R is maximum when R = r.
Reason : Power consumed by a resistor of constant resistance R is maximum when current through it is maximum.

3. **Assertion :** Electric field inside a current carrying wire is zero.
Reason : Net charge on wire is zero.

4. **Assertion :** In a chain of bulbs, 50 bulbs are joined in series. One bulb is fused now. If the remaining 49 bulbs are again connected in series across the same supply then light gets decreased in the room.
Reason : The resistance of 49 bulbs will be more than 50 bulbs.

5. **Assertion :** A metal has resistance and gets often heated by flow of current.
Reason : When free electrons drift through a metal they makes occasional collisions with the lattice. These collisions inelastic and transfer energy to the lattice as internal energy

6. **Assertion :** Kirchoff's loop rule indicates that electrostatic field is conservative.
Reason : Potential difference between two points in a circuit does not depends on path.

7. **Assertion :** The coil of a heater is cut into two equal halves and only one of them is used into heater. The heater will new require half the time to produce the same amount of heat.
Reason : Heat produced in a coil is directly proportional to square of the current, through it.

8. **Assertion :** Current is passed through a metallic wire, heating it red. When cold water is poured over half of its portion, rest of the portion becomes more hot.
Reason : Resistance decreases due to decrease in temperature so current through wire increases.

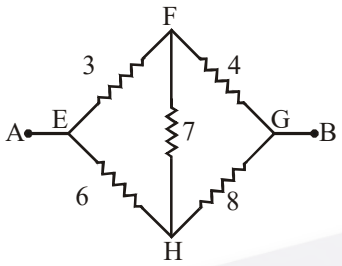
9. **Assertion :** A steady current is flowing in a conductor hence there is an electric field within the conductor.
Reason : In case of steady current, there can be no accumulation of charges, so no electric field can be established.

10. **Assertion :** A wire of uniform cross section and uniform resistivity is connected across an ideal cell. Now the length of the wire is doubled keeping volume of wire constant. The drift velocity of electrons after stretching the wire becomes one fourth of what it was before stretching the wire.
Reason : If a wire (of uniform resistivity and uniform cross-section) of length l_o is stretched to length nl_o, then its resistance becomes n^2 times of what it was before stretching the wire(the volume of wire is kept constant in stretching process). Further at constant potential difference, current is inversely proportional to resistance. Finally drift velocity of free electron is directly proportional to current and inversely proportional to cross section area of current carrying wire.

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Exercise # 4 PART - 1 PREVIOUS YEAR (NEET/AIPMT)

1. A bridge circuit is shown in figure. The equivalent resistance btween A and B will be



(A) 21 Ω **(B)** 7 Ω

(C) $\frac{252}{85}\Omega$ **(D)** $\frac{14}{3}\Omega$

2. Potentiometer measures the potential difference more accurately than a voltmeter, because

(A) it has a wire of high resistance

(B) it has a wire of low resistance

(C) it does not draw current from external circuit

(D) it draws a heavy current from external circuit

3. A cell has an emf 1.5 V. When connected across an external resistance of 2 Ω , the terminal potential difference falls to 1.0 V. The internal resistance of the cell is

(A) 2 Ω **(B)** 1.5 Ω

(C) 1.0 Ω **(D)** 0.5 Ω

4. In a Wheatstone bridge resistance of each of the four sides is 10 Ω. If the resistance of the galvanometer is also 10 Ω , then effective resistance of the bridge will be

(A) 10 Ω **(B)** 5 Ω

(C) 20 Ω **(D)** 40 Ω

5. Resistivity of potentiometer wire is 10^{-7} Ω-m and its area of cross-section is 10^{-6} m^2. When a current i = 0.1 A flows through the wire, its potential gradient is

(A) 10^{-2} V/m **(B)** 10^{-4} V/m

(C) 0.1 V/m **(D)** 10 V/m

6. The specific resistance of a conductor increases with

(A) increase in temperature

(B) increase in cross-sectional area

(C) decrease in length

(D) decrease in cross-sedctional area

7. For a cell, the terminal potential difference is 2.2 V when circuit is open and reduces to 1.8 V when cell is connected to a resistance R = 5 Ω, the internal resistance (r) of cell is

(A) $\frac{10}{9}\Omega$ **(B)** $\frac{9}{10}\Omega$

(C) $\frac{11}{9}\Omega$ **(D)** $\frac{5}{9}\Omega$

8. In a Wheatstone bridge, all the four arms have equal resistance R. If the resistance of the galvanometer arm is also R, the equivalent resistance of the combination as seen by the battery is

(A) R **(B)** 2 R

(C) $\frac{R}{4}$ **(D)** $\frac{R}{2}$

9. A battery is charged at a potential of 15 V for 8 h when the current flowing is 10 A. The battery on discharge supplies a current of 5 A for 15 h. The mean terminal voltage during discharge is 14 V. The watt-hour efficiency of the battery is

(A) 82.5% **(B)** 80%

(C) 90% **(D)** 87.5%

10. The electric resistance of a certain wire of iron is R. It its length and radius are both doubled, then

(A) the resistance will be doubled and the specific resistance will be halved

(B) the resistance will be halved and the specific resistance will remain unchanged

(C) the resistance will be halved and the specific resistance will be doubled

(D) the resistance and the specific resistance will both remain unchanged

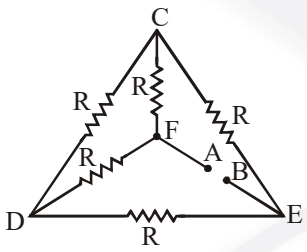
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11. n resistances each of r ohm, when connected in parallel give an equivalent resistance of R ohm. If these resistances were connected series, the combination would have a resistance in ohms, equal to

(A) n^2R **(B)** $\frac{R}{n^2}$

(C) $\frac{R}{n}$ **(D)** nR

12. Five equal resistances each of resistance R are connected as shown in the figure. A battery of 4 V volts is connected between A and B. The current flowing in AFCEB will be



(A) $\frac{3V}{R}$ **(B)** $\frac{V}{R}$

(C) $\frac{V}{2R}$ **(D)** $\frac{2V}{R}$

13. A 6 V battery is connected to the terminals of a 3m long wire of uniform thickness adn resistance of 100 Ω. The difference of potential between two points on the wire separated by a distance of 50 cm will be

(A) 2 V **(B)** 3 V

(C) 1 V **(D)** 1.5 V

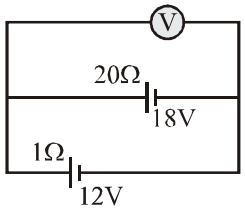
14. Two batteries, one emf 18V and internal resistance 2Ω and the other of emf 12 V and internal resistance 1 Ω, are connected as shown. The voltmeter V will record a reading of

(A) 15 V

(B) 30 V

(C) 14 V

(D) 18 V

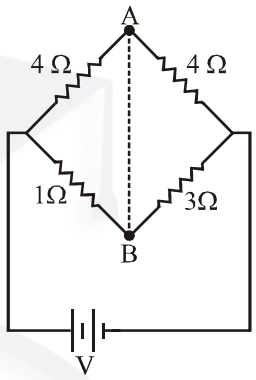


15. When a wire of uniform cross-section a, length *l* and resistance R is bent into a complete circle, resistance between two of diametrically opposite points will be

(A) $\frac{R}{4}$ **(B)** $\frac{R}{8}$

(C) 4 R **(D)** $\frac{R}{2}$

16. In the circuit shown, if a conducting wire is connected between points A and B, the currents in this wire will



(A) flow from A to B

(B) flow in the direction which will decided by the value of V

(C) be zero

(D) flow from B to A

17. Two cells, having the same emf are connected in series through an external resistance R. Cells have internal resistances r_1 and r_2 ($r_1 > r_2$) respectively. When the circuit is closded, the potential difference across the first cell is zero. The value of R is

(A) $r_1 - r_2$ **(B)** $\frac{r_1 + r_2}{2}$

(C) $\frac{r_1 - r_2}{2}$ **(D)** $r_1 + r_2$

18. The resistance of an ammeter is 13 Ω and its scale is graduated for a current upto 100 A. After an additional shunt has been connected to this ammeter it becomes possible to measure currents upto 750 A by this meter. The value of shunt resistance is

(A) 20 Ω **(B)** 2 Ω

(C) 02 Ω **(D)** 2 Ω

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19. Three resistance P, Q, R each of 2 Ω and an unknown resistance S form the four arms of a Wheatstone bridge circuit. When a resistance of 6 Ω is connected in parallel to S the bridge gets balanced. What is the value of S?

(A) 2 Ω **(B)** 3 Ω
(C) 6 Ω **(D)** 1 Ω

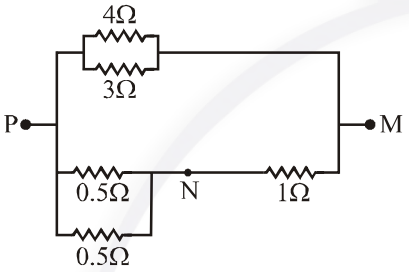
20. A wire of a certain material is stretched slowly by 10 percent. Its new resistance and specific, resistance becomes respectively

(A) 1.2 times, 1.1 time **(B)** 1.21 times, same
(C) Both remains the same **(D)** 1.1 time, 1.1 times

21. A cell can be balanced against 110 cm and 100 cm of potentiometer wire, respectively with and without being short circuited through a resistance of 10 Ω. Its internal resistance is

(A) 1.0 Ω **(B)** 0.5 Ω
(C) 2.0 Ω **(D)** zero

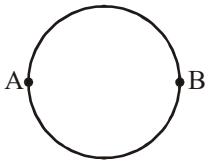
22.



In the circuit shown, the current through the 4Ω resistor is 1 A when the points P and M are connected to a DC voltage source. The potential difference between the points M and N is

(A) 1.5 V **(B)** 1.0 V
(C) 0.5 V **(D)** 3.2 V

23. A wire of resistance 12 Ω m^{-1} is bent to form a complete circle of radius 10 cm. The resistance between its two diametrically opposite points A and B as shown in the figure is

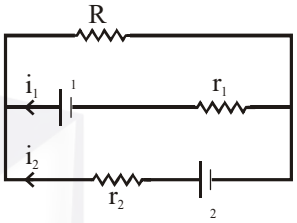


(A) 0.6 π Ω **(B)** 3 Ω
(C) 6 π Ω **(D)** 6 Ω

24. A student measures the terminal potential differene (V) of a cell (of emf ε and internal resistance r) as a function of the current (*I*) flowing through it. The slop and intercept of the graph between V and I, respectively, equal to

(A) ε and – r **(B)** – r and ε
(C) r and – ε **(D)** – ε and r

25. See the electrical circuit shown in this figure. Which of the following equations is a correct equation for it?



(A) $\varepsilon_1 - (i_1 + i_2)R - i_1 r_1 = 0$
(B) $\varepsilon_2 - i_2 r_2 - \varepsilon_1 - i_1 r_1 = 0$
(C) $-\varepsilon_2 - (i_1 + i_2)R + i_2 r_2 = 0$
(D) $\varepsilon_1 - (i_1 + i_2)R + i_1 r_1 = 0$

26. The mean free path of electrons in a metal is 4×10^{-8} m. The electric field which can give on an average 2 eV energy to an electron in the metal will be in unit of Vm^{-1}

(A) 8×10^{7} **(B)** 5×10^{-11}
(C) 8×10^{-11} **(D)** 5×10^{7}

27. Consider the following two statements :

I. Kirchhoff's junction law follows from the conservation of charge.

II. Kirchhoff's loop law follows from the conservation of energy.

Which of the following is correct?

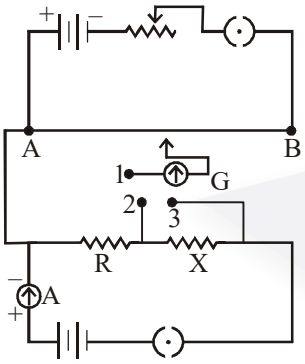
(A) Both I and II are wrong
(B) I is correct and II is wrong
(C) I is wrong and Ii is correct
(D) Both I and II are correct

28. A galvanometer has a coil of resistance 100 Ω and gives a full scale deflection for 30 mV current. If it is to work as a voltmeter of 30 V range, the resistance required to be added will be

(A) 900 Ω **(B)** 1800 Ω
(C) 500 Ω **(D)** 1000 Ω

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29. A potentiometer circuit is set up as shown. The potential gradient across the potentiometer wire, is K volt/cm and the ammeter, present in the circuit, reads 1.0 A when two way key is switched off. The balance points, when the key between the terminals (A) 1 and 2 (B) 1 and 3, is plugged in, are found to be at length l_1 cm and l_2 cm respectively. The magnitudes, of the resistors R and X in ohm, are then equal, respectively to

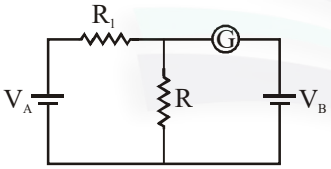


(A) $k(l_2 - l_1)$ and kl_2 **(B)** kl_1 and $k(l_2 - l_1)$
(C) $k(l_2 - l_1)$ and kl_1 **(D)** kl_1 and kl_2

30. A current of 2 A flows through a 2Ω resistor when connected across a battery. The same battery supplies a current of 0.5 A when connected across a 9Ω resistor. The internal resistance of the battery is

(A) 1/3 Ω **(B)** 1/4 Ω
(C) 1 Ω **(D)** 0.5 Ω

31. In the circuit shown, the cells, A and B have negligible resistances. For $V_A = 12$ V, $R_1 = 500$ Ω and R = 100 Ω the galvanometer (G) shows no deflection. The value of V_B is



(A) 4 V **(B)** 2 V
(C) 12 V **(D)** 6 V

32. A millivoltmeter of 25 mV ranges is to be converted into an ammeter of 25 A range. The value (in ohm) of necessary shunt will

(A) 0.001 **(B)** 0.01
(C) 1 **(D)** 0.05

33. The resistances of the four arms P, Q, R and S in a Wheatstone bridge are 10 Ω, 30 Ω, 30 Ω and 90 Ω , respectively. The emf anf internal resistance of the cell are 7 V and 5 Ω respectively. If the galvanometer resistance is 50 Ω. If the galvanometer resistance is 50 Ω , the current drawn from the cell will be

(A) 1.0 A **(B)** 0.2 A
(C) 0.1 A **(D)** 2.0 A

34. The internal resistance of a 2.1 V cell which gives a current of 0.2 A through a resistance of 10 Ω is

(A) 0.2 Ω **(B)** 0.5 Ω
(C) 0.8 Ω **(D)** 1.0 Ω

35. A wire of resistance 4Ω is stretched to twice its original length. The resistance of stretched wire would be

(A) 2 Ω **(B)** 4 Ω
(C) 8 Ω **(D)** 16 Ω

36. In an ammeter 0.2% of main current passes through the galvanometer. If resistance of galvanometer is G, the resistance of ammeter will be

(A) $\frac{1}{499}$G **(B)** $\frac{499}{500}$G
(C) $\frac{1}{500}$G **(D)** $\frac{500}{499}$G

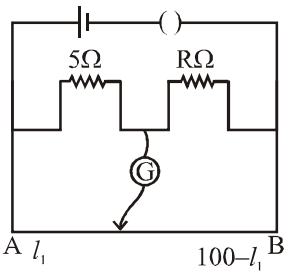
37. A potentiometer circuit has been set up for finding the internal resistance of a given cell. the main battery, used across the potentiometer wire, has an emf of 2.0 V and a negligible internal resistance. The potentiometer wire itself is 4 m long. When the resistance r, connected across the given cell, has values of (i) infinity,, (ii) 9.5 Ω, the balancing lengths, on the potentiometer wire are found to be 3 m and 2.85 m, respectively.

The value of internal resistance of the cell is

(A) 0.25 Ω **(B)** 0.95 Ω
(C) 0.5 Ω **(D)** 0.75 Ω

38. The resistances in the two arms of the meter bridge are 5 Ω and R Ω, respectively. When the resistance R is shunted with an equal resistance, then new balance point is at 1.6 l_1. The resistance R, is

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(A) 10 Ω (B) 15 Ω
(C) 20 Ω (D) 25 Ω

39. A potentiometere wire of length L and a resistance r are connected in series with a battery of e.m.f. E_0 and a resistance r_1. An unknown e.m.f. is balanced at a length l of the potentiometer wire. The e.m.f. E will be given by

(A) $\frac{LE_0r}{lr_1}$ (B) $\frac{E_0r}{(r+r_1)}\cdot\frac{l}{L}$

(C) $\frac{E_0l}{L}$ (D) $\frac{LE_0r}{(r+r_1)l}$

40. A circuit contains an ammeter, a battery of 30 V and a resistance 40.8 Ω all connected in series. If the ammeter has a coil of resistance 480 Ω and a shunt of 20 Ω, then reading in the ammeter will be

(A) 0.5 A (B) 0.25 A
(C) 2 A (D) 1 A

41. Two metal wires of identical dimensions are connected in series. If σ_1 and σ_2 are the conductivities of the metal wires respectively, the effective conductivity of the combination is

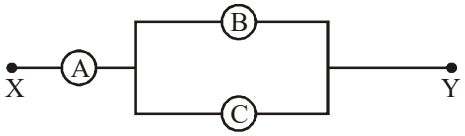
(A) $\frac{2\sigma_1\sigma_2}{\sigma_1+\sigma_2}$ (B) $\frac{\sigma_1+\sigma_2}{2\sigma_1\sigma_2}$

(C) $\frac{\sigma_1+\sigma_2}{\sigma_1\sigma_2}$ (D) $\frac{\sigma_1\sigma_2}{\sigma_1+\sigma_2}$

42. Across a metallic conductor of non-uniform cross-section, a constant potential difference is applied. the quantity which remain constant along the conductor is

(A) current density (B) current
(C) drift velocity (D) electric field

43. A, B and C are voltmeters of resistance R, 1.5 R and 3R respectively as shown in the figure. When some potential difference is applited between X and Y, the voltmeter readings are V_A, V_B and V_C respectively. Then,

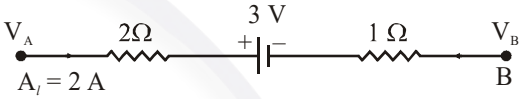


(A) $V_A = V_B = V_C$ (B) $V_A \neq V_B = V_C$
(C) $V_A = V_B \neq V_C$ (D) $V_A \neq VB \neq V_C$

44. A potentiometer wire has length 4 m and resistance 8Ω. The resistance that must be connected in series with the wire and an accumulator of emf 2V, so as to get a potential gradient 1 mV per cm on the wire is

(A) 32 Ω (B) 40 Ω
(C) 44 Ω (D) 48 Ω

45. The potential difference $(V_A - V_R)$ between the points A and B in the given figure is

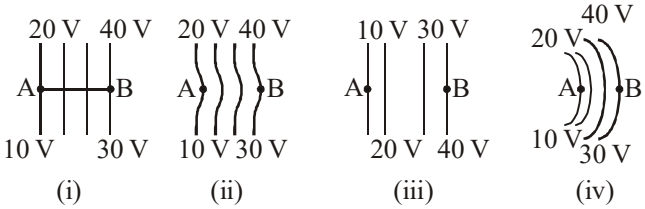


(A) –3 V (B) +3V
(C) +6 V (D) +9 V

46. A potentiometer wire is 100 cm long and a constant potential difference is maintained across it. Two cells are connected in series first to support one another and then in opposite direction. The balance points are obtained at 50 cm and 10 cm from the positive end of the wire in the two cases. The ratio of emf is

(A) 5 : 4 (B) 3 : 4
(C) 3 : 2 (D) 5 : 1

47. The diagrams below show regions of equipotentials.



A positive charge is moved from A to B in each diagram.

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(A) maximum work is required to mvoe q in figure (iii)

(B) In all the four cases, the work done is the same

(C) Minimum work is required to move q in figure (i)

(D) Maximum work is required to move q in figure (ii)

48. A potentiometer is an accurate and versatile device to make electrical measurement of of EMF because the method involves

(A) cells

(B) potential gradients

(C) a condition of no current flow through the galvanometer

(D) a combination of cells, galvanometer and resistance

49. The resistance of a wire is R ohm. If it is melted and stretched to n times its original length, its new resistance will be

(A) nR (B) $\frac{R}{n}$

(C) n^2R (D) $\frac{R}{n^2}$

THERMAL AND CHEMICAL EFFECTS OF CURRENT

50. Two bulbs 25 W, 220 V and 100 W, 220 V are given. Which has higher resistacne?

(A) 25 W bulb

(B) 100 W bulb

(C) Both bulbs will have equal resistanec

(D) Resistance of bulbs cannot be compared

51. In electrolysis the mass deposited on an electrode is directed proportional to

(A) current

(B) square of current

(C) concentration of solution

(D) inverse of current

52. Fuse wire is a wire of

(A) low resistance and low melting point

(B) low resistance and high melting point

(C) high resistance and high melting point

(D) high resistance and low melting point

53. An electric kettle has two heating coils, When one of the coils is connected to an AC source, the water in the kettle boils in 10 min. When the other coil is used the water boils in 40 min. If both the coils are connected in parallel, the time taken by the same quantity of water to boil will be

(A) 25 min (B) 15 min

(C) 8 min (D) 4 min

54. Two 220 v, 100 W bulbs are connected first in series and then in parallel. Each time the combination is connected to a 220 V AC supply line. The power drawn by the combination in each case respectively

(A) 200 W, 150 W (B) 50 W, 200 W

(C) 50 W, 100 W (D) 100 W, 50 W

55. When three identical bulbs of 60 W, 200 V rating are connected in series to a 200 V supply, the power drawn by them will be

(A) 60 W (B) 180 W

(C) 10 W (D) 20 W

56. In India, electricity is supplied for domastic use at 220 V. It is supplied at 110 V in USA. If thee resistance of a 60 W bulb for use in India is R, the resistance of a 60 W bulb for use in USA will be

(A) R (B) 2 R

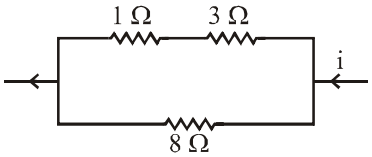
(C) $\frac{R}{4}$ (D) $\frac{R}{2}$

57. A 5 A fuse wire can withstand a maximum power of 1 W in circuit. The resistance of the fuse wire is

(A) 0.2 Ω (B) 5 Ω

(C) 0.4 Ω (D) 0.04 Ω

58. Power dissipated across the 8 Ω resistor in the circuit shown here is 2 Ω. The power dissipated in watt units across the 3 Ω resistor is



(A) 2.0 (B) 1.0

(C) 0.5 (D) 3.0

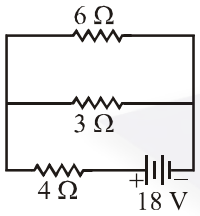
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59. If the cold junction of a thermocouple is kept at 0°C and the hot junction is kept at T°C, then the relation between neu tral temperature (T_n) and temperature of inversion (T_i) is

(A) $T_n = \frac{T_i}{2}$ **(B)** $T_n = 2T_i$

(C) $T_n = T_i - T$ **(D)** $T_n = T_i + T$

60. The total power dissipated in watts in the circuit shown here is



(A) 16 **(B)** 40

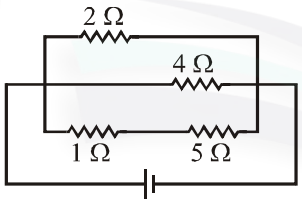
(C) 54 **(D)** 4

61. A steady current of 1.5 A flows through a copper voltameter for 10 min. If the electrochemical equivalent of copper is 30×10^{-5} g C^{-1}, the mass of copper deposited on the electrode will be

(A) 0.40 g **(B)** 0.50 g

(C) 0.67 g **(D)** 0.27 g

62. A current of 3 A flows through the 2 Ω resistor shown in the circuit. The power dissipated in the 5 Ω resistor is



(A) 4 W **(B)** 2 W

(C) 1 W **(D)** 5 W

63. An electric kettle takes 4 A current at 220 V. How much time will it take to boil 1 kg of water from temperature 20°C?

(A) 6.3 min **(B)** 8.4 min

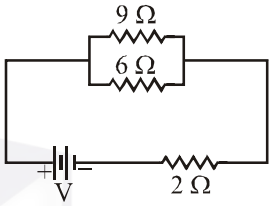
(C) 12.6 min **(D)** 4.2 min

64. In producing chlorine by electrolysis 100 kW power at 125 V is being consumed. How much chlorine per minute is liberated (ECE of chlorine is 0.367×10^{-6} kg C^{-1})

(A) 1.76×10^{-3} kg **(B)** 9.67×10^{-3} kg

(C) 17.61×10^{-3} kg **(D)** 3.67×10^{-3} kg

65. If power dissipated in the 9Ω resistor in the circuit shown in 36W, the potential difference across the 2 Ω resistor is



(A) 8 V **(B)** 10 V

(C) 2 V **(D)** 4 V

66. If voltage across a bulb rated 220 V-100 W drops by 2.5% of its rated value, the percentage of the rated value by which the power would decrease is

(C) 5% **(D)** 10%

67. Two cities are 150 km apart. Electric power is sent from one city to another city through copper wires. The fall of potential per km is 8 V and the average resistance per km is 0.5 Ω . The power loss in the wire is

(A) 19.2 W **(B)** 19.2 kW

(C) 19.2 J **(D)** 12.2 kW

68. A filament bulb (500 W, 100 V) is to be used in a 230 V main supply. When a resistance R is connected in series, it works perfectly and the bulb consumes 500 W. The value of R is

(A) 230 Ω **(B)** 46 Ω

(C) 26 Ω **(D)** 13 Ω

69. The charge following through a resistance R varies with time t as $Q = at - bt^2$, where a and b are positive constants. The total heat produced in R is

(A) $\frac{a^3R}{3b}$ **(B)** $\frac{a^3R}{2b}$

(C) $\frac{a^3R}{b}$ **(D)** $\frac{a^3R}{6b}$

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70. A spherical black body with a radius of 12 cm radiates 450 watt power at 500 K. If the radius were halved and the temperature doubled, the power radiated in watt would be

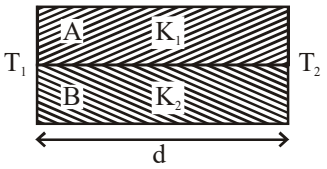
(A) 225

(B) 450

(C) 1000

(D) 1800

71. Two rods A and B of different materials are welded together as shown in figure. Their thermal conductivities are K_1 and K_2. The thermal conductivity of the composite rod will be



(A) $\frac{K_1 + K_2}{2}$

(B) $\frac{3(K_1 + K_2)}{2}$

(C) $K_1 + K_2$

(D) $2(K_1 + K_2)$

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Exercise # 4 PART - 2 PREVIOUS YEAR (AIIMS)

CURRENT ELECTRICITY

1. Given a current carrying wire of non uniform cross section. Which of the following is constant throughout the length of the wire ?

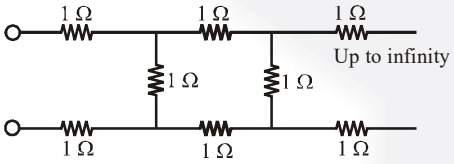
(A) Current, electric field and drift speed

(B) Drift speed only

(C) Current and drift speed

(D) Current only.

2. The resistance between the terminal points A and B of the given infinitely long circuit will be



(A) $(\sqrt{3}-1)\Omega$ **(B)** $(1-\sqrt{3})\Omega$

(C) $(1+\sqrt{3})\Omega$ **(D)** $(2+\sqrt{3})\Omega$

3. Two resistance filaments of same length are connected first in series and then in parallel. Find the ratio of power dissipated in both cases assuming that equal current flows in the main circuit.

(A) 1 : 4 **(B)** 4 : 1

(C) 1 : 2 **(D)** 2 : 1

4. A 60 W incandescent lamp-operates at 120 V. The number of electrons passing through the filament per second will be

(A) 1.61×10^{12} **(B)** 3.12×10^{18}

(C) 7.21×10^{12} **(D)** 12.40×10^{13}

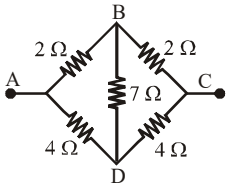
5. The equivalent resistance between A and C of the given circuit, is

(A) 8 Ω

(B) $\frac{32}{4}\Omega$

(C) $\frac{4}{3}\Omega$

(D) $\frac{8}{3}\Omega$



6. When a wire is stretched and its radius becomes r/2, then its resistance will be

(A) 16R **(B)** 2R

(C) 4R **(D)** R.

7. Antimony and Bismuth are usually used in thermocouple, because

(A) a constant thermo e.m.f. is produced

(B) higher thermo e.m.f. is produced

(C) a negative thermo e.m.f. is produced

(D) lower thermo e.m.f. is produced.

8. A metal rod consumes power P on passing current. If it is cut into two half and joined in parallel, it will consume power

(A) P **(B)** 2P

(C) 4P **(D)** P/4

9. An electric bulb marked 40 W and 200 V, is used in a circuit of supply voltage 100 V. Now its power is

(A) 100 W **(B)** 20 W

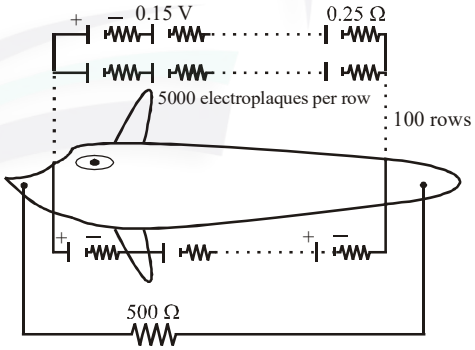
(C) 40 W **(D)** 10 W

10. A wire of length L is drawn such that its diameter is reduced to half of its original diameter. If the initial resistance of the wire was 10 Ω, its ne resistance would be

(A) 40 Ω **(B)** 80 Ω

(C) 120 Ω **(D)** 160 Ω

11.



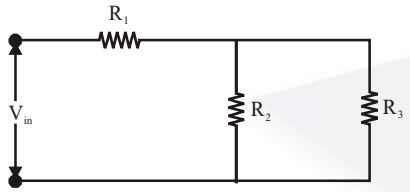
Eels are able to generate current with biological cells called electroplaques. The electroplaques in an eel are arranged in 100 rows, each row stretching horizontally along the body of the fish containing 5000 electroplaques.

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The arrangement is suggestively shown here. Each electroplaques has an emf of 0.15 V and internal resistance of 0.25 Ω. The water surrounding the eel completes a circuit between the head and its tail. If the water surrounding it has a resistance of 500 Ω, the current an eel can produce in water is about

(A) 1.5 A **(B)** 3.0 A
(C) 15 A **(D)** 30 A

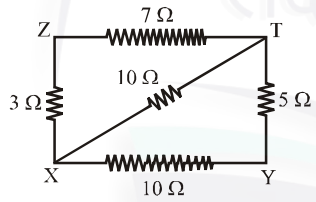
12. For ensuring dissipation of same energy is all three resistors (R_1, R_2, R_3) connected as shown in figure, their values must be related as



(A) $R_1 = R_2 = R_3$
(B) $R_2 = R_3$ and $R_1 = 4R_2$
(C) $R_2 = R_3$ and $R_1 = (1/4)R_2$
(D) $R_1 = R_2 + R_3$.

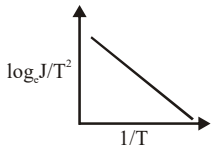
13. Faraday law of electrolysis indirectly shows
(A) quantisation of charge
(B) quantisation of angular momentum
(C) Quantisation of current
(D) quantisation of viscosity

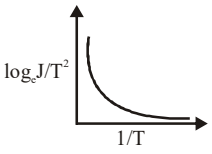
14. The equivalent resistance between the points X and Y in the following circuit diagram will be

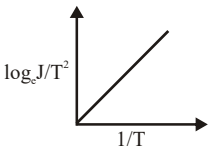


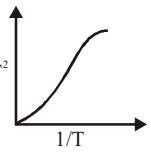
(A) 10 Ω **(B)** 5 Ω
(C) 7 Ω **(D)** 3 Ω

15. The current curve between $\log_e \frac{J}{T^2}$ and $\frac{1}{T}$ is

(A)


(B)


(C)


(D)


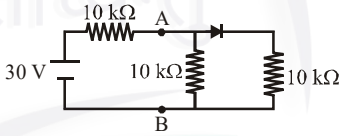
16. A bulb and a condenser are connected in series with an A.C. source. On increasing the frequency of the source its brightness will
(A) increase
(B) decrease
(C) sometimes increase and sometimes decrease
(D) neither increase nor decrease.

17. Two heater wires, made of the same material and having the same length and the same radius, are first connected in series and then in parallel to a constant potential difference. If the rates of heat produced in the two cases are H_s and H_p respectively, then H_s/H_p will be

(A) 1/2 **(B)** 2
(C) 1/4 **(D)** 4

18. A bulb of 25 W, 200 V and another bulb of 100 W, 200 V are connected in series with a supply line of 220 V. Then
(A) both bulbs will glow with same brightness
(B) both bulbs will get fused
(C) 25 W bulb will glow more brightly
(D) 100 W bulb will glow more brightly.

19. In the given circuit, the potential difference between A and B is



(A) 0 **(B)** 5 volt
(C) 10 volt **(D)** 15 volt

20. When a current is passed in a conductor, 3°C in temperature is observed. If the strength of current is made thrice, then rise in temperature will approximately be

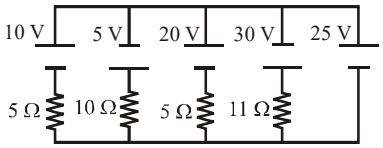
(A) 36°C **(B)** 27°C
(C) 18°C **(D)** 9°C

21. In a metal with positive Thomson coefficient, current is passed from the lower temperature to higher temperature side. Then heat will be

(A) absorbed **(B)** constant
(C) evolved **(D)** either (B) or (C)

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22. In the circuit shown, current flowing through 25 V cell is

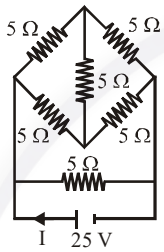


(A) 7.2 A **(B)** 10 A
(C) 12 A **(D)** 14.2 A

23. Transmission lines transmit a voltage of V volt to our houses from power station, then the power P supplied by them is proportional to

(A) $\frac{1}{V}$ **(B)** V
(C) V^2 **(D)** $\frac{1}{V^2}$

24. Calculate I for the given circuit diagram



(A) 10 A **(B)** 5 A
(C) 2.5 A **(D)** 20 A

25. Calculate the heat emitted by a bulb of 100 W in 1 min.

(A) 100 J **(B)** 1000 J
(C) 600 J **(D)** 6000 J

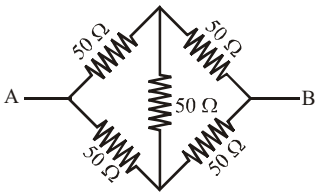
26. A circuit consisting of five resistors each of resistance R, forming a Wheatstone bridge. What is the equivalent resistance of the circuit ?

(A) 2R **(B)** R
(C) 2R/3 **(D)** R/2

27. 2, 4 and 6 S are the conductances of three conductors. When they are joined in parallel, their equivalent conductance will be

(A) 12 S **(B)** (1/12) S
(C) (12/11) S **(D)** 11/12 S

28. What is the equivalent resistance between A and B in given figure ?



(A) 50 Ω
(B) 25 Ω
(C) 75 Ω
(D) 100 Ω

29. When a current is passed in a conductor, 5°C rise in temperature is observed. If the strength of current is made thrice, rise in temperature will be

(A) 5 °C
(B) 20 °C
(C) 45 °C
(D) 15 °C

30. Ten identical cells each of potential E and internal resistance r are connected in series to form a closed circuit. An ideal voltmeter connected across three cells will read

(A) 10E
(B) 3E
(C) 13E
(D) 7E

31. A steady current flows in a metallic conductor of non-uniform cross-section. Which of these quantities is constant along the conductor ?

(A) Electric field
(B) Drift velocity
(C) Current
(D) Current density

32. On increasing the temperature of a conductor, its resistance increases because the

(A) relaxation time increases
(B) electron density decreases
(C) relaxation time decreases
(D) relaxation time remains constant

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ASSERTION AND REASON

33. **Assertion :** Good conductors of heat are also good conductors of electricity and vice versa.

Reason : Mainly electrons are responsible for these conductions.

34. **Assertion :** Electric appliances with metallic body e.g., heaters, presses etc., have three pin connections, whereas an electric bulb has a two pin connection.

Reason : Three pin connections reduce heating of connecting cables.

35. **Assertion :** In a simple battery circuit, the point of the lowest potential is positive terminal of the battery.

Reason : The current flows towards the point of the higher potential, as it does in such a circuit from the negative to the positive terminal.

36. **Assertion :** A larger dry cell has higher emf.

Reason : the emf of a dry cell is proportional to its size.

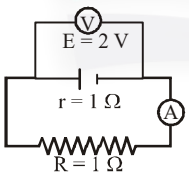
37. **Assertion :** A current continues to flow in superconducting coil even after switch is off.

Reason : Superconducting coils show Meissner effect.

38. **Assertion :** Ohm's law is applicable for all conducting elements.

Reason : Ohm's law is fundamental law.]

39. **Assertion :** In the following circuit, emf is 2 V and internal resistance of the cell is 1 W and R = 1 Ω, then reading of the voltmeter is 1 V.



Reason : V = E – IR where E = 2 V.

I = 2/2 = 1 A.

40. **Assertion :** A domestic electrical appliance, working on a three pin will continue working even if the top pin is removed.

Reason : The third pin is used only as a safety device.

41. **Assertion :** A bird perches on a high power line and nothing happens to the bird.

Reason : The level of bird is very high from the ground

42. **Assertion :** It is advantageous to transmit electric power at high voltage.

Reason : High voltage implies high current.

43. **Assertion :** Electric appliances with metallic body. e.g., heaters, presses etc., have three pin connections, whereas an electric bulb has a two pin connection

Reason : Three pin connections reduce heating of connecting cables.

44. **Assertion :** Total current entering a circuit is equal to leaving the circuit by Kirchhoff's law.

Reason : It is based on conservation of energy.

45. **Assertion :** Current is passed through a metallic wire so that it becomes red hot. When cold water is poured on half of its portion, the rest of the half portion becomes more hot.

Reason : Resistance decreases due to decrease in temperature.

46. **Assertion :** The conductivity of an electrolyte is very low as compared to a metal at room temperature.

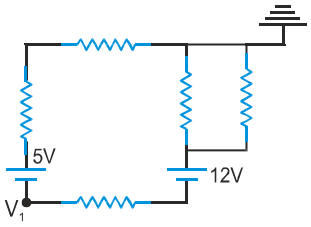
Reason : The number density of free ions in electrolyte is much smaller as compared to number density of free electrons in metals. Further, ions drift much more slowly, being heavier.

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MOCK TEST

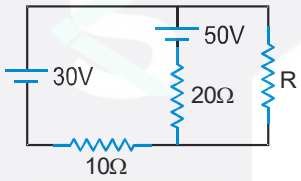
STRAIGHT OBJECTIVE TYPE

1. In the circuit shown, each resistances is 2 W. The potential V_1 as indicated in the circuit, is equal to



(A) 11 V **(B)** – 11V **(C)** 9 V **(D)** – 9 V

2. In the circuit shown, the value of R in ohm that will result in no current through the 30 V battery, is :



(A) 10 Ω **(B)** 25 Ω **(C)** 30 Ω **(D)** 40 Ω

3. The maximum current in a galvanometer can be 10 mA. It's resistance is 10Ω. To convert it into an ammeter of 1 Amp. a resistor should be connected in

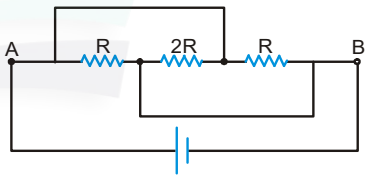
(A) series, 0.1Ω **(B)** parallel, 0.1Ω **(C)** series, 100 Ω **(D)** parallel, 100Ω.

4. When a galvanometer is shunted with a 4Ω resistance, the deflection is reduced to one - fifth. If the galvanometer is further shunted with a 2Ω wire, the further reduction (find the ratio of decrease in current to the previous current) in the deflection will be (the main current remains the same).

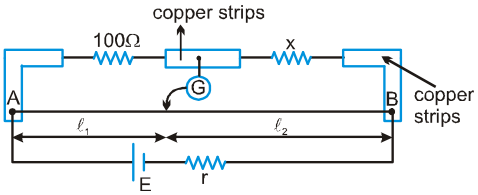
(A) (8/13) of the deflection when shunted with 4Ω only
(B) (5/13) of the deflection when shunted with 4Ω only
(C) (3/4) of the deflection when shunted with 4Ω only
(D) (3/13) of the deflection when shunted with 4Ω only

5. In the figure shown the current flowing through 2 R is :

(A) from left to right
(B) from right to left
(C) no current
(D) None of these



6. In a practical wheat stone bridge circuit as shown, when one more resistance of 100 Ω is connected is parallel with unknown resistance 'x', then ratio ℓ_1/ℓ_2 become '2'. ℓ_1 is balance length. AB is a uniform wire. Then value of 'x' must be:

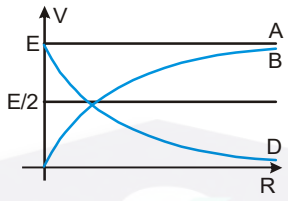


(A) 50 Ω **(B)** 100 Ω **(C)** 200 Ω **(D)** 400 Ω

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7. A battery of internal resistance 2 Ω is connected to a variable resistor whose value can vary from 4 Ω to 10 Ω. The resistance is initially set at 4 Ω. If the resistance is now increased then
(A) power consumed by it will decrease
(B) power consumed by it will increase
(C) power consumed by it may increase or may decrease
(D) power consumed will first increase then decrease.

8. A cell of emf E having an internal resistance 'r' is connected to an external resistance R. The potential difference 'V' across the resistance R varies with R as shown by the curve:



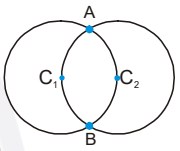
(A) A **(B)** B **(C)** C **(D)** D

9. 'n' identical light bulbs, each designed to draw P power from a certain voltage supply are joined in series and that combination is connected across that supply. The power consumed by one bulb will be-
(A) n P **(B)** P **(C)** P/n **(D)** P/n^2

10. To get maximum current through a resistance of 2.5 Ω, one can use 'm' rows of cells, each row having 'n' cells. The internal resistance of each cell is 0.5 Ω. What are the values of n & m, if the total number of cells is 45.

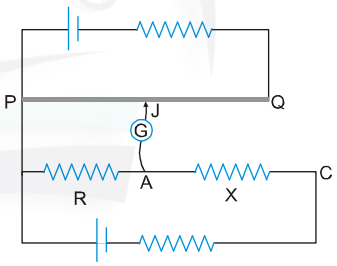
(A) 3, 15 **(B)** 5, 9 **(C)** 9, 5 **(D)** 15, 3

11. Two circular rings of identical radii and resistance of 36Ω each are placed in such a way that they cross each other's centre C_1 and C_2 as shown in figure. Conducting joints are made at intersection points A and B of the rings. An ideal cell of emf 20 volts is connected across AB. The power delivered by cell is



(A) 80 watt **(B)** 100 watt **(C)** 120 watt **(D)** 200 watt

12. Circuit for the measurement of resistance by potentiometer is shown. The galvanometer is first connected at point A and zero deflection is observed at length PJ = 10 cm. In second case it is connect at point C and zero deflection is observed at a length 30 cm from P. Then the unknown resistance X is



(A) 2R **(B)** $\frac{R}{2}$
(C) $\frac{R}{3}$ **(D)** 3R

13. Two long coaxial and conducting cylinders of radius a and b are separated by a material of conductivity σ and a constant potential difference V is maintained between them, by a battery. Then the current, per unit length of the cylinder flowing from one cylinder the other is :

(A) $\frac{4\pi\sigma}{\ell n(b/a)}V$ **(B)** $\frac{4\pi\sigma}{(b+a)}V$ **(C)** $\frac{2\pi\sigma}{\ell n(b/a)}V$ **(D)** $\frac{2\pi\sigma}{(b+a)}V$

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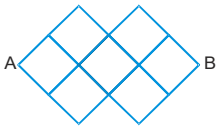
14. 50 V battery is supplying current of 10 amp when connected to a resistor. If the efficiency of battery at this current is 25%. Then internal resistance of battery is :

(A) 2.5 Ω **(B)** 3.75 Ω **(C)** 1.25 Ω **(D)** 5 Ω

15. A battery is supplying power to a tape-recorder by cable of resistance of 0.02 Ω. If the battery is generating 50 W power at 5V, then power received by tape-recorder is : (neglect internal resistance of battery)

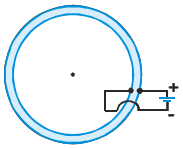
(A) 50 W **(B)** 45 W **(C)** 30 W **(D)** 48 W

16. In the shown wire frame, each side of a square (the smallest square) has a resistance R. The equivalent resistance of the circuit between the points A and B is :



(A) R **(B)** 2R **(C)** 4R **(D)** 8R

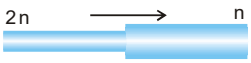
17. A spherical shell, made of material of electrical conductivity $\frac{10^9}{\pi}(\Omega\text{-m})^{-1}$, has thickness t = 2 mm and radius r = 10 cm. In an arrangement, its inside surface is kept at a lower potential than its outside surface.



The resistance offered by the shell is equal to -

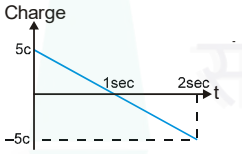
(A) $5\pi \times 10^{-12}\ \Omega$ **(B)** $2.5 \times 10^{-11}\ \Omega$ **(C)** $5 \times 10^{-12}\ \Omega$ **(D)** $5 \times 10^{-11}\ \Omega$

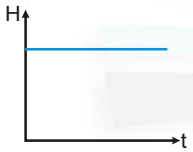
18. Two cylindrical rods of uniform cross-section area A and 2A, having free electrons per unit volume 2n and n respectively are joined in series. A current I flows through them in steady state. Then the ratio of drift velocity of free electron in left rod to drift velocity of electron in the right rod is $\left(\frac{v_L}{v_R}\right)$ is :

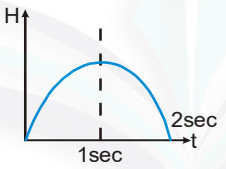


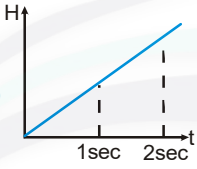
(A) $\frac{1}{2}$ **(B)** 1 **(C)** 2 **(D)** 4

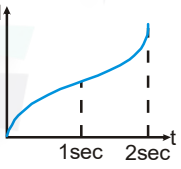
19. A charge passing through a resistor is varying with time as shown in the figure. The amount of heat generated in time 't' is best represented (as a function of time) by:



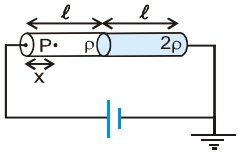
(A)


(B)


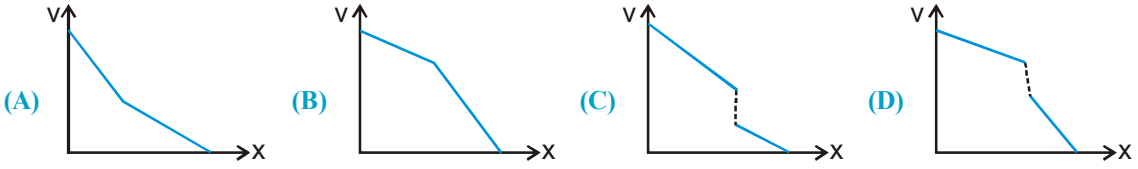
(C)


(D)


20. Two cylindrical rods of same cross-section area and same length are connected in series to an ideal cell as shown. The resistivity of left rod is ρ and that of right rod is 2ρ. Then the variation of potential at any point P distant x from left end of combined rod system is given by.



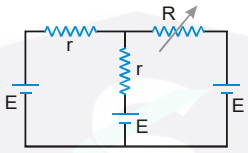
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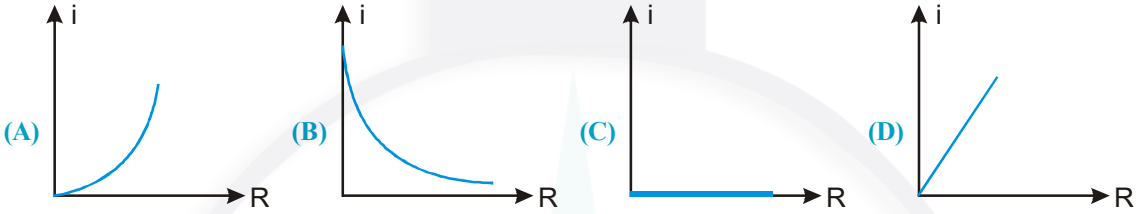
21. A copper sphere of 10cm diameter is lowered into a water filled hemispherical copper vessel of 20 cm diameter so that the sphere and the vessel becomes concentric. Electrical conductivity of water is $\sigma = 10^{-3}\ (\Omega - m)^{-1}$. The electrical resistance between the sphere and the vessel is :

(A) 1591.6 Ω **(B)** 1450 Ω **(C)** 1682.4 Ω **(D)** 1489.6 Ω

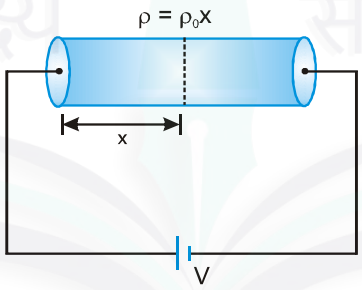
22. In the shown circuit the resistance R can be varied :



The variation of current through R against R is correctly plotted as :



23. A cylindrical solid of length L and radius a is having varying resistivity given by $\rho = \rho_0 x$ where ρ_0 is a positive constant and x is measured from left end of solid. The cell shown in the figure is having emf V and negligible internal resistance. The electric field as a function of x is best described by :



(A) $\frac{2V}{L^2} \times x$ **(B)** $\frac{2V}{\rho_0 L^2} \times x$ **(C)** $\frac{V}{L^2} \times x$ **(D)** None of these

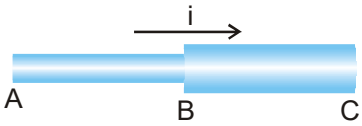
24. Two wires that are made up of two different materials whose specific resistance are in the ratio 2 : 3, length 3 : 4 and area 4 : 5. The ratio of their resistances is

(A) 6 : 5 **(B)** 6 : 8 **(C)** 5 : 8 **(D)** 1 : 2

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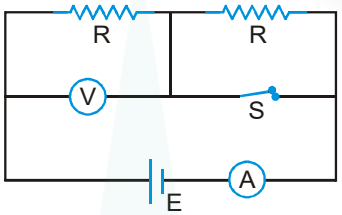
MATRIX - MATCH TYPE

25. Column I gives physical quantities of a situation in which a current i passes through two rods I and II of equal length that are joined in series. The ratio of free electron density (n), resistivity (ρ) and cross-section area (A) of both are in ratio $n_1 : n_2 = 2 : 1$, $\rho_1 : \rho_2 = 2 : 1$ and $A_1 : A_2 = 1 : 2$ respectively. Column II gives corresponding results. Match the ratios in Column I with the values in Column II .



	Column I	Column II
(A)	$\frac{\text{Drift velocity of free electron in rod I}}{\text{Drift velocity of free electron in rod II}}$	**(P)** 0.5
(B)	$\frac{\text{Electric field in rod I}}{\text{Electric field in rod II}}$	**(Q)** 1
(C)	$\frac{\text{Potential difference across rod I}}{\text{Potential difference across rod II}}$	**(R)** 2
(D)	$\frac{\text{Average time taken by free electron to move from A to B}}{\text{Average time taken by free electron to move from B to C}}$	**(S)** 4

26. In the circuit shown, battery, ammeter and voltmeter are ideal and the switch S is initially closed as shown. When switch S is opened, match the parameter of column I with the effects in column II .



(A)	Equivalent resistance across the battery	**(p)** Remains same
(B)	Power dissipated by left resistance R	**(q)** Increases
(C)	Voltmeter reading	**(r)** decreases
(D)	Ammeter reading	**(s)** Becomes zero.

ASSERTION AND REASON TYPE

These questions contains, Statement 1 (assertion) and Statement II (reason).

(A) Statement-1 is True, Statement-2 is True; Statement-2 **is** a correct explanation for Statement-1

(B) Statement-1 is True, Statement-2 is True; Statement-2 **is NOT** a correct explanation for Statement-1

(C) Statement-1 is True, Statement-2 is False

(D) Statement-1 is False, Statement-2 is True.

27. **Assertion :** When an external resistor of resistance R (connected across a cell of internal resistance r) is varied, power consumed by resistance R is maximum when R = r.

Reason : Power consumed by a resistor of constant resistance R is maximum when current through it is maximum.

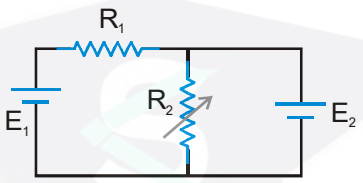
28. **Assertion :** The current density $\vec{J}$ at any point in ohmic resistor is in direction of electric field $\vec{E}$ at that point.

Reason : A point charge when released from rest in a region having only electrostatic field always moves along electric lines of force.

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29. **Assertion :** A wire of uniform cross section and uniform resistivity is connected across an ideal cell. Now the length of the wire is doubled keeping volume of wire constant. The drift velocityof electrons after stretching the wire becomes one fourth of what it was before stretching the wire.
Reason : If a wire (of uniform resistivity and uniform cross-section) of length ℓ_o is stretched to length $n\ell_o$, then its resistance becomes n^2 times of what it was before stretching the wire (the volume of wire is kept constant in stretching process). Further at constant potential difference, current is inversely proportional to resistance. Finally drift velocity of free electron is directly proportional to current and inversely proportional to cross section area of current carrying wire..

30. **Assertion :** In the circuit shown both cells are ideal and of fixed emf, the resistor of resistance R_1 has fixed resistance and the resistance of resistor R_2 can be varied(but R_2 is always non-zero). Then the electric power delivered to resistor of resistance R_1 is independent of value of resistance R_2.



Reason : If potential difference across a fixed resistance is unchanged, the power delivered to the resistor remains constant.

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ANSWER KEY

EXERCISE - 1

1. A **2.** C **3.** B **4.** B **5.** C **6.** A **7.** A **8.** A **9.** D **10.** C **11.** D **12.** D **13.** A

14. C **15.** A **16.** A **17.** C **18.** B **19.** C **20.** B **21.** C **22.** D **23.** A **24.** C **25.** B **26.** C

27. C **28.** B **29.** A **30.** B **31.** B **32.** D **33.** C **34.** A **35.** A **36.** B **37.** A **38.** A **39.** B

40. A **41.** A **42.** C **43.** D **44.** D **45.** C **46.** C **47.** A **48.** D **49.** C **50.** C **51.** A **52.** B

53. C **54.** B **55.** B **56.** C **57.** C **58.** A **59.** B **60.** C **61.** A **62.** C **63.** C **64.** A **65.** D

66. D **67.** B **68.** C **69.** C **70.** A **71.** D **72.** C **73.** D **74.** D **75.** C **76.** D **77.** B **78.** D

79. B **80.** A **81.** B **82.** C **83.** D **84.** A **85.** C **86.** B **87.** A **88.** A **89.** A **90.** A

EXERCISE - 2

1. D **2.** C **3.** D **4.** C **5.** C **6.** C **7.** C **8.** B **9.** C **10.** A **11.** B **12.** A **13.** B

14. C **15.** B **16.** D **17.** C **18.** C **19.** D **20.** D **21.** B **22.** B **23.** C **24.** A **25.** B **26.** A

27. B **28.** B **29.** B **30.** B **31.** A **32.** A **33.** D **34.** C **35.** B **36.** D

EXERCISE - 3 : PART # 1

1. A → P ; B → Q, S ; C → S ; D → P, R, S

2. A → Q ; B → P ; C → P ; D → Q

3. A → Q ; B → P ; C → P

4. A → P ; B → P ; C → Q ; D → Q,S

PART # 2

1. C **2.** B **3.** D **4.** E **5.** A **6.** A **7.** B **8.** A **9.** C **10.** D

EXERCISE - 4 : PART # 1

1. D **2.** C **3.** C **4.** A **5.** A **6.** A **7.** A **8.** A **9.** D **10.** B **11.** A **12.** C **13.** C

14. C **15.** A **16.** D **17.** A **18.** B **19.** B **20.** B **21.** A **22.** D **23.** A **24.** B **25.** A **26.** D

27. D **28.** A **29.** C **30.** A **31.** B **32.** A **33.** B **34.** B **35.** D **36.** C **37.** C **38.** B **39.** B

40. A **41.** A **42.** B **43.** A **44.** A **45.** D **46.** C **47.** B **48.** C **49.** C **50.** A **51.** A **52.** D

53. C **54.** B **55.** D **56.** C **57.** D **58.** D **59.** A **60.** C **61.** D **62.** D **63.** A **64.** C **65.** B

66. C **67.** B **68.** C **69.** D **70.** D **71.** A

PART # 2

1. D **2.** C **3.** B **4.** B **5.** D **6.** A **7.** B **8.** C **9.** D **10.** D **11.** A **12.** C **13.** A

14. B **15.** A **16.** A **17.** C **18.** C **19.** C **20.** B **21.** A **22.** C **23.** B **24.** A **25.** D **26.** B

27. A **28.** A **29.** C **30.** B **31.** C **32.** C **33.** A **34.** C **35.** D **36.** D **37.** B **38.** D **39.** C

40. A **41.** C **42.** C **43.** C **44.** A **45.** A **46.** A

MOCK TEST

1. D **2.** C **3.** B **4.** A **5.** B **6.** B **7.** A **8.** B **9.** D

10. D **11.** B **12.** A **13.** C **14.** B **15.** D **16.** B **17.** D **18.** B

19. C **20.** B **21.** A **22.** C **23.** A **24.** C **25.** A → Q ; B → S ; C → S; D → Q

26. A → Q; B → R ; C → R ; D → R **27.** B **28.** C **29.** D **30.** A

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HINTS & SOLUTIONS

EXERCISE - 1
NEET LEVEL

1. (A) Number of electrons flowing per second

$\frac{n}{t} = \frac{i}{e} = 4.8/1.6\times10^{-19} = 3\times10^{19}$

2. (C) $v_d = \frac{J}{ne} \Rightarrow v_d \propto J$ (current density)

$J_1 = \frac{i}{A}$ and $J_2 = \frac{2i}{2A} = \frac{i}{A} = J_1$; $\therefore (v_d)_1 = (v_d)_2 = v$

3. (B) Order of drift velocity $= 10^{-4} m/sec = 10^{-2} cm/sec$

4. (B) Density of $Cu = 9\times10^3 kg/m^3$ (mass of 1 m^3 of Cu)

$\because$ 6.0×10^{23} atoms has a mass $= 63\times10^{-3}$ kg

$\therefore$ Number of electrons per m^3 are

$= \frac{6.0\times10^{23}}{63\times10^{-3}}\times9\times10^3 = 8.5\times10^{28}$

Now drift velocity $= v_d = \frac{i}{neA}$

$= \frac{1.1}{8.5\times10^{28}\times1.6\times10^{-19}\times\pi\times(0.5\times10^{-3})^2}$

$= 0.1\times10^{-3} m/sec$

5. (C) Because 1 $H.P. = 746$ $J/s = 746$ $watt$

6. (A) $R \propto l^2 \Rightarrow \frac{\Delta R}{R} = \frac{2\Delta l}{l} \Rightarrow \frac{\Delta R_0}{R}\% = 2\times0.1 = 0.2\%$

7. (A) $R = \frac{\rho l}{A} = 50\times10^{-8}\times\frac{50\times10^{-2}}{(50\times10^{-2})^2} = 10^{-6}\Omega$

8. (A) Resistivity of some material is its intrinsic property and is constant at particular temperature. Resistivity does not depend upon shape.

9. (D) $\frac{\rho_1}{\rho_2} = \frac{(1+\alpha t_1)}{(1+\alpha t_2)} \Rightarrow \frac{1}{2} = \frac{(1+0.00125\times27)}{(1+0.00125\times t)}$

$\Rightarrow t = 854°C \Rightarrow T = 1127K$

10. (C) $R_1 \propto \frac{l}{A} \Rightarrow R_2 \propto \frac{2l}{2A}$ *i.e.* $R_2 \propto \frac{l}{A}$

$\therefore R_1 = R_2$

11. (D) In case of stretching of wire $R \propto l^2$

$\Rightarrow$ If length becomes 3 times so Resistance becomes 9 times *i.e.* $R' = 9\times20 = 180\Omega$

12. (D) Resistivity is the property of the material. It does not depend upon size and shape.

13. (A) Because with rise in temperature resistance of conductor increase, so graph between V and i becomes non linear.

14. (C) Because V-i graph of diode is non-linear.

15. (A) $v_d = \frac{e}{m}\times\frac{V}{l}\tau$ or $v_d = \frac{e}{m}\cdot\frac{El}{l}\tau$ (Since $V = El$)

$\therefore v_d \propto E$

16. (A) Resistance of conductor depends upon relation as $R \propto \frac{1}{\tau}$. With rise in temperature *rms* speed of free electron inside the conductor increase, so relaxation time decrease and hence resistance increases

17. (C) $i = \frac{q}{t} = \frac{4}{2} = 2$ $ampere$

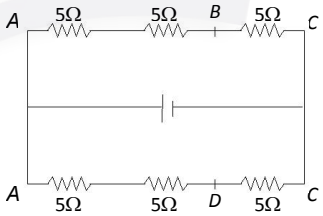
18. (B) Volume $= Al = 3 \Rightarrow A = \frac{3}{l}$

Now $R = \rho\frac{l}{A} \Rightarrow 3 = \frac{\rho\times l}{3/l} = \frac{\rho l^2}{3} \Rightarrow l^2 = \frac{9}{\rho} = \frac{3}{\sqrt{\rho}}$

19. (C) $i = \frac{ne}{t} = \frac{62.5\times10^{18}\times1.6\times10^{-19}}{1} = 10$ $ampere$

20. (B) In twisted wire, two halves each of resistance 2Ω are in parallel, so equivalent resistance will be $\frac{2}{2} = 1\Omega$.

21. (C) The given circuit can be redrawn as follows



For identical resistances, potential difference distributes equally among all. Hence potential difference across each resistance is $\frac{2}{3}V$, and potential difference between A and B is $\frac{4}{3}V$.

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22. **(D)** Equivalent resistance of parallel resistors is always less than any of the member of the resistance system.

23. **(A)** Each part will have a resistance $r = R/10$

Let equivalent resistance be r_R, then

$$\frac{1}{r_R} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r} \text{.....10 times}$$

$$\therefore \frac{1}{r_R} = \frac{10}{r} = \frac{10}{R/10} = \frac{100}{R} \Rightarrow r_R = \frac{R}{100} = 0.01R$$

24. **(C)** $R_{equivalent} = \frac{(30+30)30}{(30+30)+30} = \frac{60\times 30}{90} = 20\Omega$

$$\therefore i = \frac{V}{R} = \frac{2}{20} = \frac{1}{10} ampere$$

25. **(B)** Resistance of parallel group $= \frac{R}{2}$

$\therefore$ Total equivalent resistance $= 4\times\frac{R}{2} = 2R$

26. **(C)** Resistance of 1 *ohm* group $= \frac{R}{n} = \frac{1}{3}\Omega$

This is in series with $\frac{2}{3}\Omega$ resistor.

$\therefore$ Total resistance $= \frac{2}{3}+\frac{1}{3} = \frac{3}{3}\Omega = 1\Omega$

27. **(C)** Lowest resistance will be in the case when all the resistors are connected in parallel.

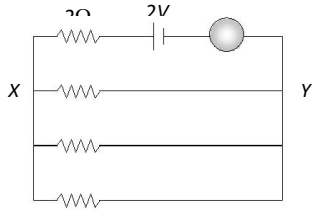
$$\frac{1}{R} = \frac{1}{0.1} + \frac{1}{0.1} \text{..... 10 times}$$

$$\frac{1}{R} = 10+10\text{.....10 times}$$

$$\frac{1}{R} = 100 \text{ i.e. } R = \frac{1}{100}\Omega$$

28. **(B)** Resistance across $XY = \frac{2}{3}\Omega$

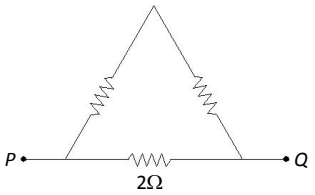
Total resistance $= 2+\frac{2}{3} = \frac{8}{3}\Omega$



Current through ammeter $= \frac{2}{8/3} = \frac{6}{8} = \frac{3}{4}A$

29. **(A)** Equivalent resistance of the combination

$$= \frac{(2+2)\times 2}{2+2+2} = \frac{8}{6} = \frac{4}{3}\Omega$$



30. **(B)** In parallel, $x = \frac{R}{n}$ $R = nx$

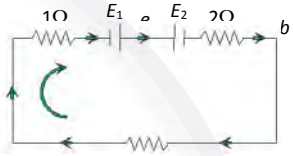
In series, $R+R+R$ .... n times $= nR = n(nx) = n^2x$

31. **(B)** For no current through galvanometer, we have

$$\left(\frac{E_1}{500+X}\right)X = E \Rightarrow \left(\frac{12}{500+X}\right)X = 2 \Rightarrow X = 100\,\Omega$$

32. **(D)** Since $E_1(10\,V) > E_2(4V)$

So current in the circuit will be clockwise.



Applying Kirchoff's voltage law

$-1\times i + 10 - 4 - 2\times i - 3i = 0 \Rightarrow i = 1A(a \text{ to } b \text{ via } e)$

$\therefore$ Current $= \frac{V}{R} = \frac{10-4}{6} = 1.0\, ampere$

33. **(C)** For maximum power, external resistance = internal resistance.

34. **(A)** $0.9(2+r) = 0.3(7+r) \Rightarrow 6+3r = 7+r \Rightarrow r = 0.5\,\Omega$

35. **(A)** Since both the resistors are same, therefore potential difference $= V+V = E \Rightarrow V = \frac{E}{2}$

36. **(B)** Let the current in the circuit $= i = \frac{V}{R}$

Across the cell, $E = V + ir \Rightarrow r = \frac{E-V}{i} = \frac{E-V}{V/R} = \left(\frac{E-V}{V}\right)R$

37. **(A)** For maximum energy, we have

External resistance of the circuit

= Equivalent internal resistance of the circuit *i.e.* $R = \frac{r}{2}$

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38. (A) Kirchhoff's first law is based on the law of conservation of charge.

39. (B) Kirchhoff's second law is based on the law of conservation of energy.

40. (A) According to Kirchhoff's first law

At junction A, $i_{AB} = 2 + 2 = 4A$

At junction B, $i_{AB} = i_{BC} - 1 = 3A$



At junction C, $i = i_{BC} - 1.3 = 3 - 1.3 = 1.7\ amp$

41. (A) In meter bridge experiment, it is assumed that the resistance of the L shaped plate is negligible, but actually it is not so. The error created due to this is called, end error. To remove this the resistance box and the unknown resistance must be interchanged and then the mean reading must be taken.

42. (C) To convert a galvanometer into an ammeter a low value resistance is to be connected in parallel to it called shunt.

43. (D) Balance point has some fixed position on potentiometer wire. It is not affect by the addition of resistance between balance point and cell.

44. (D) Resistance of voltmeter should be greater than the external circuit resistance. An ideal voltmeter has infinite resistance.

45. (C) $S = \frac{i_g G}{i - i_g} = \frac{100 \times 0.01}{(10 - 0.01)} = \frac{1}{10} = 0.1\Omega$

46. (C) Equivalent resistance of the circuit $R_{eq} = 100\Omega$

current through the circuit $i = \frac{2.4}{100} A$

P.D. across combination of voltmeter and 100 Ω resistance $= \frac{2.4}{100} \times 50 = 1.2V$

Since the voltmeter and 100 Ω resistance are in parallel, so the voltmeter reads the same value *i.e.* $1.2V$.

47. (A) Potential gradient $= \frac{e}{(R + R_h + r)} \cdot \frac{R}{L}$

$= \frac{2}{(15 + 5 + 0)} \times \frac{5}{1} = 0.5 \frac{V}{m} = 0.005 \frac{V}{cm}$

48. (D) $S = \frac{i_g G}{(i - i_g)} \Rightarrow \frac{G}{S} = \frac{i - i_g}{i_g} = \frac{10 - 1}{1} = \frac{9}{1}$

49. (C) Ammeter is used to measure the current through the circuit.

50. (C) $S = \frac{i_g G}{(i - i_g)} = \frac{1 \times 0.018}{10 - 1} = \frac{0.018}{9} = 0.002\Omega$

51. (A) $1\ kWh = 1000\ W\ 3600\ sec = 36 \times 10^5\ W\text{-}sec\ (\text{or}\ J)$

52. (B) $P \propto \frac{1}{R} \Rightarrow \frac{P_1}{P_2} = \frac{R_2}{R_1} \Rightarrow \frac{200}{100} = \frac{R_2}{R_1} \Rightarrow R_2 = 2R_1$

53. (C) $P = \frac{V^2}{R} \Rightarrow R_1 = \frac{V_1^2}{P_1} = \frac{(200)^2}{40} = 1000\Omega$

and $R_2 = \frac{V_2^2}{P_2} = \frac{(200)^2}{100} = 400\Omega$

54. (B) When two bulbs are connected in series, the current will be same in both the bulbs. As a result potential drop will be more in the bulb of higher resistance *i.e.,* bulb of lower wattage.

55. (B) When 1 bulb fuses, the total resistance of the circuit decreases hence the current increases. Since $P = i^2 R$, therefore illumination increases.

56. (C)

57. (C) We know that $\frac{P_1}{P_2} = \frac{R_2}{R_1} = \frac{2}{1}$

58. (A) $P = \frac{V^2}{R} \Rightarrow P \propto \frac{1}{R}$ and $R \propto l$

$\therefore P \propto \frac{1}{l} \Rightarrow \frac{P_1}{P_2} = \frac{l_1}{l_2} = \frac{2}{1}$

59. (B) $R_{\text{conductor}} \propto$ Temperature and

$R_{\text{semiconductor}} \propto \frac{1}{\text{Temperature}}$

60. (C)

61. (A) In series, current is same in both the bulbs, hence

$P \propto R (P = i^2 R)$ $\quad \therefore \frac{P_1}{P_2} = \frac{R_1}{R_2} = \frac{1}{2}$

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62. (C) In this case, $P=\frac{V^2}{R}$ or $P\propto\frac{1}{R}$ and R will be minimum, when divided four parts are joints in parallel to the battery.

63. (C) Length is immaterial for an electric fuse wire.

64. (A) $P_{Rated}\propto\frac{1}{R}$ and $R\propto\frac{1}{(\text{Thickness of filament})^2}$

So $P_{Rated}\propto(\text{Thickness of filament})^2$

65. (D) In series $P_S=\frac{P}{n}\Rightarrow 10=\frac{P}{3}\Rightarrow P=30\,W$

In parallel $P_P=nP=3\times30=90\,W$

66. (D) Energy consumed in $kWh=\frac{Watt\times hour}{1000}$

$\Rightarrow$ For 30 days, $P=\frac{10\times50\times10}{1000}\times30=150kWh$

67. (B) $W=qV$ also $P=i\times V=\frac{W}{t}$

68. (C) Because given voltage is very high,

69. (C) $P_p=nP=2\times40=80\,W$

70. (A) In series, $P\propto R(\because i$ is same), *i.e.* in series Fine wire (high R) liberates more energy.

In parallel, $P\propto\frac{1}{R}(V$ is same) *i.e.* thick wire (less R) liberates more energy.

71. (D) As sugar cannot be decomposed into ions and ions are responsible for conduction.

72. (C) $\because\ \frac{Z_1}{Z_2}=\frac{E_1}{E_2}\ \Rightarrow Z_2=\left(\frac{E_2}{E_1}\right).Z_1$

73. (D) $\frac{m_{Zn}}{m_{Ag}}=\frac{E_{Zn}}{E_{Ag}}\Rightarrow m_{Ag}=W\left(\frac{E_{Ag}}{E_{Zn}}\right)=3.3\,W=3.5\,W$

74. (D) 96500 *coulombs* of charge is needed to deposit one gram equivalent of an element at an electrode.

75. (C) As $\frac{m_{Cu}}{m_{Ag}}=\frac{E_{Cu}}{E_{Ag}}=\frac{\frac{1}{2}(\text{Atomic weight})_{Cu}}{(\text{Atomic weight})_{Ag}}$

76. (D) $V_2=\frac{22.4\times1}{1}=22.4$ *litre* at NTP

$\because$ 11.2 *litre* of H_2 is liberated by 96,500 C

$\therefore$ 22.4 *litre* of H_2 is liberated by $96500\times2=1,93,000\,C$

77. (B) From $m=ZQ$; if $Q=1C\Rightarrow m=Z$

78. (D)

79. (B) Because H has positive charge.

80. (A) Because H_2O is used as electrolyte.

81. (B) Production of e.m.f. by temperature difference is known Seeback effect.

82. (C) Production of heat at junctions due to current is known as Peltier effect.

83. (D) **84. (A)**

85. (C) When there is no deflection, then this temperature is called inversion temperature. It is given by the relation

$\theta_n=\frac{\theta_i+\theta_c}{2}$

Where θ_c is temperature of cold junction $=20^oC$ and neutral temperature $\theta_n=270^oC$

$\therefore\ \theta_i=2\theta_n-\theta_c=540-20=520^oC$

86. (B)

87. (A) Thermo e.m.f. of a thermo couple depends on the nature of metals.

88. (A)

89. (A) According to the definition.

90. (A) $T_n=\frac{T_i+T_C}{2}\Rightarrow T_i=2T_n-T_C$

EXERCISE - 2
AIIMS LEVEL

1. (D) $j=\frac{I}{A}=nev_d$

$\frac{4I}{\pi d^2}=nev$ ...(i) $\quad\frac{16I}{\pi d^2}=nev'$ ...(ii)

From equation (i) & (ii) $\frac{4I}{16I}=\frac{v}{v'}\Rightarrow v'=4v$

2. (C) $j\rightarrow$ Current density $\quad n\rightarrow$ Charge density

$j=-nev_d\qquad v_{d_1}=\frac{j}{n_1e}$

$v_{d_2}=\frac{j}{n_2e},\ \frac{n_1}{n_2}=\frac{1}{4}\Rightarrow n_2=4n_1$

$\frac{v_{d_1}}{v_{d_2}}=\frac{n_2}{n_1}=\frac{4n_1}{n_1}=4:1$

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3. **(D)** $i = nev_dA;\ I = \frac{2envA}{4} - (-nevA) = \frac{3}{2}nevA$

4. **(C)** $v_d = \frac{i}{Ane}$ As $A\uparrow$ so $v_d\downarrow \Rightarrow v_P > v_Q$

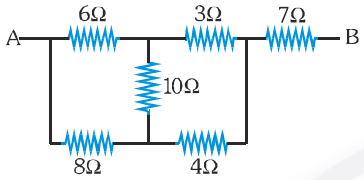
5. **(C)** $R = \frac{\rho L}{A}\frac{L}{L} = \frac{\rho L^2}{V} \Rightarrow R \propto L^2$

6. **(C)** $R = \frac{\rho L}{A}\frac{L}{L} = \frac{\rho L^2}{AL} = \frac{\rho L^2}{V} = \frac{\rho L^2 d}{m}$

$d, \rho \rightarrow$ same for all as the material is same for all.

$\Rightarrow R_1 : R_2 : R_3 = \frac{25}{1} : \frac{9}{3} : \frac{1}{5} = 125 : 15 : 1$

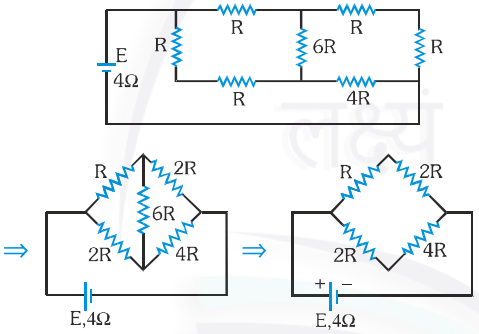
7. **(C)**



Balanced Wheatstone Bridge

As $\frac{1}{9} + \frac{1}{12} = \frac{7}{36} = \frac{36}{7}$ So $R_{AB} = \frac{36}{7} + 7 = \frac{85\Omega}{7}$

8. **(B)**



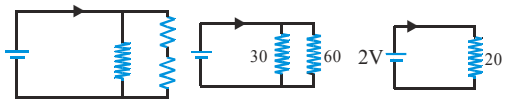
This is balanced wheat stone bridge

From maximum power transfer theorem

Internal resistance = External resistance

$\Rightarrow 4 = \frac{3R \times 6R}{3R + 6R} \Rightarrow 4 = 2R \Rightarrow R = 2\,\Omega$

9. **(C)**



$V = IR \Rightarrow 2 = (I)(20) \Rightarrow I = \frac{1}{10}A$

10. **(A)** $P = I^2R = \left(\frac{V}{R}\right)^2 R = \frac{\varepsilon^2}{(R+r)^2}R$

ε is constant and (R+ r) increases rapidly Then P$\downarrow$

11. **(B)** $P = \frac{V^2}{R}$ Initially, $I = \frac{V}{2R}$

Power across $P_X = P_Y = \left(\frac{\varepsilon^2}{4R}\right)R$

Finally, $I = \frac{2V}{3R}$, Power $P_X = \frac{4V^2}{9R}, P_y = P_z = \frac{2V^2}{9R}$

Hence P_x increases, P_y decreases.

Alternative method :

Brightness $\propto i^2R$ when S is closed current drawn from battery increases because R_{eq} decreases. i.e. current in X increases. So brightness of X increases and current in Y decreases. So brightness of Y decreases.

12. **(A)** $R_1 = \frac{\rho\ell}{A_1}, R_2 = \frac{\rho\ell}{A_2}$ As $A_1 < A_2$ So $R_1 > R_2$

In series $H = I^2Rt$ $H \propto R$; $H_1 > H_2$

In parallel $H = \frac{V^2}{R}t$ $H \propto \frac{1}{R}$; $H_1 < H_2$

13. **(B)** $P = i^2R \Rightarrow 10 = i^2 5 \Rightarrow i^2 = \frac{10}{5} = 2 \Rightarrow i = \sqrt{2}$

$i_4 = \frac{i_5}{2} \Rightarrow P_4 = \left(\frac{i}{2}\right)^2 4$, $P_5 = (i^2)5$

$\frac{P_4}{P_5} = \frac{1}{5} \Rightarrow P_4 = \frac{P_5}{5}$, $P_4 = \frac{10}{5} = 2$ cal/s

14. **(C)** $V = \varepsilon + i(r) \Rightarrow 12.5 = \varepsilon + \frac{1}{2}(1) \Rightarrow \varepsilon = 12$ V

(As the battery is a storage battery it is getting charged)

15. **(B)** $V = IR \Rightarrow 0.2 = I(20)$

$I_g = 0.01$A (through the galvanometer)

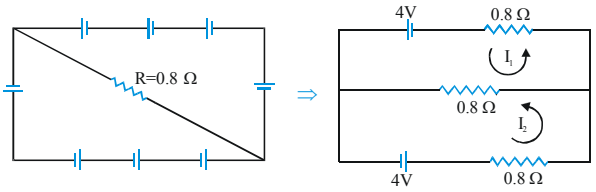
$I_g G = (i - i_g)S \Rightarrow (0.01)(20) = (10 - 0.01)S$

$\Rightarrow S = 0.020\,\Omega$

16. **(D)** The correct answer is R = 0

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17. (C)



$1.6\,I_1 - 0.8\,I_2 = 4$ ...(i)

$1.6\,I_2 - 0.8\,I_1 = 4$ ...(ii)

from eq. $I_1 = I_2 = 5$

voltage difference across any of the battery.



$V_a - 1 + 0.2 \times 5 - V_b = 0$

$V_a - V_b = 0$ Volt

18. (C) $R_v = \frac{V}{i_g} - G \Rightarrow 910 = \frac{V}{10 \times 10^{-3}} - 90$

$\Rightarrow V = 10 \Rightarrow$ No. of divisions $= \frac{10}{0.1} = 100$

19. (D) $I = \frac{12}{4 + 2 + \infty} = 0$. If i=0,

potential difference is equal of EMF of cell. = 12V

20. (D) $20 + R = \frac{12}{0.1} \Rightarrow R = 100\Omega$

21. (B) $E = \left(\frac{V}{\ell}\right) \times \frac{\ell}{3}$ & $E = \left(\frac{V}{3\ell/2}\right)(\ell') \Rightarrow \ell' = \frac{\ell}{2}$

22. (B) $\frac{P}{S} = \frac{Q}{625} \Rightarrow \frac{P}{Q} = \frac{S}{625}$ ...(i)

$\frac{Q}{S} = \frac{P}{676} \Rightarrow \frac{P}{Q} = \frac{676}{S}$ ...(ii)

From (i) & (ii) $\frac{676}{S} = \frac{S}{625}$

$(676)(625) = S^2 \Rightarrow S = 650\Omega$

23. (C) Potential gradient

$x = \left(\frac{12}{8+16}\right) \times 4 = 2 Vm^{-1}$

Effective emf of E_1 and E_2

$E = E = \frac{\frac{E_2}{r_2} - \frac{E_2}{r_1}}{1/r_1 + 1/r_2} = \frac{1}{2}$ volt

Balancing length $AN = \left(\frac{1}{2}\right)\left(\frac{1}{2}\right) = \frac{1}{4} m = 25 cm$

24. (A) Potential gradient

$x = \left(\frac{5}{0.5+4.5}\right)\left(\frac{4.5}{3}\right) = 1.5\ Vm^{-1}$

Here $(x)(AC) = 3 \Rightarrow AC = \frac{3}{1.5} = 2m$

25. (B) Potential gradient $x = \left(\frac{E}{10r}\right)\left(\frac{9r}{L}\right)$

According to question

$\frac{E}{2} = \left(\frac{E}{10r}\right)\left(\frac{9r}{L}\right)(\ell) \Rightarrow \ell = \frac{5L}{9}$

26. (A) (25W– 220V)

$P_1 = \frac{V_1^2}{R_1}$, $R_1 = \frac{(220)^2}{25} = 1936\Omega$

(100W–220V)

$P_2 = \frac{V_2^2}{R_2}$, $R_2 = \frac{(220)^2}{100} = 484\,\Omega$

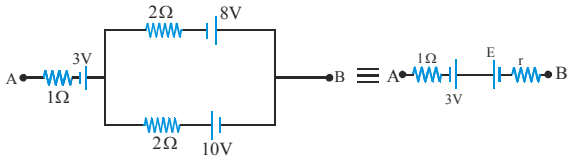
In Series (I same)

$H = I^2Rt$, $H \propto R$ so if $R_1 > R_2$ then $H_1 > H_2$

R_1 is likely to fuse

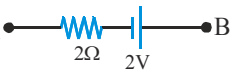
27. (B) $P = \frac{V^2}{R} = \frac{V^2 A}{\rho\ell} \alpha \frac{r^2}{\ell}$ [V → same]

28. (B)



$E = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2}}{\frac{1}{r_1} + \frac{1}{r_2}} = \frac{\frac{10}{2} + \frac{(-8)}{2}}{\frac{1}{2} + \frac{1}{2}} = 1$ volt and

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$r=\frac{r_1r_2}{r_1+r_2}=1\Omega$. Therefore 

29. (B) $P \Rightarrow \frac{V^2}{R} \Rightarrow \frac{V^2A}{L\rho}$ ...(i)

$P' = \frac{V^2A}{\left(L-\frac{L}{10}\right)\rho} \Rightarrow \frac{10V^2A}{9L\rho}$ ...(ii)

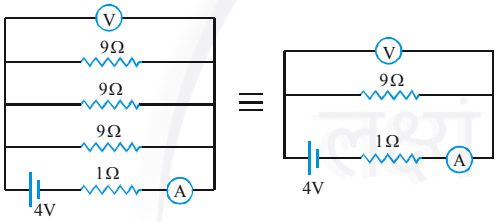
from eq. (i) & (ii) $P' = \frac{10}{9}P$

$\frac{\Delta P}{P}\times 100 \Rightarrow \frac{\left(\frac{10}{9}P-P\right)}{P}\times 100$

$\Rightarrow \frac{1}{9}\times 100 \Rightarrow 11.11\%$

30. (B) In parallel combination the equivalent resistance is less than the two individual resistance connected and in series combination equivalent resistance is more than the two individual components.

31. (A) Given circuit can be reduced to



Reading of ammeter $= \frac{4}{3+1} = 1A$

Reading of voltmeter $= 3\times 1 = 3V$

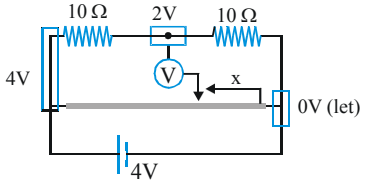
32. (A)

33. (D) $I_{wire} = \frac{4V}{0.4\times 50\Omega} = 0.2\,A$

Potential difference across voltmeter,

$V = Ir - 2$

$\Rightarrow$ $2\sin\pi t = 0.2\times 50\ x - 2 \Rightarrow 2\pi\cos\pi t = 10$ V



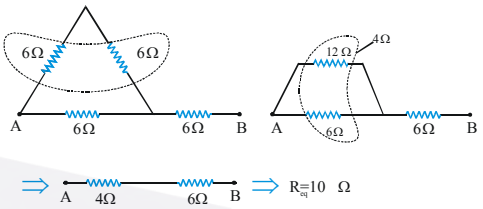
$\Rightarrow$ $V = 20\,\pi\,(\cos\pi t)$ cm/s

34. (C) Total length of wire = 90 + 90 = 180 m ; Total resistance of wire = 180/5 = 12 Ω.

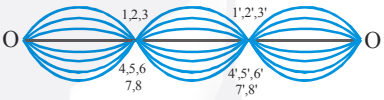
As $I = \frac{nE}{R+nr} \Rightarrow 0.25 = \frac{n\times 1.4}{12+5+n\times 2} \Rightarrow n = 4.7$

$\Rightarrow$ Total number of cells required = 5

35. (B)



36. (D)



Points 1, 2, 3.....8 are of same potential and 1', 2', 3'.....8' are of same potential.

$R_{eq} = \frac{3R}{8}$

EXERCISE - 3

P-1 (Matrix Match)

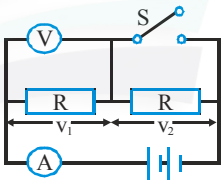
1. A → P ; B → Q, S ; C → S ; D → P, R, S

2. A → Q ; B → P ; C → P ; D → Q

3. A → Q ; B → P ; C → P

After closing the switch net resistance decreases therefore there will be increases in the current.

After closing the switch V_2 becomes zero hence $V = V_1$.



After short circuiting current in the resistance becomes zero therefore power become zero.

4. A → P ; B → P ; C → Q ; D → Q,S

For potentiometer short circuit = x ℓ_1

x Depends only on primary circuit

(A) $E_1\uparrow \Rightarrow x\uparrow \Rightarrow \ell_1\downarrow$ if secondary circuit remain same

(B) $R\uparrow \Rightarrow x\downarrow \Rightarrow \ell_1\uparrow$ if secondary circuit remain same

(C) S.C$\uparrow = \ell_1\uparrow$ if x remain same

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EXERCISE - 3

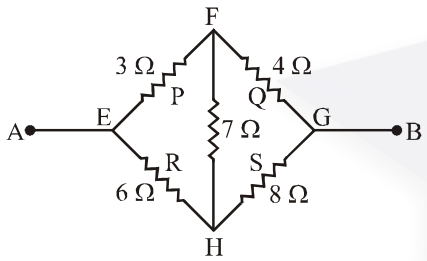
P-2 (Assertion & Reason)

1. C **2.** B **3.** E **5.** A **6.** A **7.** B
8. A **9.** C **10.** D

EXERCISE - 4

P-1 (NEET/AIPMT)

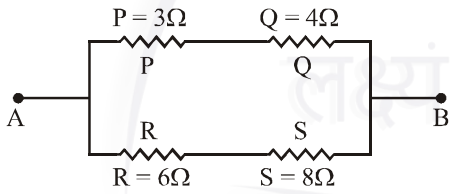
1. **(D)** The bridge circuit can be shown as



The balanced condition of bridge circuit is given by

$$\frac{P}{Q}=\frac{3}{4},\frac{R}{S}=\frac{6}{8}=\frac{3}{4}\Rightarrow\frac{P}{Q}=\frac{R}{S}$$

Thus, it is balanced Wheatstone bridge, so potential at F is equal to potential at H. Therefore, no current will flow through 7Ω resistance. So, circuit can be redrawn as



P and Q are in series, so their equivalent resistance

$=3+4=7\,\Omega$

R and S are also in series, so their equivalent resistance

$=6+8=14\,\Omega$

Now, 7 Ω and 14 Ω resistances are in parallel, so

$$R_{AB}=\frac{7\times14}{7+14}=\frac{7\times14}{21}=\frac{14}{3}\Omega$$

Note

Normally, in Wheatstone bridge in middle arm galvanometer must be connected. In Wheatstone bridge, cell and galvanometer arms are interchangeable.

In both the cases, condition of balanced bridge is

$$\frac{P}{Q}=\frac{R}{S}$$

2. **(C)** When we measure the emf of a cell by the potentiometer then no current is drawn from the external circuit. Thus, in this condition the actual value of a cell is found. In this way potentiometer is equiavlent to an ideal voltmeter of infinte resistance.

Note

The emf by the potentiometer is measured from null method in which zero deflection position is found on the wire.

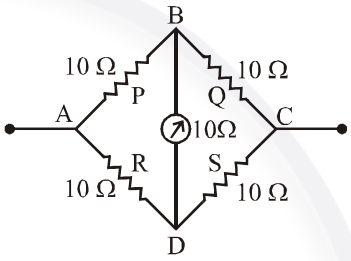
3. **(C)** Internal resistance of the cell is given by

$$r=\left(\frac{E-V}{V}\right)R$$

Given, $E=1.5\,V,\ V=1.0\,V,\ R=2\,\Omega$

$$\therefore\quad r=\left(\frac{1.5-1.0}{1.0}\right)\times2=\frac{0.5}{1.0}\times2=1\,\Omega$$

4. **(A)** The given circuit can be shown as,



From figure, $\frac{P}{Q}=\frac{10}{10}=1$

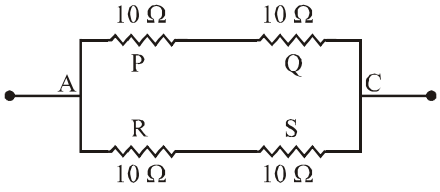
$$\frac{R}{S}=\frac{10}{10}=1$$

$$\therefore\quad\frac{P}{Q}=\frac{R}{S}$$

Hence, Wheatstone bridge is balanced.

Therefore, the galvanometer will be ineffective.

The above Wheatstone bridge can be redrawn as



Resistance P and Q are in series, so

$R'=10+10=20\,\Omega$

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Resistance R and S are in series, so

$$R'' = 10 + 10 = 20\,\Omega$$

Now, R′ and R″ are in parallel hence, net resistance of the circuit

$$= \frac{R' \times R''}{R' + R''} = \frac{20 \times 20}{20 + 20} = 10\Omega$$

5. **(A)** Potential gradient

= Potential fall per unit length = $\frac{V}{l}$

= current × resistance per unit length

$$= i \times \frac{R}{l}$$

but $R = \frac{\rho l}{A} \Rightarrow \frac{R}{l} = \frac{\rho}{A}$

where, symbols have their usual meanings.

$$\therefore \text{ Potential gradient} = i \times \frac{\rho}{A}$$

Here, $\rho = 10^{-7}\,\Omega$-m, $i = 0.1$ A

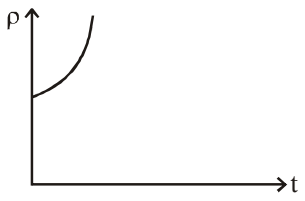
and $A = 10^{-6}\,m^2$

Hence, potential gradient $= 0.1 \times \frac{10^{-7}}{10^{-6}} = \frac{0.1}{10}$

$$= 0.01 = 10^{-2}\,V/m$$

6. **(A)** The specific resistance (resistivity) of a metallic conductor nearly increases with increasing temperature as shown in figure. This is because, with the increase in temperature the ions of the conductors vibrate with greater amplitude and the collisions between electrons and ions become more frequent, over a small temperature range (upto 100°C). The resistivity of a metal can be represented approximately by the equation

$$\rho_t = \rho_0 (1 + \alpha t)$$



The factor α is called the temperature coefficient of resistivity.

7. **(A)** In an open circuit, emf of cell

$$E = 2.2\,V$$

In a closed circuit, terminal potential difference

$$V = 1.8\,V$$

External resistance, $R = 5\,\Omega$

Thus, internal resistance of cell is

$$r = \left(\frac{E}{V} - 1\right) R = \left(\frac{2.2}{1.8} - 1\right) 5$$

$$= \left(\frac{11}{9} - 1\right) 5 = \frac{2}{9} \times 5 = \frac{10}{9}\,\Omega$$

8. **(A)** $\frac{R_{AB}}{R_{BC}} = \frac{R_{AD}}{R_{DC}}$

As bridge is in balanced condition, no current will flow through BD.

$$R_1 = R_{AB} + R_{BC}$$
$$= R + R$$
$$= 2R$$
$$R_2 = R_{AD} + R_{CD}$$
$$= R + R = 2R$$

R_1 and R_2 are in parallel combination.

Hence, equivalent resistance between A and C will be

$$\therefore \quad R_{eq} = \frac{R_1 R_2}{R_1 + R_2} = \frac{4R^2}{4R} = R$$

9. **(D)** Input energy when the battery is charged

$$E_{in} = V\,it$$
$$= 15 \times 10 \times 8$$
$$= 1200\,Wh$$

Energy released when the battery is discharged

$$E_{out} = 14 \times 5 \times 15$$
$$= 1050\,Wh$$

Hence, watt hour efficiency of battery is given by

$$= \frac{\text{Energy output}}{\text{Energy input}} = \frac{1050}{1200}$$

$$= 0.875 = 87.5\%$$

10. **(B)** The formula for resistanc of wire is

$$R = \frac{\rho l}{A}$$

where, ρ = specific resistance of the wire

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$$\Rightarrow \quad R \propto \frac{l}{A}$$

$$\Rightarrow \quad R \propto \frac{l}{r^2} \qquad (\because A = \pi r^2)$$

$$\therefore \quad \frac{R_1}{R_2} = \frac{l_1}{l_2} \times \frac{r_2^2}{r_1^2} \qquad ...(i)$$

Given, $l_1 = l, l_2 = 2l, r_1 = r, r_2 = 2r, R_1 = R$.

Substituting these values in Eq. (i), we get

$$\frac{R_1}{R_2} = \frac{l}{2l} \times \frac{(2r)^2}{r^2}$$

$$\frac{R_1}{R_2} = 2$$

$$\Rightarrow \quad R_2 = \frac{R}{2}$$

Therefore, resistance will be halved.

Now, the specific resistance of the wire does not depend on the geometry of the wire. Hence, it remains uncharged.

11. (A) Equivalent resistance of n resistances each of r ohm in parallel is given by

$$\frac{1}{R} = \frac{1}{r} + \frac{1}{r} + ... + \text{n times} = \frac{n}{r}$$

So, $r = nR$

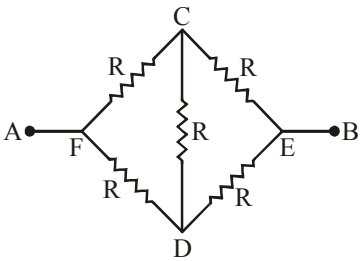
When these resistances are connected in series, effective resistance is

$$R' = r + r + ... + \text{n times } nr$$

$$\therefore \quad R' = n(nR) = n^2 R$$

12. (C) The given circuit can be redrawn as shown.

From circuit, $\frac{FC}{CE} = \frac{FD}{DE} = 1$



Thus, it is balanced Wheatstone bridge, so, resistance in arm CD is ineffective and so no current flows in this arm.

Net resistance of the circuit is

$$\frac{1}{R'} = \frac{1}{(R+R)} + \frac{1}{(R+R)}$$

$$= \frac{1}{2R} + \frac{1}{2R} = \frac{2}{2R} = \frac{1}{R}$$

$$\therefore \quad R' = R$$

So, net current drawn from the battery is

$$i' = \frac{V}{R'} = \frac{V}{R}$$

As from symmetry, upper circuit AFCEB is half of the whole circuit and is equal to AFDEB.

So, in both the halves half of the total current will flow.

Hence, in AFCEB, the current flowing is

$$i = \frac{i'}{2} = \frac{V}{2R}$$

13. (C) Total current drawn from the battery

$$i = \frac{E}{R+r} = \frac{6}{100+0} = 0.06A$$

Resistance of 50 cm wire is

$$R' = \frac{\rho l'}{A} = \left(\frac{\rho}{A}\right) l' = \left(\frac{R}{l}\right) l' \qquad \left(\because R = \frac{\rho l}{A}\right)$$

$$= \frac{100}{300} \times 50$$

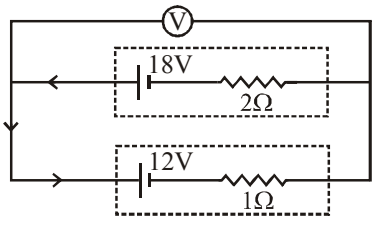
So, $R' = \frac{50}{3}\Omega$

Hence, the potential difference between two points on the wire separated by adistance l' is given by Ohm's law

i.e. $V = iR' = 0.06 \times \frac{50}{3} = 1\ V$

14. (C) It is clear that the two cells oppose each other hence, the effective emf in closed circuit is 18 – 12 = 6 V and net resistance is 1 + 2 = 3 Ω (because in the closed circuit the internal resistances of two cells are in series).

The current in circuit will be in direction of arrow shown in figure.



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$$I = \frac{\text{Effective emf}}{\text{Total resistance}} = \frac{6}{3} 2A$$

The potential difference across V will be same as the terminal voltage of either cell.

Since, current is drawn from the cell 18 V, hence,

$$V_1 = E_1 - ir_1 = 18 - (2 \times 2) = 18 - 4 = 14\ V$$

Similarly, current enters in the cell of 12 V, hence,

$$V_2 = E_2 - ir_2 = 12 + 2 \times 1 = 12 + 2 = 14\ V$$

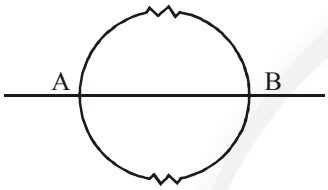
Hence, $V = 14\ V$

15. (A) When wire is bent to form a complete circle, then Total circumference, $2\pi r$ = Total length, R

$$\Rightarrow \quad r = \frac{R}{2\pi}$$

Resistance of each semicircle = πr

$$= \frac{\pi R}{2\pi} = \frac{R}{2}$$



Thus, net resistance in parallel combination of two semi-circular resistances

$$R' = \frac{\frac{R}{2} \times \frac{R}{2}}{\frac{R}{2} + \frac{R}{2}} = \frac{\frac{R^2}{4}}{R} = \frac{R}{4}$$

16. (D) Resistance 4 Ω and 4 Ω are connected in series, so their effective resistance is

$$R' = 4 + 4 = 8\ \Omega$$

Similarly, 1 Ω and 3 Ω are in series

So, $R'' = 1 + 3 = 4\ \Omega$

Now R′ and R″ will be in paralle, hence effective resistance

$$R = \frac{R' \times R''}{R' + R''}$$

$$= \frac{8 \times 4}{8 + 4} = \frac{32}{12} = \frac{8}{3}\Omega$$

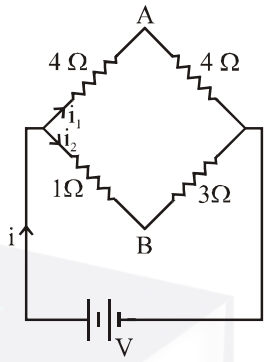
Current through the circuit, from Ohm's law

$$i = \frac{V}{R} = \frac{3V}{8} A$$

Let currents i_1 and i_2 flow in the branches as shown.

As voltage remains same in parallel combination

i.e. $V_1 = V_2$



$$\therefore \quad 8i_1 = 4\, i_2$$

$$\Rightarrow \quad i_2 = 2\, i_1 \qquad ...(i)$$

Also, $i = i_1 + i_2$

$$\Rightarrow \quad \frac{3V}{8} = i_1 + 2i_1$$

$$\Rightarrow \quad i_1 = \frac{V}{8} A \text{ and } i_2 = \frac{V}{4} A$$

Potential drop at A,

$$V_A = 4 \times i_1 = \frac{4V}{8} = \frac{V}{2}$$

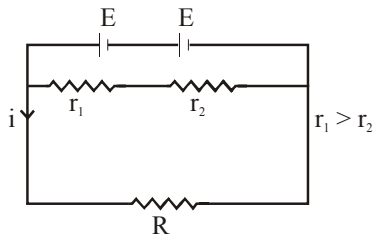
Potential drop at B,

$$V_B = 1 \times i_2 = 1 \times \frac{V}{4} = \frac{V}{4}$$

Since, drop of potential is greater in 4 Ω resistance so, it will be at lower potential than B. Hence, on connecting wire between points A and B the current will flow from B to A.

17. (A) Net resistance of the circuit = $r_1 + r_2 + R$

Net emf in series = E + E = 2E



Therefore, from Ohm's law, current in the circuit

$$i = \frac{\text{Net emf}}{\text{Net resistance}}$$

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$$\Rightarrow \quad i = \frac{2E}{r_1 + r_2 + R} \qquad ...(i)$$

It is given that, as circuit is closed, potential difference across the first cell is zero.

i.e., $V = E - ir_1 = 0$

$$\Rightarrow \quad i = \frac{E}{r_1} \qquad ...(ii)$$

Equating Eqs. (i) and (ii), we get

$$\frac{E}{r_1} = \frac{2E}{r_1 + r_2 + R} \Rightarrow 2r_1 = r_1 + r_2 + R$$

$\therefore$ R = external resistance

$\Rightarrow \quad R = r_1 - r_2$

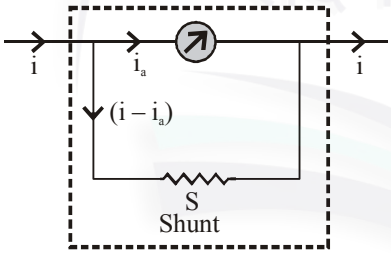
Note :

The questions is wrong as the statement is when the circuit is closed, the potential difference across the first cell is zero which implies that in a series circuit, one part cannot conduct current which is wrong, Kirchhoff's law is violated. The question must have been modified.

18. (B) Let i_a be the current flowing through ammeter and i be the total current. So, a current $i - i_a$ will flow through shunt resistance.

Potential difference across ammeter and shunt resistance is same.

i.e. $i_a \times R = (i - i_a) \times S$



High reading ammeter

$$\text{or} \quad S = \frac{i_a R}{i - i_a} \qquad ...(i)$$

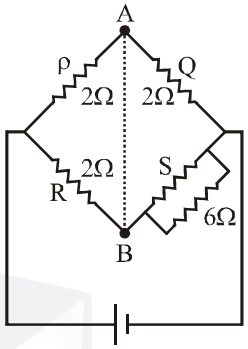
Given, $i_a = 100\,A, i = 750\,A,$

$R = 13\,\Omega$

Hence, $S = \frac{100 \times 13}{750 - 100} = 2\Omega$

19. (B) Concept Balancing condition of Wheatstone bridge is used to calculate the value of unknown resistance.

The situation can be depicted as shown in figure.



As resistances S and 6 Ω are in parallel their effective resistance is

$$\frac{6S}{6+S}\Omega$$

As the bridge is balanced, hence it is balanced Wheatstone bridge.

For balancing condition,

$$\frac{P}{Q} = \frac{R}{\left(\frac{6S}{6+S}\right)} \quad \text{or} \quad \frac{2}{2} = \frac{2(6+S)}{6S}$$

or $3S = 6 + S$ or $S = 3\,\Omega$

20. (B) After stretching, specific resistance (ρ) will remains same,

Original resistance of wire, $R = \frac{\rho l}{A}$

Ratio of resistance before and after stretching,

$$\frac{R_2}{R_1} = \frac{l_2}{l_1} \times \frac{A_1}{A_2} = \left[\frac{l_2}{l_1}\right]^2$$

$$\frac{R_2}{R_1} = \frac{(l + 10\%l)^2}{l^2}$$

$$\frac{R_2}{R_1} = \frac{\left(\frac{11}{10}l\right)^2}{l^2}$$

21. (A) In potentiometer experiment in which we find internal resistance of a cell. Let E be the emf of the cell and V be the terminal potential difference,

then

$$\frac{E}{V} = \frac{l_1}{l_2}$$

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where, l_1 and l_2 are lengths of potentiometer wire with and without being short circuited through a resistance.

Since,

$$\frac{E}{V}=\frac{R+r}{R} \qquad [\because E=I(R+r) \text{ and } V=IR]$$

$$\therefore \quad \frac{R+r}{R}=\frac{l_1}{l_2}$$

$$\text{or} \quad 1+\frac{r}{R}=\frac{110}{100}$$

$$\text{or} \quad \frac{r}{R}=\frac{10}{100}$$

$$\text{or} \quad r=\frac{1}{10}\times 10$$

$$=1\ \Omega$$

22. (D) Potential across PM,

$$V_{PM}=4\times 1=4\ V$$

Now, equivalent resistance across PN

$$\frac{1}{R_{eq}}=\frac{1}{0.5}+\frac{1}{0.5}$$

$$R_{eq}=\frac{0.5}{2}-0.25\Omega$$

Effective resistance between P and M

$$R_{PM}=0.25+1$$

$$=1.25\ \Omega$$

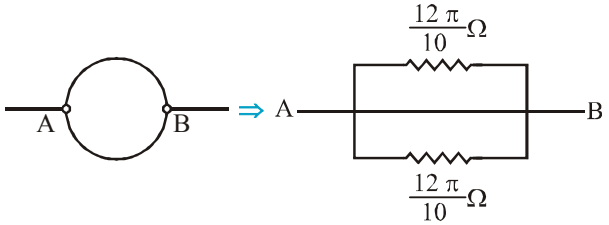
For balancing condition,

$$\frac{V_{MN}}{V_{MN}}=\frac{R_{MN}}{R_{PM}}$$

$$V_{MN}=\frac{V_{PM}\times R_{MN}}{R_{PM}}=\frac{1}{1.25}\times 4$$

$$=3.2\ V$$

23. (A)



Circumference of circle $=2\pi r=2\times\pi\frac{10}{100}$

$$=\frac{2\pi}{10}=\frac{\pi}{5}$$

Resistance of wire $=12\times\frac{\pi}{5}=\frac{12\pi}{5}$

Resistance of each section $=\frac{12\pi}{10}\Omega$

$\therefore$ Equivalent resistance $=\frac{\frac{12\pi}{10}\times\frac{12\pi}{10}}{\frac{12\pi}{10}+\frac{12\pi}{10}}$

$$\Rightarrow \qquad =\frac{6\pi}{10}=0.6\pi\Omega$$

24. (B) According to Ohm's law

$$\frac{dV}{dI}=-r \text{ and } V=\varepsilon \text{ if } I=0 \qquad [\text{As } V+Ir=\varepsilon]$$

So, slope of the graph $= -r$ and intercept $=\varepsilon$

25. (A) The algebraic sum of the changes in potential in complte transversal of a mesh (closed loop) is zero. i.e. $\Sigma V=0$

So, $\varepsilon_1-(i_1+i_2)R-i_1r_1=0$

26. (D) Energy $=2eV$

$$2V_0=2\ eV$$

$$\Rightarrow \qquad V_0=2$$

So, electric field, $E=\frac{2}{4\times10^{-8}}$

$$=0.5\times10^8$$

$$=5\times10^7\ V/m$$

27. (D) Kirchhoff's junction law follows from the conservation of charge.

Kirchhoff's loop law follows from the conservation of energy.

28. (A) Required resistance to convert a galvanometer into voltmeter of 30 V is given by

$$R=\frac{V}{i_g}-G$$

Symbols have their equal meaning

$$=\frac{30}{30\times10^{-3}}-100=900\Omega$$

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29. **(C)** The balancing length for R (when 1, 2 are connected) be l_1 and balancing length for R + X (when 1, 3 is connected) is l_2.

Then, $iR = kl_1$ and $i(R+X) = kl_2$

Given, $i = 1\ A$

$\therefore \quad R = kl_1 \quad ...(i)$

$R + X = kl_2 \quad ...(ii)$

Also, subtracting Eq. (i) from Eq. (ii), we get

$X = k(l_2 - l_1)$

30. **(A)** Current in circuit connected with battery of emf E with internal resistance r is given by

Current, $i = \dfrac{E}{R+r}$

Case I $2 = \dfrac{E}{2+r} \quad ...(i)$

Case II $0.5 = \dfrac{E}{9+r} \quad ...(ii)$

From Eqs. (i) and (ii), we have, $\dfrac{2}{0.5} = \dfrac{9+r}{2+r}$

$4 = \dfrac{9+r}{2+r} \Rightarrow 3r = 1 \Rightarrow r = \dfrac{1}{3}\Omega$

31. **(B) Concept** If potential difference across R Ω resistor is equal to potential difference of cell B, galvanometer shows no deflection.

Applying Kirchhoff's law,

$500\,I + 100\,I = 12$

So, $I = \dfrac{12 \times 10^{-2}}{6} = 2 \times 10^{-2}\ A$

Hence, $V_B = 100\,(2 \times 10^{-2}) = 2V$

32. **(A)** The full scale deflection current

$i_g = \dfrac{25mV}{G} A$

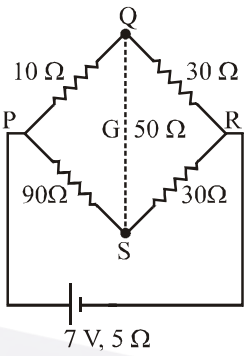
where, G is the resistance of the meter.

The value of shunt required for converting it into ammeter of range 25 A is $S = \dfrac{i_g G}{i - i_g}$

$\Rightarrow \quad S = i_g \dfrac{G}{i} \quad (\text{as } i >> i_g)$

So that, $S \approx \dfrac{25mV}{G} \cdot \dfrac{G}{i} = \dfrac{25mV}{25} = 0.001\Omega$

33. **(B)** Effective resistance,



$\dfrac{1}{R_{eff}} = \dfrac{1}{R_1} + \dfrac{1}{R_2}$

then, $R_1 = 10 + 30$

$R_1 = 40$

Now, $R_2 = 90 + 30 = 120$

By Eq. (i),

$\dfrac{1}{R_{eff}} = \dfrac{1}{40} + \dfrac{1}{120}$

$R_{eff} = \dfrac{40 \times 120}{120 + 40} = \dfrac{4800}{160} = 30\Omega$

In the balancing condition,

$\therefore$ Current, $I = \dfrac{7}{(30+5)} = \dfrac{7}{35} = 0.2A \qquad \left[\because I = \dfrac{E}{R+r}\right]$

34. **(B)** As, $I = \dfrac{E}{R+r}$

E = emf of cell

R = external resistance

r = internal resistance

I = current of circuit

or $E = I\,(R+r), 2.1 = 0.2\,(10+r)$

$10 + r = \dfrac{2.1}{2} \times 10$

$\therefore \quad r = 10.5 - 10 = 0.5\,\Omega$

35. **(D)** As the resistance of stretched wire to length n times of original length is

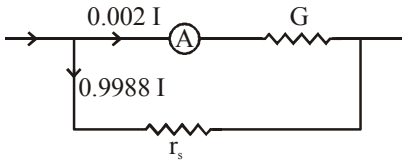
$R' = n^2 R = 2^2 \times 4 = 4 \times 4 = 16\,\Omega$

where, R = original resistance

R′ = final resistance

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36. **(C)** For ammeter,



$0.002I \times G = 0.998I = r_s$

$$r_s = \frac{0.002}{0.998}G$$

$$\therefore \quad \frac{1}{R} = \frac{1}{G} + \frac{1}{G/499}$$

$$\Rightarrow \quad R = \frac{G}{500}$$

37. **(C)** Given, $e = 2V$ and $l = 4$ m

Potential drop per unit length

$$\phi = \frac{e}{l} = \frac{2}{4} = 0.5V/m$$

Case I

$e' = \phi l_1$ ...(i) (e' = emf of the given cell)

Case II

$V = \phi l_2$ ...(ii)

From Eqs. (i) and (ii),

$e'/V = l_1/l_2$

$\therefore \quad e' = I(r+R)$

and $V = IR$ for the second case

$$\frac{I(r+R)}{IR} = \frac{l_1}{l_2}$$

So, $r = R\left(\frac{l_1}{l_2} - 1\right)$

$$= 9.5\left(\frac{3}{2.85} - 1\right)$$

$$= 9.5(1.05 - 1)$$

$$= 9.5 \times 0.05 = 0.475$$

$$\simeq 9.5 \times 0.05 = 0.475 \simeq 0.5\,\Omega$$

38. **(B)** For first case, balanced condition of meter bridge will be

$$\frac{5}{l_1} = \frac{R}{(100 - l_1)} \qquad ...(i)$$

Now, by shunting resistance R by an equal resistance R, new resistance in that arm become $\frac{R}{2}$.

So, new balanced condition will be

$$\frac{5}{1.6l_1} = \frac{R/2}{(100 - 1.6l_1)} \qquad ...(ii)$$

From Eqs. (i) and (ii)

$$\frac{1.6}{1} = \frac{(100 - 1.6l_1)}{100 - l_1} \times 2$$

$$\Rightarrow \quad 160 - 1.6\,l_1 = 200 - 3.2\,l_1$$

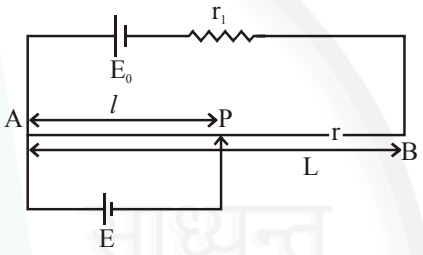
$$1.6\,l_1 = 40$$

$$l_1 = \frac{40}{1.6} = 25\text{m}$$

$\Rightarrow$ From Eq. (i), $\frac{5}{25} = \frac{R}{75} \Rightarrow R = 15\,\Omega$

39. **(B)** Consider a potentiometer wire of length L and a resistance r are connected in sereis with a battery of emf E_0 and a resistance r_1 as shown in figure.

Current in wire AB = $\frac{E_0}{r_1 + r}$



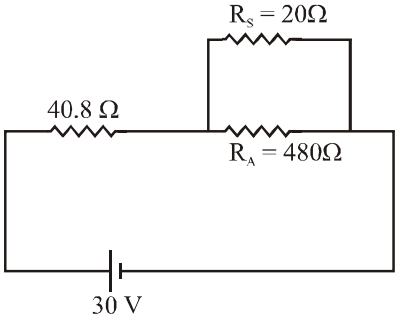
Potential gradient,

$$x = \frac{Ir}{L} = \left[\frac{E_0}{r_1 + r}\right]\frac{r}{L}$$

emf produced across E will be given by

$$E = x \cdot l = \left[\frac{E_0 r}{r_1 + r}\right]\frac{l}{L}$$

40. **(A)** Effective resistance of a circuit,



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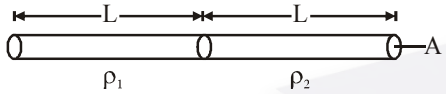
$$R_{eff} = 40.8 + \frac{480 \times 20}{480 + 20} = 40.8 + 19.2 = 60\ \Omega$$

So, current flowing across ammeter,

$$I = \frac{V}{R} = \frac{30}{60} = \frac{1}{2} = 0.5A$$

Hence, reading of ammeter = 0.5 A

41. **(A)** Net resistance of a metal wire having resistivity ρ, we have



$$R_1 = \rho_1 \frac{L}{A}$$

Similarly, $R_2 = \rho_2 \frac{L}{A}$

Then, net effective resistance of two metal wire,

$$R_{eg} = R_1 + R_2 \Rightarrow \rho \frac{2L}{A} = \rho_1 \frac{L}{A} + \rho_2 \frac{L}{A}$$

$$\Rightarrow \quad 2\rho = \rho_1 + \rho_2$$

As, conductivity $\sigma = \frac{1}{\rho}$, we have

$$\frac{2}{\sigma} = \frac{1}{\sigma_1} + \frac{1}{\sigma_2} \Rightarrow \frac{2}{\sigma} = \frac{\sigma_1 + \sigma_2}{\sigma_1 \sigma_2}$$

$\Rightarrow$ Net effective conductivity of combined wires,

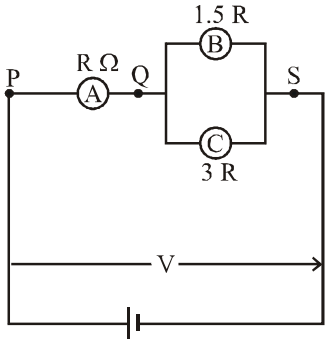
$$\sigma = \frac{2\sigma_1 \sigma_2}{\sigma_1 + \sigma_2}$$

42. **(C)** As the cross-sectional area of the conductor is non-uniform so current density will be different

As $I = JA$

It is clear from Eq. (i), when area increases the current density decreases so the number of flow of electrons will be same and thus the current will be constant.

43. **(A)** The equivalent resistance between Q and S is given by



$$\frac{1}{R'} = \frac{1}{1.5R} + \frac{1}{3R} = \frac{2+1}{3R}$$

$$\Rightarrow \quad R' = R$$

Now, $V_{PQ} = V_A = IR$

Also $V_{QS} = V_B = V_C = IR$

Hence, $V_A = V_B = V_C$

44. **(A)** Given, l = 4 m,

R = potentiometer wire resistance = 8 Ω

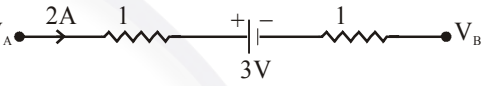
$$\text{Potential gradient} = \frac{dV}{dr} = 1mV/cm$$

So, for 400 cm, $\Delta V = 400 \times 1 \times 10^{-3} = 0.4$ V

$$\Delta V = \frac{V}{R + R_S} \times R \Rightarrow 0.4 = \frac{2}{8 + R} \times 8$$

$$\Rightarrow \quad 8 + R = \frac{16}{0.4} = 40 \quad \Rightarrow R = 32\ \Omega$$

45. **(D)**



Applying KVL, $V_A + \Sigma V = V_B + 2 \times 2 + 2 \times 1$

$$V_A - V_B - 3 = 4 + 2;\ V_A - V_B = 9\ V$$

46. **(C)** According to question, emf of the cell is directly proportional to the balanceing length is

$$E \propto l \qquad ...(i)$$

Now, in the first case, cells are connected in series to support one another i.e.

Net, $emf = E_1 + E_2$

From Eq. (i), $E_1 + E_2 = 50$ cm (given) ...(ii)

Again cells are connected in series in opposite direction i.e.

Net emf $= E_1 - E_2$

From Eq. (i), $E_1 - E_2 = 10$ ...(iii)

From Eqs. (ii) and (iii)

$$\frac{E_1 + E_2}{E_1 - E_2} = \frac{50}{10} \Rightarrow \frac{E_1}{E_2} = \frac{5+1}{5-1} = \frac{6}{4} = \frac{3}{2}$$

47. **(B)** We know that,

Work done (W) = q ΔV

ΔV is same in all the cases. So, work done will be same in the all cases.

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48. **(C)** When a cell is balanced against potential drop across a certain length of potentiometer wire, no current flows through the cell

$\therefore$ emf of cell = potential drop across balance length of potentiometer wire.

So, potentiometer is a more accurate device for measuring emf of a cell or no current flows through the cell during measurement of emf.

49. **(C) Thinking Process** Volume of material remains same in stretching.

As volume remains same, $A_1l_2 = A_2l_2$

Now, given $l_2 = nl_1$

$$\therefore \text{ New area } A_2 = \frac{A_1l_1}{l_2} = \frac{A_1}{n}$$

Resistance of wire after stretching

$$R_2 = \rho\frac{l_2}{A_2} = \rho.\frac{nl_1}{A_1/n}$$

$$= \left(\rho\frac{l_1}{A_1}\right)\cdot n^2 = n^2\cdot R \qquad \left[\because R = \left(\rho\frac{l_1}{A_1}\right)\right]$$

50. **(A)** Power of electric bulb, $P = \frac{V^2}{R}$

So, resistance of electric bulb, $R = \frac{V^2}{P}$

Given, $P_1 = 25$ W, $P_2 = 100$ W,

$V_1 = V_2 = 220$ V

Therefore, for same potential difference V,

$$R \propto \frac{1}{P}$$

Thus, we observe that for minimum power, resistance will be maximum and vice-versa.

Hence, resistance of 25 W bulb is maximum and 100 W bulb is minimum.

51. **(A)** According to first law of Faraday, the mass of a substance deposited on an electrode is directly proportional to the charge flowing through the electrolyte i.e.

$m \propto q$

If a current i passes for a time t, then we know,

$q = it$

Hence, $m \propto it$ or $m \propto i$

Thus, mass deposited on an electrode is directly proportional to current passed through it.

52. **(D)** The electric fuse is a device which is used to limit the current in an electric circuit. Thus, the use fo fuse safeguards the circuit and the appliances connected in the circuit from being damaged. It is always connected with the live (or phase) wire. The fuse wire is a short piece of wire made of material of high resistance and low melting point so that it may easily melt due to overheating when excessive current passes through it.

53. **(C)** Let R_1 and R_2 be the resistance of the coils, V be the supply voltage, H be the heat required to boil the water.

For first coil, $H = \frac{V^2t_1}{R_1}$ ...(i)

For second coil, $H = \frac{V^2t_2}{R_2}$ ...(ii)

Equating Eqs. (i) and (ii), we get

$$\frac{t_1}{R_1} = \frac{t_2}{R_2}$$

i.e. $\frac{R_2}{R_1} = \frac{t_2}{t_1} = \frac{40}{10} = 4$ $\qquad [t_1 = 10\,\text{min},\ t_2 = 40\,\text{min}]$

When the two heating coils are in paralle,

equivalent resistance is given by

$$R = \frac{R_1Rl}{R_1 + R_2} = \frac{R_1\times 4R_1}{R_1 + 4R_1} = \frac{4R_1}{5}$$

and $H = \frac{V^2t}{R}$ ...(iv)

Comparing Eqs. (i) and (iv), we get

$$\frac{V^2t_1}{R_1} = \frac{V^2t}{R}$$

$$\Rightarrow \quad t = \frac{R}{R_1}\times t_1 \qquad [t_1 = 10\,\text{min}]$$

$$\therefore \quad t = \frac{4}{5}\times 10 = 8\,\text{min}$$

54. **(B)** Power P = 100 W, Voltage, V = 220 V

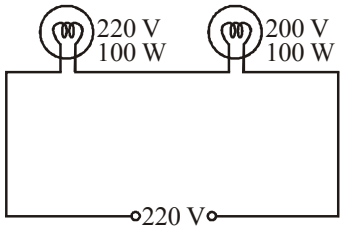
$$P = \frac{V^2}{R}$$

$$\therefore \quad R = \frac{V^2}{P} = \frac{(220)^2}{100} = \frac{220\times 220}{100}\Omega$$

As both the bulb have same voltage and power so, resistance of bulbs will also be same.

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Case I When two bulbs are connected in series.

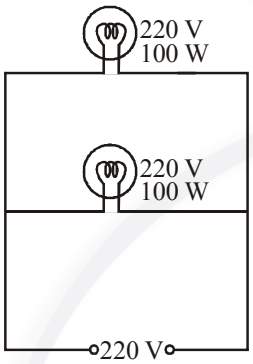


In series, $R_{eq} = R_1 + R_2$

$$= \left(\frac{220\times220}{100}\right)\times 2$$

Hence, $P_{eq} = \frac{V^2}{R_{eq}} = \frac{220\times220}{\left(\frac{220\times220}{100}\times 2\right)}$

Case II When two bulbs are connected in parallel.



In paralle, $R_{eq} = \frac{R_1R_2}{R_1+R_2} = \frac{\left(\frac{220\times220}{100}\right)^2}{\frac{220\times220}{100}\times 2}$

$$R_{eq} = \frac{220\times220}{100}\times\frac{1}{2}$$

Hence, $P_{eq} = \frac{V^2}{R_{eq}} = \frac{220\times220}{\frac{220\times220}{100}\times\frac{1}{2}}$

Alternative

For series, $P_{eq} = \frac{P_1P_2}{P_1+P_2}$

$$= \frac{100\times100}{200} = 50\text{W}$$

For paralle, $P_{eq} = P_1 + P_2$

$$= 100 + 100 = 200 \text{ W}$$

Note

Power equivalent of two or more resistance in series is given by $\frac{1}{P_{eq}} = \frac{1}{P_1} + \frac{1}{P_2}$ and for parallel combination $P_{eq} = P_1 + P_2$

55. (D) Let R_1, R_2 and R_3 are the resistances of three bulbs respectively.

In series order,

$$R = R_1 + R_2 + R_3$$

but, $R = \frac{V^2}{P}$ and supply voltage in series order is the same as the rated voltage.

$$\therefore \quad \frac{V^2}{P} = \frac{V^2}{P_1} + \frac{V^2}{P_2} + \frac{V^2}{P_3}$$

or $\frac{1}{P} = \frac{1}{60} + \frac{1}{60} + \frac{1}{60}$

or $P = \frac{60}{3} = 20 \text{ W}$

Alternative

As three bulbs have same power and voltage so, they have equal resistance. So, power equivalent when connected in series is given by,

$$\frac{1}{P_{EQ}} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3}$$

$$\frac{1}{P_{EQ}} = \frac{1}{P} + \frac{1}{P} + \frac{1}{P} \qquad (\text{as } P_1 = P_2 = P_3 = P)$$

So, $P_{EQ} = \frac{P}{3} \Rightarrow \frac{60}{3} = 20 \text{ W}$

56. (C) Since, power rating of bulb in both the countries India and USA is same, so

$$\frac{V_1^2}{R_1} = \frac{V_2^2}{R_2} \qquad \left[P = \frac{V^2}{R}\right]$$

$$\Rightarrow \frac{220\times220}{R_1} = \frac{110\times110}{R_2}$$

$$\Rightarrow \frac{R_2}{R_1} = \frac{110\times110}{220\times220}$$

$$\Rightarrow R_2 = \frac{R}{4} \qquad (\because R_1 = R)$$

57. (D) As we know that,

Power $P = i^2 R$ $\left[\begin{matrix}\text{where, } i = \text{current in circuit}\\ R = \text{resistance}\end{matrix}\right]$

$$R = \frac{p}{i^2}$$

Given, $P = 1 \text{ W}, i = 5 \text{ A}$

$$\therefore \quad R = \frac{1}{(5)^2} = 0.04\ \Omega$$

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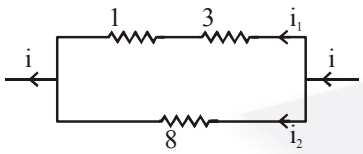
58. (D) Problem Solving Strategy Find the equivalent resistance of the circuit and then calculate the power dissipated by the circuit.

Resistances 1 Ω and 3 Ω are connected in series.

so, effective resistance

$R' = 1 + 3 = 4\ \Omega$

Now, R′ and 8 Ω are in paralle. We know that potential difference across resistances in parallel is same.



So, from Kirchhoff's law, $V_1 = V_2$

$R' \times i_1 = 8i_2$ or $4 \times i_1 = 8i_2$

or $i_1 = \frac{8}{4} i_2 = 2i_2$

or $i_1 = 2\, i_2$ ...(i)

Power dissipated across 8 Ω resistance is

$i_2^2 (8)\, t = 2$ W [$\because P = iRT$]

or $i_2^2 t = \frac{2}{8} = 0.25$ W ...(ii)

Power dissipated across 3 Ω resistance is

$H = i_1^2 (3)\, t$

$= (2i_2)^2 (3)t = 12\, i_2^2 t$

but $i_2^2\, t = 0.25$ W

$\therefore$ $H = 12 \times 0.25 = 3$ W

59. (B) It is found that temperature of inversion (T_i) is as much above the neutral temperature (T_n) as neutral temperature is above the temperature of the cold junction T_0, i.e.

$Ti - T_n = T_n - T_0$

or $Ti = 2T_n - T_0$

But, here the cold junction is kept at 0°C.

Thus, $T_i = 2T_n$ or $T_n = \frac{T_i}{2}$

60. (C) The resistance of 6 Ω and 3 Ω are in parallel in the given circuit, their equivalent resistance is

$$\frac{1}{R_1} = \frac{1}{6} + \frac{1}{3} = \frac{1+2}{6} = \frac{1}{2}$$

or $R_1 = 2\Omega$

Again, R_1 is in series with 4 Ω resistance, hence

$R = R_1 + 4 = 2 + 4 = 6\ \Omega$

Thus, the total dissipated in the circuit

$$P = \frac{V^2}{R}$$

Here, $V = 18$ V, $R = 6\ \Omega$

Thus, $P = \frac{(18)^2}{6} = 54$W

61. (D) If m is the mass of a substance deposited or liberated on an electrode during electrolysis when a charge q passes through electrolysis, then according to Faraday's first law of electrolysis. Mass deposited is directly proportional to the charge flows.

i.e. $m \propto q$ or $m = Zq$

where, Z is a constant of poroportionality and is called electrochemical equivalent (ECE) of the substance.

If an electric current i flows through the electrolyte, then

$m = Zit$ [$q = it$]

Given, $i = 1.5$ A, $t = 10$ min $= 10 \times 60$ s,

$Z = 30 \times 10^{-5}\ gC^{-1}$

Hence, mass of copper deposited on the electrode

$m = 30 \times 10^{-5} \times 1.5 \times 10 \times 60$

$= 27 \times 10^{-2} = 0.27$ g

62. (D) Voltage across 2 Ω,

$= 3 \times 2 = 6$ V

Voltage across 4 Ω and (5 Ω + 1 Ω) resistor is same.

So, current across 5 Ω $= \frac{6}{1+5} = 1$A $\left[i = \frac{V}{R}\right]$

Power across 5 Ω $= P = i^2 R$

$= (1)^2 \times 5$

$= 5$ W

63. (A) $Vit = mas\Delta T$

$$\Rightarrow t = \frac{ms\Delta t}{Vi} = \frac{1 \times 4200 \times 80}{220 \times 4} = 381.82s$$

$= 3.3$ min

64. (C) Mass of the substance deposited at the cathode is given by

$m = Zit$ (Z = electrochemical equivalent)

$$= Z\left(\frac{W}{V}\right)t = 0.367 \times 10^{-6} \times \frac{100 \times 10^3}{125} \times 60 = 17.6 \times 10^{-3}\,kg$$

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65. (B) Electric power, $P = i^2 R$

$\therefore$ Current, $i = \sqrt{\frac{P}{R}}$

For resistance of 9 Ω,

$$i_1 = \sqrt{\frac{36}{9}} = \sqrt{4} = 2A$$

$$i_2 = \frac{i_1 \times R}{6} = \frac{2 \times 9}{6} = 3A$$

$$I = i_1 + i_2 = 2 + 3 = 5\,A$$

So, $V_2 = IR_2 = 5 \times 2 = 10\,V$

66. (C) Power, $(P) = \frac{V^2}{R}$

For small variation,

$$\frac{\Delta P}{P} \times 100 = 2 \times \frac{\Delta V}{V} \times 100 = 2 \times 2.5 = 5\%$$

Therefore, power would decrease by 5% .

67. (B) Potential drop between two cities is

$= 150 \times 8 = 1200\,V$

Average resistane of total wire $= 0.5 \times 150 = 75\,\Omega$

So, power loss $P = \frac{V^2}{R} = \frac{1200 \times 1200}{75} = 19200W$

$= 19.2\,kW$

68. (C) If a rated voltage and power are given,

then $P_{rated} = \frac{V_{rated}^2}{R}$

$\therefore$ Current in the bulb, $i = \frac{P}{V}$ $(\because P = Vi)$

$$i = \frac{500}{100} = 5A$$

$\therefore$ Resistance of bulb, $R_b = \frac{100 \times 100}{500} = 20\Omega$

$\because$ Resistance R is connected in series,

$\therefore$ $\text{Current}, i = \frac{E}{R_{net}} = \frac{230}{R + R_b}$

$\Rightarrow$ $R + 20 = \frac{230}{5} = 46$

$\therefore$ $R = 26\,\Omega$

69. (D) Given, charge $Q = at - bt^2$

$\because$ We know that current, $I = \frac{d\theta}{dt}$

So, eq. (i) can be written as

$$I = \frac{d}{dt}(at - bt^2) \Rightarrow I = a - 2bt \qquad ...(ii)$$

For maximum value of t, till the current exist is given by

$\Rightarrow$ $a - 2bt = 0$

$\therefore$ $t = \frac{a}{2b}$ ...(iii)

$\because$ The total heat produced (H) can be given as

$$H = \int_0^t I^2 R\,dt$$

$$= \int_0^{a/2b} (a - 2bt)^2 R\,.\,dt \qquad \left\{\because t = \frac{a}{2b}\right\}$$

$$= \int_0^{a/2b} (a^2 + 4b^2t^2 - 4abt)R\,dt$$

$$H = \left[a^2 t + 4b^2 \frac{t^3}{3} - \frac{4abt^2}{2}\right]_0^{a/2b} R$$

Solving above equation, we get

$\Rightarrow$ $H = \frac{a^3 R}{6b}$

70. (D) Radiated power of a black body.

$P = \sigma AT^4$

where, A= surface area of the body

T = temperature of the body

and σ = Stefan's constant

When radius of the sphere is havled, new area,

$$A' = \frac{A}{4}$$

$\therefore$ Power radiated,

$$P' = \sigma\left(\frac{A}{4}\right)(2T)^4 = \frac{16}{4} \cdot (\sigma AT^4)$$

$= 4\,P = 4 \times 450 = 1800$ watts

71. (A) In parallel arrangement of n rods Equivalent thermal conductivity is given by

$$K_{eq} = \frac{K_1A_1 + K_2A_2 + ... + K_nA_n}{A_1 + A_2 + ... + A_n}$$

If rods are of same area, then

$$K_{eq} = \frac{K_1 + K_2 + ... + K_n}{n}$$

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Now, in the question, it is not given that rods ar of same area. But we can judge from given diagram.

$\therefore$ Equivalent thermal conductivity of the system of two rods

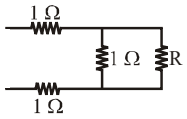
$$\Rightarrow \quad K_{eq} = \frac{K_1 + K_2}{2}$$

EXERCISE - 4

P-2 (AIIMS)

1. **(D)** In steady state condition the current at each cross-section will be the same. Drift velocity and electric field depend on the current density. Current density which varies from one cross section to another.

2. **(C)** The equivalent circuit may be shown as :



where R may be treated as the total resistance.

Hence $1 + \frac{1 \times R}{1 + R} + 1 = R.$

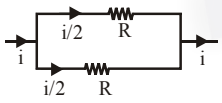
This gives $R = 1 \pm \sqrt{3}\,\Omega.$

Since $(1 - \sqrt{3})\,\Omega$ gives – ve value,

therefore $R = (1 + \sqrt{3})\,\Omega.$

3. **(B)** Required ratio

$$= \frac{i^2R + i^2R}{(i/2)^2R + (i/2)^2R} = 4:1.$$



Parallel Combination



Series Combination

4. **(B)** The power of the incandescent lamp P = 60 W Operating voltage V = 120 V

$\therefore$ Current through the filament

$$I = \frac{P}{V} = \frac{60}{120} = \frac{1}{2} \text{ A}$$

Now $Q = I \times t$. For $t = 1$ sec, $Q = 1 = \frac{1}{2}$ C

$\Rightarrow$ $ne = \frac{1}{2}$ where e = electronic charge, and

n = number of electrons.

$$\therefore \quad n = \frac{1}{2e} = \frac{1}{2 \times 1.6 \times 10^{-19}} = 3.12 \times 10^{18}$$

5. **(D)** From the given circuit, we find that R_{BD} is ineffective as it is a balanced Wheatstone bridge. Since both the upper resistance are in a series combination, therefore their equivalent resistance $(R_U) = 2 + 2 = 4\ \Omega$. Similarly both the lower resistances are in a series combination, therefore their equivalent resistance $(R_L) = 4 + 4 = 8\ \Omega$. Now we see that both the resistance R_U and R_L are in a parallel combination. Therefore equivalent resistance between

$$\text{A and C} = \frac{R_U \times R_L}{R_U + R_L} = \frac{4 \times 8}{4 + 8} = \frac{32}{12}\Omega = \frac{8}{3}\Omega$$

6. **(A)** : Initial radius of wire, $r_1 = r$ and

final radius of wire, $r_2 = r/2 = 0.5r$.

Since volume of the wire after stretch remains constant, therefore $l_1A_1 = l_2A_2$

or $$\frac{l_1}{l_2} = \frac{A_2}{A_1} = \frac{r_2^2}{r_1^2} = \left(\frac{0.5r}{r}\right) = \frac{1}{4}$$

The resistance $(R) = \rho\frac{l}{A} \propto \frac{l}{A}$

Therefore $$\frac{R_1}{R_2} = \frac{l_1}{l_2} \times \frac{A_2}{A_1} = \frac{1}{4} \times \frac{1}{4} = \frac{1}{16}$$

or $R_2 = 16R_1 = 16R$.

7. **(B)** Antimony and bismuth are the pair of metals producing a higher thermo e.m.f. in comparison with other pairs of metals. Therefore this pair is usually used in thermocouple.

8. **(C)** Let the resistance of the rod be R. If the rod is divided into two equal parts, then each part of the rod will have a resistance of R/2. Now these two parts of the rod are connected in parallel and a voltage V is applied across them. Hence the total power consumed in

$$P' = \frac{V^2}{R/2} + \frac{V^2}{R/2} = 4\frac{V^2}{R} = 4P \text{ where}$$

$P = \frac{V^2}{R}$ is the power consumed by the original rod when voltage V is applied across it.

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9. **(D)** Actual power of bulb $(P_1) = 40$ W

Actual voltage of bulb $(V_1) = 200$ V and

supply voltage $(V_2) = 100$ V.

Power $(P) = \frac{V^2}{R} \propto V^2$. Therefore $\frac{P_1}{P_2} = \frac{V_1^2}{V_2^2}$

or, $\frac{40}{P_2} = \frac{(200)^2}{(100)^2} = 4$ or $P_2 = \frac{40}{4} = 10$ W

(where P_2 = power when voltage is 100 V).

10. **(D)** Let the original diameter of the wire be D.

Therefore the new diameter is D/2.

Original area of cross-section is $\frac{\pi D^2}{4}$

and the final area of cross-section is $\frac{\pi D^2}{16}$

$$L \times \frac{\pi D^2}{4} = L' \times \frac{\pi D^2}{16} \Rightarrow L' = \frac{16}{4} L = 4L$$

Resistance is given by $R = \rho \frac{L}{A}$.

$$\therefore \quad R' = \rho \frac{L'}{A'} = \rho \frac{4L}{A/4} = 16R. \qquad \left[\because A' = \frac{\pi D^2}{16} = \frac{A}{4}\right]$$

$\therefore$ $R' = 16 \times 10 = 160\ \Omega$.

11. **(A)** In each row all the 5000 electroplaques are connected in series.

Therefore, equivalent emf $= 0.15 \times 5000 = 750$ V.

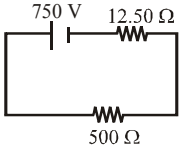
Equivalent resistance $= 0.25 \times 5000 = 1250\ \Omega$.

All 100 rows are connected in parallel.

Therefore voltage = 750 V.

Equivalent resistance $= \frac{1250}{100} = 12.50\ \Omega$.

Thus resultant circuit of eel becomes



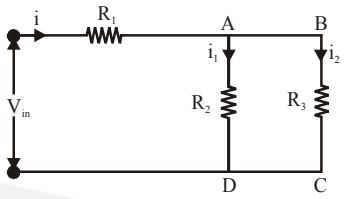
Thus across 500 Ω $= \frac{V}{R} = \frac{750}{500 + 12.50} = 1.46$ A

$I \approx 1.5$ A.

12. **(C)** As the voltage in R_2 and R_3 is same therefore, according to,

$$H = \frac{V^2}{R}.t, \quad R_2 = R_3$$

Also the energy in all resistance in same.



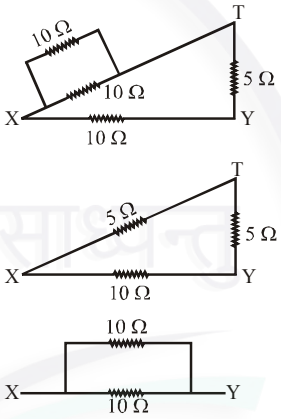
$\therefore$ $i^2 R_1 t = i_1^2 R_2 t$

Using $i_1 = \frac{R_3}{R_2 + R_3} i = \frac{R_3}{R_3 + R_3} i = \frac{1}{2} i$

Thus $i^2 R_1 t = \frac{i^2}{4} R_2 t$ or, $R_1 = \frac{R_2}{4}$

13. **(A)**

14. **(B)**



$R_{XY} = \frac{10 \times 10}{10 + 10} = 5\Omega$.

15. **(A)** We know that $J = AT^2 e^{-b/T}$

$$\frac{J}{T^2} = Ae^{-b/T}$$

Taking log on both side, we get

$$\log_e \frac{J}{T^2} = \log_e (A \cdot e^{-b/T})$$

$$\log_e \frac{J}{T^2} = \log_e A - \frac{b}{T}$$

Comparing with $y = mx + C$

we get correct option (A).

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16. **(A)** With increase in frequency, reactance of LC circuit will increase. As a result, voltage increases. So, brightness will increase.

17. **(C)** When heater wires are connected in series, then equivalent resistance,

$R_s = R_1 + R_2 = 2R$ $(\because R_1 = R_2)$

Rate of heat produced, $H_s = \frac{V^2}{R_s}$

$$H_s = \frac{V^2}{2R} \quad ...(i)$$

In second case, $R_p = \frac{R_1 R_2}{R_1 + R_2} = \frac{R \cdot R}{2R}$

or $R_p = \frac{R}{2}$

$\therefore$ Rate of heat produced, $H_p = \frac{V^2}{R_p}$

$$H_p = \frac{2V^2}{R} \quad ...(ii)$$

Dividing (i) by (ii), we get

$$\frac{H_s}{H_p} = \frac{(v^2/2R)}{(2V^2/R)} = \frac{V^2}{2R} \times \frac{R}{2V^2} = \frac{1}{4}.$$

18. **(C)** Resistance of 25 W, 200 V bulb

$$R_1 = \frac{(200)^2}{25}\Omega$$

Resistance of 100 W, 200 v bulb

$$R_2 = \frac{(200)^2}{100}\Omega.$$

Clearly, $R_1 > R_2$. $\therefore$ $H_1 > H_2$.

$\therefore$ 25 W bulb will glow more brightly.

19. **(C)** Here p-n junction is forward biased. If p-n junction is ideal, its resistance is zero. The effective resistance across A and B

$$= \frac{10 \times 10}{10 + 10} = 5\ k\Omega$$

Current in the circuit

$$I = \frac{30}{(10+5) \times 10^3} = \frac{2}{10^3} A$$

$\therefore$ Current in each arm $= \frac{I}{2} = \frac{1}{10^3}$ A.

Pot. diff. across A and B $= \frac{1}{10^3} \times 10 \times 10^3 = 10$ V

20. **(B)** $H = I^2 R t = mc \Delta\theta$

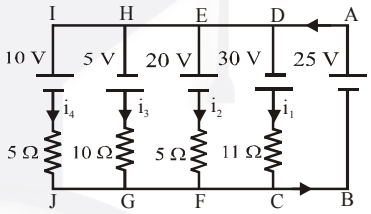
$\therefore$ $\Delta\theta \propto I^2$

Hence $\frac{\Delta\theta_2}{\Delta\theta_1} = \left(\frac{I_2}{I_1}\right)$ or $\frac{\Delta\theta_2}{3} = \left(\frac{3I}{I}\right)^2$

or $\Delta\theta_2 = 9 \times 3 = 27°C$

21. **(A)** According to positive Thomson's effect the potential at a point of lower temperature is lower than at the point at higher temperature which is at higher potential. When current is passed from lower temperature to higher temperature of a metal, work is to be done, hence energy is absorbed.

22. **(C)**



Applying KVL in loop ABCDA, ABFEa, ABGHA and ABJIA, we get

$30 - i_1 \times 11 = -25$ ...(i)

$20 + i_2 \times 5 = 25$ ...(ii)

$5 - i_2 \times 10 = -25$ ...(iii)

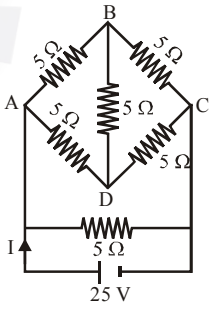
$10 + i_4 \times 5 = 25$ ...(iv)

Solving equations (i), (ii), (iii) and (iv) we get $i_1 = 5$ A, $i_2 = 1$ A, $i_3 = 3$ A and $i_4 = 3$ A.

Hence, current flowing through 25 V cell is 12 A.

23 **(B)**

24. **(A)** It is a balanced Wheatstone bridge. Hence no current flows through resistance of arm BD and the resistance of arm BD is ineffective



$\therefore$ $\frac{R_{AB}}{R_{BC}} = \frac{R_{AD}}{R_{DC}}$

$\Rightarrow$ $\frac{5\Omega}{5\Omega} = \frac{5\Omega}{5\Omega}$

Resistance o f arm

ABC = 5 Ω + 5 Ω = 10 Ω

Resistance of arm

ADC = 5 Ω + 5 Ω = 10 Ω

The effective resistance between A and C is

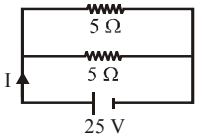
$$\frac{1}{R_{AC}} = \frac{1}{10} + \frac{1}{10} \text{ or } R_{AC} = 5\Omega$$

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Now the equivalent circuit becomes

$\therefore$ The equivalent resistance of the circuit

$\frac{1}{R}=\frac{1}{5}+\frac{1}{5}$ or $R=2.5\ \Omega$



Current in the circuit,

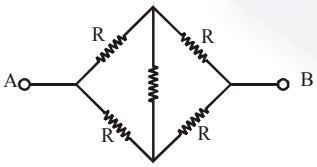
$I=\frac{V}{R}=\frac{25}{2.5}=10\ A$

25. (D) Here, $P=100\ W, t=10\ min=60\ s$

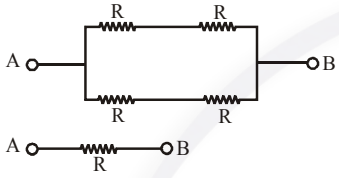
Heat developed in time t

$H=P\times t=(100\ W)(60\ s)=6000\ J$

26. (B)



Equivalent circuit,

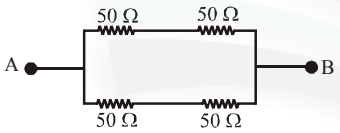


27. (A) Here, $R_1=1/2\ \Omega, R_2=1/4\ \Omega; R_3=1/6\ \Omega$

In parallel; $\frac{1}{R_p}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}=2+4+6=12$

or equivalent conductance, $G=\frac{1}{R_p}=12\ S$

28. (A) Given circuit is a balanced Wheatstone bridge. So circuit becomes



Equivalent resistance,

$R=\frac{(50+50)\times(50+50)}{(50+50)+(50+50)}=\frac{100\times100}{200}=50\ \Omega$

29. (C) Joule heating in a wire,

$H=I^2Rt$

For given R and t, $H\propto I^2$

$\therefore\quad \frac{H_1}{H_2}=\frac{I_1^2}{I_2^2}$ ....(i)

Also, $H=ms\Delta T$

For given m and s, $H\propto\Delta T$

$\therefore\quad \frac{H_1}{H_2}=\frac{\Delta T_1}{\Delta T_2}$

For eqn. (i) and (ii)

$\frac{I_1^2}{I_2^2}=\frac{\Delta T_1}{\Delta T_2}$

Here, $I_1=1, \Delta T_1=5\ °C, I_2=3I$

$\Delta T_2=?$

$\therefore\quad \left(\frac{I}{3I}\right)^2=\frac{5}{\Delta T_2}$ or $\Delta T_2=45°C$

30. (B) Given: Initial number of cells $(n_1)=10$;

Potential of each cell = E;

Internal resistance of each cell = r and

final number cell $(n_2)=3$.

We know from the Ohm's law, total voltage of ten cells $=10\times E=10E$ and total resistance in ten cells $=10\times r=10r$. Therefore current in the circuit,

$I=\frac{10E}{10r}=\frac{E}{r}$ or potential difference across three cells =

$I\times3r=\frac{E}{r}\times3r=3E.$

(Since the voltmeter is ideal, therefore it will read 3E).

31. (C) The current flowing through a conductor of non-uniform cross-section remain same in the whole of the conductor.

32. (C) Resistance of a conductor, $R=\frac{m}{ne^2\tau}\frac{l}{A}$ where the symbols have their usual meaning. As the temperature increases, the relaxation time τ decreases.

33. (A) Metals are good conductors of electricity. It is because of the presence of a large number of free electrons in metals. And for metals electrons are the main cause for thermal conduction. That's why all good conductors of heat are also good conductors of electricity.

34. (C) In case the circuit inside becomes faulty, an electric appliance might end with some charge. Because of which on touching the appliance, the user might get a shock. The third pin provided is for grounding purpose so that all accumulated charges might get discharged to the ground and the appliance remains safe. Now appliances like heater, where there can be more charge accumulation than the electric bulb, grounding is a must. That's why, electric appliances with metallic body, such as heaters have three pin connections.

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35. **(D)** In a battery circuit, the point of lowest potential is the negative terminal of the battery. And the current flows from higher potential to lower potential.

36. **(D)** The electrical force of a cell or battery called electromotive force (emf). This force, which makes electrons flow around a circuit. Each kind of cell has a particular emf. The size of a cell has no effect on its emf. The chemicals in the cell determines its emf, but large cells last longer than small cells of same basic type. This means that from a large cell, we get a particular emf for more time as compared to small cell.

37. **(B)** The assertion is true. Even when the emf is switched off, the current continues to flow because its resistance becomes zero.

The Meissner effect is another property of the superconductor and not the reason for the assertion. Meissner effect repels the magnetic field lines from the interior of the superconductor.

38. **(D)** Ohm's law is obeyed by metals for a certain range of temperature, not obeyed by superconductors, valves, diodes and semiconductors. It is not a universal law but it is purely empirical.

39. **(A)** $V = E - I(R + r)$

40. **(A)** The third pin is used for grounding purposes so that it leaves the user safe while handling the appliance by making the extra charge on it get discharged.

41. **(C)** Electric shock is due to the electric current flowing through a living body. When the bird perches on a single high power line, no current passes through its body because its body is a equipotential surface i.e., there is no potential difference. While when man touches the same line, standing bare foot on ground the electrical circuit is completed through the ground. The hands of man are at high potential and his feets are at low potential. Hence large amount of current flows through the body of the man and person therefore gets a fatal shock.

42. **(C)** As $P = Vi$, hence for the transmission of same power, high voltage implies less current. Therefore heat energy loses ($H = i^2 Rt / 4.2$) are minimized if power is transmitted at high voltage.

43. **(C)**

44. **(A)** The sum of all the currents directed towards a point in circuit is equal to the sum of all the currents directed away from that point. It is based on conservation of electrical energy.

45. **(A)** The resistance of that half portion of the metallic wire (heated red hot) on which cold water is poured decreases due to fall in its temperature. This results in a decrease in the resistance of the entire wire. As a result, the current in the wire increases and the other half portion becomes hotter than before.

46. **(A)**

MOCK TEST

1. **(D)** $i = \frac{7\,V}{7\,\Omega} = 1\,A.$

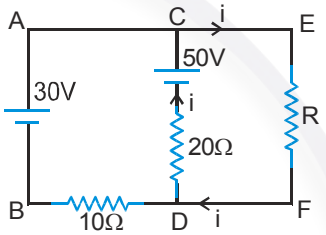
Current flows in anticolockwise direction in the loop.

Therefore $0 - 1 \times 2 - 1 \times 2 - 5 = V_1$

$V_1 = -9\,V.$

2. **(C)** $i = \frac{50}{20 + R}$

Potential drop across R = Potential drop across AB



$\Rightarrow \frac{50}{20 + R}.R = 30 \Rightarrow R = 30\,\Omega$

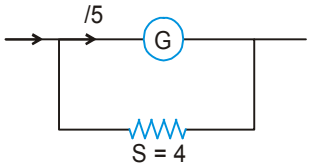
3. **(B)** $I_G = 10\,mA \Rightarrow G = 10\Omega$

$S(I - I_G) = I_G G$ where S is shunt is parallel

$S = 0.1\Omega$

4. **(A)** Case I

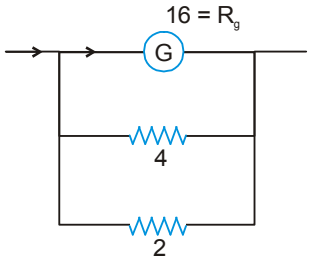
$R_g \times \frac{I}{5} = \left(I - \frac{I}{5}\right) \times 4 \quad \Rightarrow R_g = 16\,\Omega$



Case II

$16\,I_1 = \frac{4 \times 2}{6}(I - I_1) \Rightarrow I_1 = I/13$

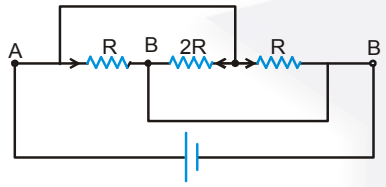
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so decrease in current to previous current

$= \frac{I/5 - I/13}{I/5} = \frac{8}{13}$ **Ans.**

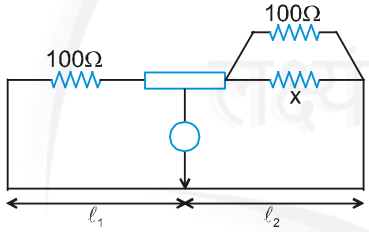
5. **(B)** In figure all resistance are connected in parallel.



So $R_{eq} = \frac{2R \times R/2}{2R + R/2}$ and current in all resistance flow from positive terminal of battery (means A end) to negative terminal of battery (means B end).

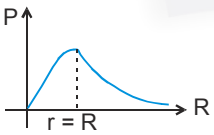
6. **(B)** ∵ wheat stone bridge is in balanced condition

So $\frac{100}{\ell_1} = \frac{\frac{100\,x}{100+x}}{\ell_2}$



$\because \frac{\ell_1}{\ell_2} = 2 \Rightarrow x = 100\ \Omega$

7. **(A)**



Power maximum when r = R.

So, power consumed by it will decrease. for R > r.

8. **(B)** $V = E - ir = -\frac{Er}{R+r} = E\left[\frac{R+r-r}{R+r}\right]$

$V = \frac{ER}{(R+r)} \Rightarrow$ $V = 0$ at $R = 0$

$V = E$ at $R = \infty$

So (B) is correct option.

9. **(D)** Voltage across each bulb will be

$V_1 = iR = \frac{V}{nR} . R = (V/n)$

so power developed by each bulb =

$iV_1 = \frac{V}{nR} . \frac{V}{n} = \frac{V^2}{n^2R}$ & $P = \frac{V^2}{R}$

So power consumed by one bulb = $\frac{P}{n^2}$

10. **(D)** For maximum current, net resistance of cells must be equal to 2.5Ω

i.e. $\frac{n\,(0.5)}{m} = 2.5$ .....(1)

& $m \times n = 45$ .....(2)

solving, we get n = 15, m = 3

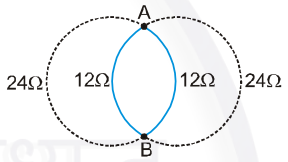
11. **(B)** From the figure.

$AC_1 = AC_2 = C_1C_2 =$ radius

$\therefore \angle AC_1B = 120°$

Hence the resistance of four sections are

Hence equivalent resistance R across AB is



$\frac{1}{R} = \frac{1}{24} + \frac{1}{12} + \frac{1}{12} + \frac{1}{24}$ or $R = 4\Omega$

$\therefore$ Power $= \frac{V^2}{R} = \frac{(20)^2}{4} = 100$ watt.

12. **(A)** In potentiometer wire potential difference is directly proportional to length

Let potential drop per unit length a potentiometer wire be K.

For zero deflection the current will flow independently in two closed circuits

$IR = K \times 10$ .... (1)

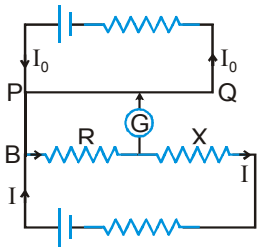
$IR + IX = K \times 30$ .... (2)

(2) – (1)

$\Rightarrow$ $IX = k \times 20$ .... (3)

Divide (1) & (3)

$\frac{R}{X} = \frac{1}{2} \Rightarrow x = 2R$



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13. (C) $E = \frac{\lambda}{2\pi\varepsilon_0 r}$,

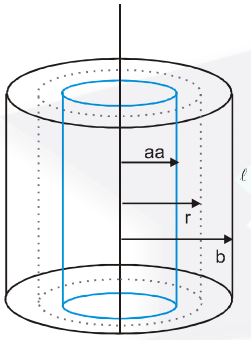
where λ is the linear charge density on the inner cylinder.

and $V = \int_a^b E.d\ell = \frac{\lambda}{2\pi\varepsilon_0}\ell n\left(\frac{b}{a}\right)$ .... (1)

Now; $I = \int \vec{J}.\overrightarrow{dA} = \sigma\int \vec{E}.\overrightarrow{dA} = \sigma\frac{\lambda}{2\pi\varepsilon_0 r}.2\pi r\ell$

Current per unti length will be :

$I = \frac{\sigma\lambda}{\varepsilon_0}$ .... (2)



From (1)

$I = \frac{2\sigma\pi\varepsilon_0}{\varepsilon_0\ell n(b/a)}V$

$= \frac{2\pi\sigma}{\ell n(b/a)}V$

Alternate

$I_b = \frac{V}{R}$

$R = \int_{x=a}^{b}\frac{1}{\sigma}\frac{dx}{2\pi x.1} = \frac{1}{2\pi\sigma}\ell n\left(\frac{b}{a}\right)$ $\therefore$ $I = \frac{2\pi\sigma V}{\ell n(b/a)}$

14. (B) $50 = 10\,[R + r]$

$R + r = 5\,\Omega$

$\eta = \frac{R}{R+r} \Rightarrow 0.25 = \frac{R}{R+r}$

$R + r = 4R$

$r = 3R$

then $R = \frac{5}{4} = 1.25\,\Omega$, and $r = 3.75\,\Omega$.

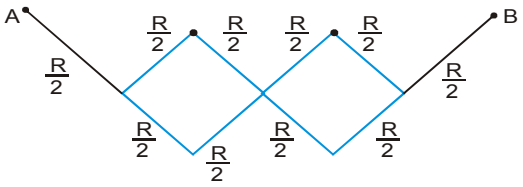
15. (D) $P = VI$, $50 = 5 \times I$

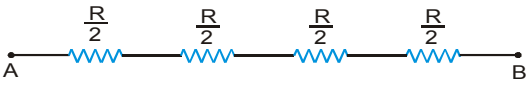
$I = 10\,A$

Power lost in cable $= I^2R = 10 \times 10 \times 0.02 = 2\,W$

Power supplied to T.R. $= 50\,W - 2\,W = 48\,W$

16. (B) The circuit can be folded about B and redrawn as





Hence equivalent resistance between A and B is 2R.

17. (D) $R = \frac{1}{\sigma}\times\frac{t}{4\pi r^2}$

Using values $R = 5 \times 10^{-11}\,\Omega$

$R = 5 \times 10^{-11}\,\Omega$

18. (B) Since current $I = neAv_d$ through both rods is same

$2(n)\,e\,A\,v_L = n\,e\,(2A)\,v_R$ or $\frac{v_L}{v_R} = 1$

19. (C) $i = \frac{dq}{dt}$ = slope of q - t graph

$= -5$ (which is constant)

Amount of heat generated in time t

$H = i^2RT$

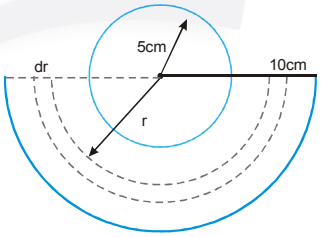
$H \propto t$.

20. (B) From relation $E = \rho J$, the magnitude of electric field is greater in right rod as compared to left rod. There fore magnitude of potential gradient in the right rod is greater. (remember potential is continuous).



Therefore the variation is shown by figure.

21. (A) The arrangement is shown in figure. Consider the hemispherical shell of radius r and thickness dr as shown. Resistance of this shell is :



$dR = \frac{dr}{\sigma\times 2\pi r^2}$

$R = \frac{1}{2\pi\sigma}\times\int_{r=5cm}^{r=10cm}\frac{dr}{r^2} = 1591.6\,\Omega$.

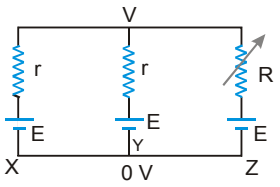
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22. **(C)** Redrawing the given circuit diagram as shown below:

Using point potential theory,

$$\frac{V-E}{r}+\frac{V-E}{r}+\frac{V-E}{R}=0$$

$$\Rightarrow (V-E)\left(\frac{2}{r}+\frac{1}{R}\right)=0$$



As $\frac{2}{r}+\frac{1}{R}\neq 0$

So $V-E=0$

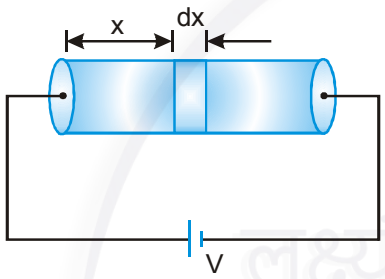
So, current through R, $i=\frac{V-E}{R}=0$

whatever be the value of R.

23. **(A)** Consider an elemental part of solid at a distance x from left end of width dx.

Resistance of this elemental part is,

$$dR=\frac{\rho dx}{\pi a^2}=\frac{\rho_0 x dx}{\pi a^2}\Rightarrow R=\int dR=\int_0^L \frac{\rho_0 x dx}{\pi a^2}=\frac{\rho_0 L^2}{2\pi a^2}$$



Current through cylinder is, $I=\frac{V}{R}=\frac{V\times 2\pi a^2}{\rho_0 L^2}$

Potential drop across element is, $dV=IdR=\frac{2V}{L^2}x\,dx$

$E(x)=\frac{dV}{dx}=\frac{2V}{L^2}x.$

24. **(C)** **Resistance** $=\rho\frac{l}{A}$

$$\frac{R_1}{R_2}=\frac{\rho_1}{\rho_2}\times\frac{l_1}{l_2}\times\frac{A_2}{A_1}=\frac{2}{3}\times\frac{3}{4}\times\frac{5}{4}=\frac{5}{8}$$

25. **A → Q ; B → S ; C → S; D → Q**

(A) Since current in both rods is same.

$\therefore\ n_1 e v_1 A_1 = n_2 e v_2 A_2$

$\therefore\ \frac{v_1}{v_2}=\frac{n_2 A_2}{n_1 A_1}=\frac{1}{2}\times\frac{2}{1}=1$

(B) $\because\ E=\rho J=\rho\frac{I}{A}$

$\therefore\ \frac{E_1}{E_2}=\frac{\rho_1}{\rho_2}\times\frac{A_2}{A_1}=\frac{2}{1}\times\frac{2}{1}=4$

(C) $\frac{\text{p.d. across rod I}}{\text{p.d. across rod II}}=\frac{E_1\times AB}{E_2\times BC}=4$

(D) $\frac{\text{Average time taken by free electron to move from A to B}}{\text{Average time taken by free electron to move from B to C}}$

$=\frac{AB}{v_1}\times\frac{v_2}{BC}=1$

26. **A → Q; B → R ; C → R ; D → R**

When switch S is opened then right side resistance R which was short circuited earlier contributes to equivalent resistance. Hence, equivalent resistance across the battery increases, power dissipated by left resistance R decreases, voltmeter reading decreases and ammeter reading decreases.

27. **(B)** Both statements 1 and 2 are true. In statement-1 R is varied while in statement-2 R is kept constant. Hence both statements are independent.

28. **(C)** From relation $\vec{J}=\sigma\vec{E}$, the current density $\vec{J}$ at any point in ohmic resistor is in direction of electric field $\vec{E}$ at that point. In space having non-uniform electric field, charges released from rest may not move along ELOF. Hence statement 1 is true while statement 2 is false.

29. **(D)** As the length of wire is doubled, the cross-section area of wire becomes half. Therefore resistance of wire becomes four times and current becomes $\frac{1}{4}$ th of the initial value.

also $v_d=\frac{I}{neA}$

Since current becomes one fourth and cross-section area of wire becomes half, therefore from above equation the drift velocity of electron becomes half. Hence statement I is false.

30. **(A)** The potential difference across the resistance is always $|E_1-E_2|$ in magnitude. Hence statement 1 and 2 are true and statement 2 is correct explanation of statement 1.

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CHAPTER 04

MAGNETIC EFFECT OF CURRENT AND MAGNETISM

Magnetic lines of force convey a far better and purer idea than the phrase magnetic current or magnetic flood: it avoids the assumption of a current or of two currents and also of fluids or a fluid, yet conveys a full and useful pictorial idea to the mind.

"MICHAEL FARADAY"

INTRODUCTION

Magnets are familiar objects. The word magnetism is derived from the province of Magnesia where the ancient Greek mine magnetic, also known as lodestone, a mineral composed of iron oxide which attracts iron.

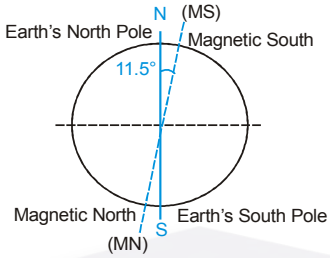
If you ask the average person what "magnetism" is, you will probably be told about the magnets those are used to hold notes on refrigerator door, or keeping paper clips in a holder or may be about lead stone (naturally occurring magnet).

Scholars still dispute about the origin of magnetism. It is believed that magnetism was originally used, not for navigation, but for geomancy ("foresight by earth") and fortune-telling by the Chinese. Chinese fortune tellers used lodestones to construct their fortune telling boards.

From Chinese text, it is known that magnetic compass (used for navigational purpose) is an old Chinese invention. An old Indian literature dates it to as back as 4th century. The compass was used in India was known as the matsya yantra, because of the placement of a metallic fish in a cup of oil.

Earth's Magnetic Field :

It is understood that a compass needle points along the horizontal component of Earth's magnetic field (a property called declination).



Earth's Geomagnetic North acts as a south pole of a magnet, while its Geomagnetic South acts as a North Pole of a magnet.

As shown in the diagram, the axis of the dipole makes an angle of about 11.5° with earth's rotational axis. The axis of dipole makes an angle of about 11.5° with the earth's rotational axis. And Earth's rotational axis makes an angle of 23.5° with the normal to the plane of earth's orbit about the sun.

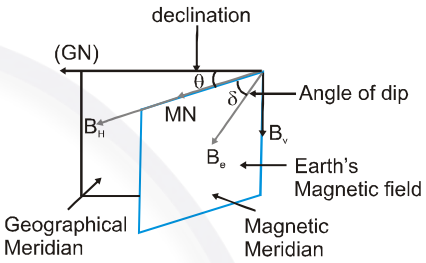
Elements of earth's magnetic field :

The earth's magnetic field is characterized by three quantities :

(a) Declination

(b) Inclination or dip

(c) Horizontal component of the field

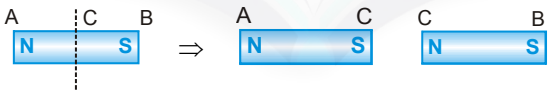


Pole Strength Magnetic Dipole and Magnetic Dipole Moment :

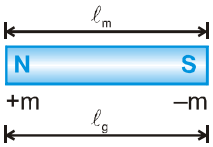
A magnet always has two poles 'N' and 'S' and like poles of two magnets repel each other and the unlike poles of two magnets attract each other they form action reaction pair.



The poles of the same magnet do not come to meet each other due to attraction. They are maintained we cannot get two isolated poles by cutting the magnet from the middle. The other end becomes pole of opposite nature. So, 'N' and 'S' always exist together.



They are known as +ve and –ve poles. North pole is treated as positive pole (or positive magnetic charge) and the south pole is treated as –ve pole (or –ve magnetic charge). They are quantitatively represented by their "POLE STRENGTH" +m and –m respectively (just like we have charges +q and –q in electrostatics). Pole strength is a scalar quantity and represents the strength of the pole hence, of the magnet also).



A magnet can be treated as a dipole since it always has two opposite poles (just like in electric dipole we have two opposite charges –q and +q). It is called MAGNETIC DIPOLE and it has a MAGNETIC DIPOLE MOMENT. It is represented by $\vec{M}$. It is a vector quantity. It's direction is from –m to +m that means from 'S' to 'N')

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$M = m.\ell_m$ here ℓ_m = magnetic length of the magnet. ℓ_m is slightly less than ℓ_g (it is geometrical length of the magnet = end to end distance). The 'N' and 'S' are not located exactly at the ends of the magnet. For calculation purposes we can assume $\ell_m = \ell_g$ [Actually $\ell_m/\ell_g \simeq 0.84$].

The units of m and M will be mentioned afterwards where you can remember and understand.

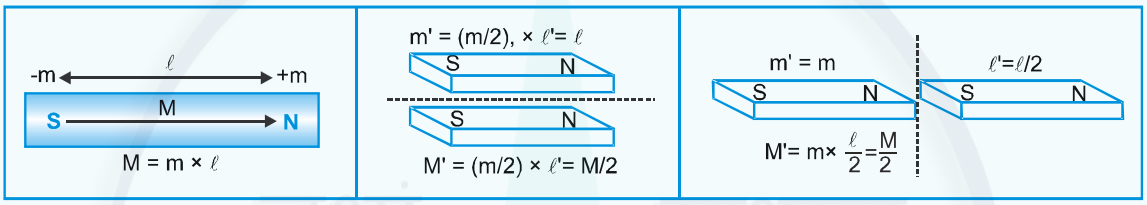
(i) Inverse square law (Coulomb law) : The magnetic force between two isolated magnetic poles of strength m_1 and m_2 lying at a distance 'r' is directly proportional to the product of pole strength and inversely proportional to the square of distance between their centres. The magnetic force between the poles can be attractive or repulsive according to the nature of the poles.

$$\left.\begin{array}{l} F_m \propto m_1 m_2 \\ F_m \propto \dfrac{1}{r^2} \end{array}\right] \quad F_m = k\,\frac{m_1 m_2}{r^2} \quad \text{where k} \begin{cases} \dfrac{\mu_0}{4\pi}\ \text{(S.I.)} \\ 1\ \text{(C.G.S.)} \end{cases}$$

Inverse square law of Coulomb in magnetism is applicable only for two long bar magents becasue isolated poles cannot exist.

(ii) If a magnet is cut into two equal parts along the length then pole strength is reduced to half and length remains unchanged. New magnetic dipole moment $M' = m'(\ell) = \frac{m}{2} \times \ell = \frac{M}{2}$.

The new magnetic dipole moment of each part becomes half of original value.

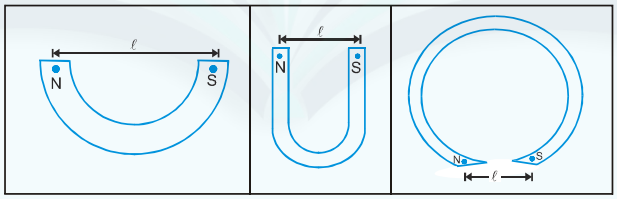


(iii) If a magnet is cut into two equal parts transverse to the length then pole strength remains unchanged and length is reduced to half. New magnetic dipole moment $M' = m\left(\frac{\ell}{2}\right) = \frac{M}{2}$.

The new magnetic dipole moment of each part becomes half of original value.

(iv) The magnetic dipole moment of a magnet is equal to product of pole strength and distance between poles.

$M = m\ell$



(v) As magnetic moment is a vector, in case of two magnets having magnetic moments M_1 and M_2 with angle θ between them, the resulting magnetic moment.

$$M = \left[M_1^2 + M_2^2 + 2M_1M_2\cos\theta\right]^{1/2} \quad \text{with} \quad \tan\phi = \left[\frac{M_2\sin\theta}{M_1 + M_2\cos\theta}\right]$$

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Magnetic Field and Strength of Magnetic Field :

The physical space around a magnetic pole has special influence due to which other pole experience a force. That special influence is called MAGNETIC FIELD and that force is called 'MAGNETIC FORCE'. This field is qualitatively represented by 'STRENGTH OF MAGNETIC FIELD' or "MAGNETIC INDUCTION" or "MAGNETIC FLUX DENSITY". It is represented by $\vec{B}$. It is a vector quantity.

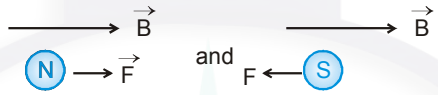
Definition of $\vec{B}$: The magnetic force experienced by a north pole of unit pole strength at a point due to some other poles (called source) is called the strength of magnetic field at that point due to the source.

Mathematically, $\vec{B} = \frac{\vec{F}}{m}$

Here $\vec{F}$ = magnetic force on pole of pole strength m. m may be +ve or –ve and of any value.

S.I. unit of $\vec{B}$ is **Tesla** or **Weber/m$_2$** (abbreviated as T and Wb/m^2).

We can also write $\vec{F} = m\vec{B}$. According to this direction of on +ve pole (North pole) will be in the direction of field and on –ve pole (south pole) it will be opposite to the direction of $\vec{B}$.

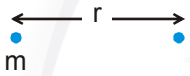


The field generated by sources does not depend on the test pole (for its any value and any sign).

(a) $\vec{B}$ due to various source

(i) Due to a single pole :

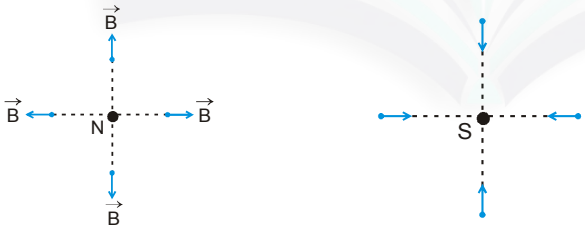
(Similar to the case of a point charge in electrostatics)



$$B = \left(\frac{\mu_0}{4\pi}\right)\frac{m}{r^2}.$$

This is magnitude

Direction of B due to north pole and due to south poles are as shown



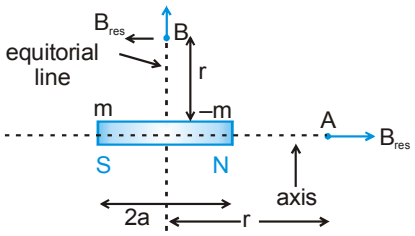
in vector form $\vec{B} = \left(\frac{\mu_0}{4\pi}\right)\frac{m}{r^3}\vec{r}$

here m is with sign and $\vec{r}$ = position vector of the test point with respect to the pole.

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(ii) Due to a bar magnet :

(Same as the case of electric dipole in electrostatics)
Independent case never found. Always 'N'
and 'S' exist together as magnet.



$$\text{at A (on the axis)} = 2\left(\frac{\mu_0}{4\pi}\right)\frac{\vec{M}}{r^3} \quad \text{for} \quad a << r$$

$$\text{at B (on the equatorial)} = -\left(\frac{\mu_0}{4\pi}\right)\frac{\vec{M}}{r^3} \quad \text{for} \quad a << r$$

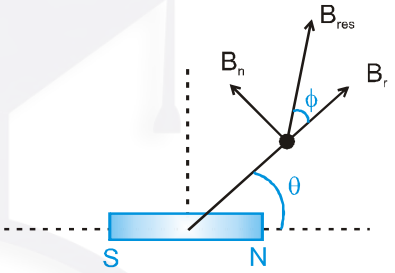
At General point :

$$B_r = 2\left(\frac{\mu_0}{4\pi}\right)\frac{M\cos\theta}{r^3}$$

$$B_n = 2\left(\frac{\mu_0}{4\pi}\right)\frac{M\sin\theta}{r^3}$$

$$B_{res} = \frac{\mu_0 M}{4\pi r^3}\sqrt{1+3\cos^2\theta}$$

$$\tan\phi = \frac{B_n}{B_r} = \frac{\tan\theta}{2}$$



MAGNETIC FIELD LINES (By Michal Faraday)

In order to visualise a magnetic field graphically, Michal faraday introduced the concept of field lines.

Field lines of magnetic field are imaginary lines which represents direction of magnetic field continuously.

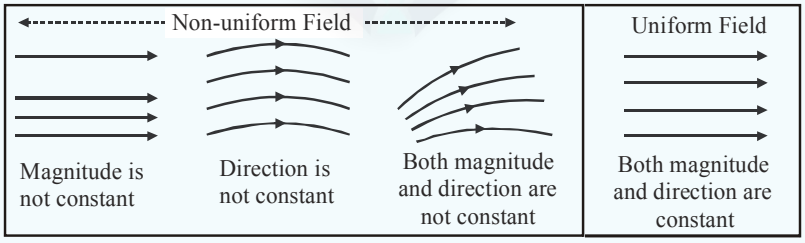
(i) Magnetic field lines are closed curves.

(ii) Tangent drawn at any point on field line represents direction of the field at that point.

(iii) Field lines never intersects to each other.

(iv) At any place crowded lines represent stronger field while distant lines represents weaker field.

(v) In any region, if field lines are **equidistant and straight** the field is uniform otherwise not.



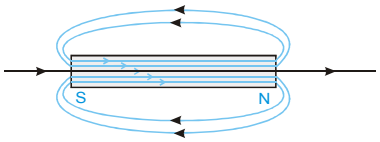
(vi) Magnetic field lines emanate from or enters in the surface of a magnetic material at any angle.

(vii) Magnetic field lines exist inside every magnetised material.

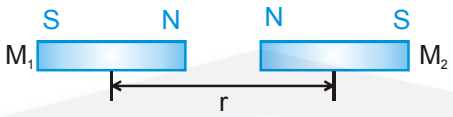
(viii) Magnetic field lines can be mapped by using iron dust or using compass needle.

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Magnetic Lines of Force of a Bar Magnet :



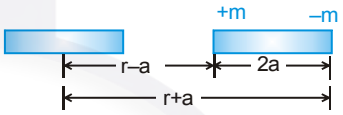
Ex. Find the magnetic force on a short magnet of magnetic dipole moment M_2 due to another short magnet of magnetic dipole moment M_1.



Sol. To find the magnetic force we will use the formula of 'B' due to a magnet. We will also assume m and –m as pole strengths of 'N' and 'S' of M_2. Also length of M_2 as 2a. B_1 and B_2 are the strengths of the magnetic field due to M_1 at +m and –m respectively. They experience magnetic forces F_1 and F_2 as shown.

$$F_1 = 2\left(\frac{\mu_0}{4\pi}\right)\frac{M_1}{(r-a)^3}m$$

and $$F_2 = 2\left(\frac{\mu_0}{4\pi}\right)\frac{M_1}{(r+a)^3}m$$



$$\therefore \quad F_{res} = F_1 - F_2 = 2\left(\frac{\mu_0}{4\pi}\right)M_1 m\left[\left(\frac{1}{(r-a)^3}\right)-\left(\frac{1}{(r+a)^3}\right)\right]$$

$$= 2\left(\frac{\mu_0}{4\pi}\right)\frac{M_1 m}{r^3}\left[\left(1-\frac{a}{r}\right)^{-3}-\left(1+\frac{a}{r}\right)^{-3}\right]$$

By using acceleration, Binomial expansion, and neglecting terms of high power we get

$$F_{res} = 2\left(\frac{\mu_0}{4\pi}\right)\frac{M_1 m}{r^3}\left[1+\frac{3a}{r}-1+\frac{3a}{r}\right]$$

$$= 2\left(\frac{\mu_0}{4\pi}\right)\frac{M_1 m}{r^3}\frac{6a}{r} = 2\left(\frac{\mu_0}{4\pi}\right)\frac{M_1 3M_2}{r^4} = 6\left(\frac{\mu_0}{4\pi}\right)\frac{M_1 M_2}{r^4}$$

Direction of F_{res} is towards right.

Alternative Method :

$$B = \frac{\mu_0}{4\pi}\cdot\frac{2M_1}{r^3} \Rightarrow \frac{dB}{dr} = -\frac{\mu_0}{4\pi}\times\frac{6M_1}{r^4}$$

$$F = -M_2 \times \frac{dB}{dr} \Rightarrow F = \left(\frac{\mu_0}{4\pi}\right)\frac{6M_1 M_2}{r^4}$$

Ex. A magnet is 10 cm long and its pole strength is 120 CGS units (1 CGS unit of pole strength = 0.1 A-m). Find the magnitude of the magnetic field B at a point on its axis at a distance 20 cm from it.

Sol. The pole strength is m = 120 CGS units = 12A-m.

Magnetic length is 2ℓ = 10 cm or ℓ = 0.05 m.

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Distance from the magnet is d = 20 cm = 0.2 m. The field B at a point in end-on position is

$$B = \frac{\mu_0}{4\pi}\frac{2Md}{(d^2-\ell^2)^2} = \frac{\mu_0}{4\pi}\frac{4m\ell d}{(d^2-\ell^2)^2}$$

$$= \left(10^{-7}\,\frac{T-m}{A}\right)\frac{4\times(12A-m)\times(0.05m)\times(0.2m)}{[(0.2m)^2-(0.05m)^2]^2} = 3.4\times10^{-5}\,T.$$

Ex. Find the magnetic field due to a dipole of magnetic moment 1.2 A-m^2 at a point 1 m away from it in a direction making an angle of 60° with the dipole-axis.

Sol. The magnitude of the field is

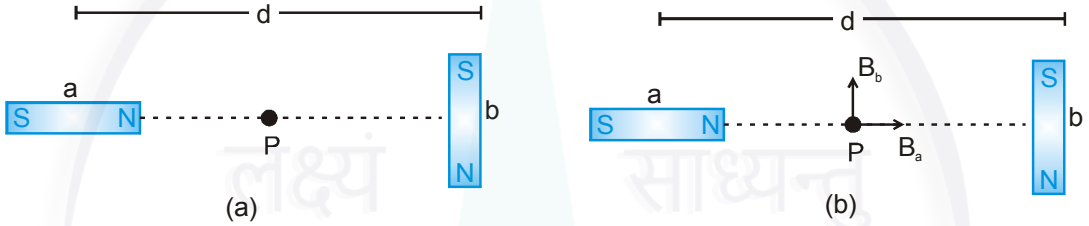
$$B = \frac{\mu_0}{4\pi}\frac{M}{r^3}\sqrt{1+3\cos^2\theta}$$

$$= \left(10^{-7}\,\frac{T-m}{A}\right)\frac{1.2A-m^2}{1\,m^3}\sqrt{1+3\cos^2 60^\circ} = 1.6\times10^{-7}\,T.$$

The direction of the field makes an angle α with the radial line where

$$\tan\alpha = \frac{\tan\theta}{2} = \frac{\sqrt{3}}{2}$$

Ex. Figure shows two identical magnetic dipoles a and b of magnetic moments M each, placed at a separation d, with their axes perpendicular to each other. Find the magnetic field at the point P midway between the dipoles.



Sol. The point P is in end-on position for the dipole **(a)** and in broadside-on position for the dipole **(b)**. The magnetic field at P due to a is $B_a = \frac{\mu_0}{4\pi}\frac{2M}{(d/2)^3}$ along the axis of a, and that due to b is $B_b = \frac{\mu_0}{4\pi}\frac{M}{(d/2)^3}$ parallel to the axis of b as shown in figure. The resultant field at P is, therefore.

$$B = \sqrt{B_a^2+B_b^2} = \frac{\mu_0 M}{4\pi(d/2)^3}\sqrt{1^2+2^2} = \frac{2\sqrt{5}\mu_0 M}{\pi d^3}$$

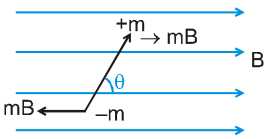
The direction of this field makes an angle α with B_a such that $\tan\alpha = B_b/B_a = 1/2$.

Magnet in an External Uniform Magnetic Field

(same as case of electric dipole)

$F_{res} = 0$ (for any angle)

$\tau = MB\sin\theta$

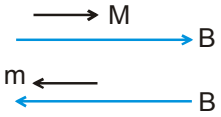


*here θ is angle between $\vec{B}$ and $\vec{M}$

Note : **(i)** $\vec{\tau}$ acts such that it tries to make $\vec{M}\times\vec{B}$.

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(ii) $\vec{\tau}$ is same about every point of the dipole it's potential energy is



$$U = -MB\cos\theta = -\vec{M}\cdot\vec{B}$$

$\theta = 0^\circ$ is stable equilibrium

$\theta = \pi$ is unstable equilibrium

for small 'θ' the dipole performs SHM about $\theta = 0^\circ$ position

$$\tau = -MB\sin\theta \; ; \quad I\alpha = -MB\sin\theta$$

for small θ, $\sin\theta \simeq \theta$

$$\alpha = -\left(\frac{MB}{I}\right)\theta$$

Angular frequency of SHM

$$\omega = \sqrt{\frac{MB}{I}} = \frac{2\pi}{T} \Rightarrow T = 2\pi\sqrt{\frac{I}{MB}}$$

Here $I = I_{cm}$ if the dipole is free to rotate $= I_{hinge}$ if the dipole is hinged

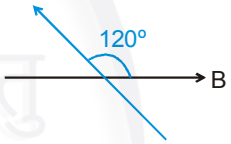
Ex. A bar magnet having a magnetic moment of 1.0×10^{-4} J/T is free to rotate in a horizontal plane. A horizontal magnetic field $B = 4 \times 10^{-5}$ T exists in the space. Find the work done in rotating the magnet slowly from a direction parallel to the field to a direction 60° from the field.

Sol. The work done by the external agent = change in potential energy

$$= (-MB\cos\theta_2) - (-MB\cos\theta_1) = -MB(\cos 60^\circ - \cos 0^\circ)$$

$$= \frac{1}{2}MB = \frac{1}{2}\times(1.0\times 10^4 \text{ J/T})\,(4\times 10^{-5}\text{ T}) = 0.2 \text{ J}$$

Ex. A magnet of magnetic dipole moment M is released in a uniform magnetic field of induction B from the position shown in the figure. Find :



(i) Its kinetic energy at $\theta = 90^\circ$

(ii) its maximum kinetic energy during the motion.

(iii) will it perform SHM? oscillation? Periodic motion? What is its amplitude?

Sol. **(i)** Apply energy conservation at $\theta = 120^\circ$ and $\theta = 90^\circ$

$-MB\cos 120^\circ + 0$

$= -MB\cos 90^\circ + (K.E.)$

$$KE = \frac{MB}{2} \quad \textbf{Ans.}$$

(ii) K.E. will be maximum where P.E. is minimum. P.E. is minimum at $\theta = 0^\circ$. Now apply energy conservation between $\theta = 120^\circ$ and $\theta = 0^\circ$.

$-mB\cos 120^\circ + 0$

$= -mB\cos 0^\circ + (KE)_{max}$

$$(KE)_{max} = \frac{3}{2}MB \quad \textbf{Ans.}$$

The K.E. is max at $\theta = 0^\circ$ can also be proved by torque method. From $\theta = 120^\circ$ to $\theta = 0^\circ$ the torque always acts on the dipole in the same direction (here it is clockwise) so its K.E. keeps on increases till $\theta = 0^\circ$. Beyond that τ reverses its direction and then K.E. starts decreasing

$\therefore$ $\theta = 0^\circ$ is the orientation of M to here the maximum K.E.

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(iii) Since 'θ' is not small.

$\therefore$ the motion is not S.H.M. but it is oscillatory and periodic amplitude is 120º.

Ex. A bar magnet of mass 100 g, length 7.0 cm, width 1.0 cm and height 0.50 cm takes π/2 seconds to complete an oscillation in an oscillation magnetometer placed in a horizontal magnetic field of 25μT.

(a) Find the magnetic moment of the magnet.

(b) If the magnet is put in the magnetometer with its 0.50 cm edge horizontal, what would be the time period?

Sol. **(a)** The moment of inertia of the magnet about the axis of rotation is

$$I = \frac{m'}{12}(L^2 + b^2) = \frac{100\times10^{-3}}{12}[(7\times10^{-2})^2 + (1\times10^{-2})^2]\ \text{kg-m}^2. = \frac{25}{6}\times10^{-5}\ \text{kg-m}^2.$$

We have, $T = 2\pi\sqrt{\frac{I}{MB}}$ or, $M = \frac{4\pi^2 I}{BT^2} = \frac{4\pi^2\times25\times10^{-5}\text{kg/m}^2}{6\times(25\times10^{-6}\text{T})\times\frac{\pi^2}{4}\text{s}^2} = 27\ \text{A-m}^2.$

(b) In this case the moment of inertia becomes

$I' = \frac{m'}{12}(L^2 + b^2)$ where b' = 0.5 cm.

The time period would be

$$T' = \sqrt{\frac{I'}{MB}} \quad \text{.... (ii)}$$

Dividing by equation **(i)**,

$$\frac{T'}{T} = \sqrt{\frac{I'}{I}} = \frac{\sqrt{\frac{m'}{12}(L^2+b'^2)}}{\sqrt{\frac{m'}{12}(L^2+b^2)}} = \frac{\sqrt{(7\,\text{cm})^2+(0.5\,\text{cm})^2}}{\sqrt{(7\,\text{cm})^2+(1.0\,\text{cm})^2}} = 0.992 \quad \text{or,}\ T' = \frac{0.992\times\pi}{2}\text{s} = 0.496\pi\ \text{s}.$$

Magnet in an External Non-uniform Magnetic Field :

No special formulae are applied is such problems. Instead see the force on individual poles and calculate the resistant force torque on the dipole.

Ex. Find the torque on M_1 due to M_2 in Que. 1

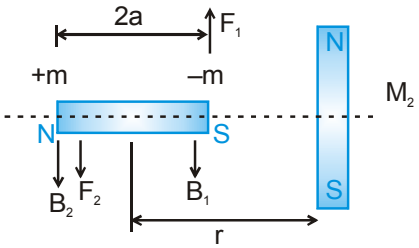
Sol. Due to M_2, magnetic fields at 'S' and 'N' of M_1 are B_1 and B_2 respectively. The forces on –m and +m are F_1 and F_2 as shown in the figure. The torque (about the centre of the dipole m_1) will be

$= F_1 a + F_2 a = (F_1 + F_2)a$

$$= \left[\left(\frac{\mu_0}{4\pi}\right)\frac{M_2}{(r-a)}m + \frac{\mu_0}{4\pi}\frac{M_2}{(r+a)}m\right]a$$

$$\cong \frac{\mu_0}{4\pi}M_2 m\left(\frac{1}{r^3}+\frac{1}{r^3}\right)a \quad \because\ a << r$$

$$= \frac{\mu_0 M_2 m}{4\pi}\frac{2}{r^3}a = \frac{\mu_0 M_1 M_2}{4\pi r^3}$$ **Ans.**



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Magnetism Due to Electricity

Hans Christian Oersted was a professor of science at Copenhagen University. In 1819 he arranged in his home a science demonstration to friends and students. He planned to demonstrate the heating of a wire by an electric current, and also to carry out demonstrations of magnetism, for which he provided a compass needle mounted on a wooden stand.

While performing his electric demonstration, Oersted noted to his surprise that every time the electric current was switched on, the compass needle moved. He kept quiet and finished the demonstrations, but in the months that followed worked hard trying to make sense out of the new phenomenon. And this is what we are going to study now.

We have seen that currents (fundamentally moving charges) are the source of magnetism. This can be readily demonstrated by placing compass needles near wire. As shown in Figure, all compass needles point in the same direction in the absence of current (in the direction of earth's magnetic field). However, when a strong current passes through (so that earth's magnetic field becomes negligible), the needles will be deflected along the tangential direction of the circular path (Figure).

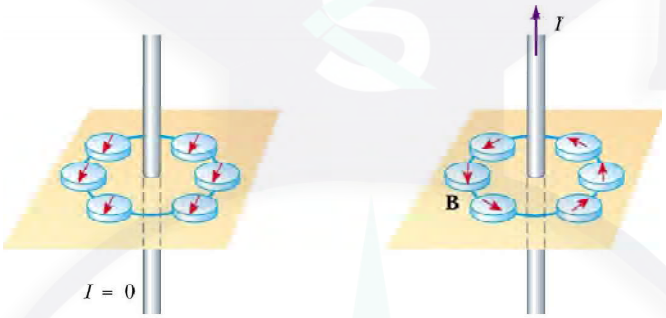


Figure : Deflection of compass needles near a current-carrying wire

Biot - Savart Law

Currents which arise due to the motion of charges are the source of magnetic fields. When charges move in a conducting wire and produce a current I, the magnetic field at any point P due to the current can be calculated by adding up the magnetic field contributions, $d\vec{B}$, from small segments of the wire $d\vec{s}$ (Figure).

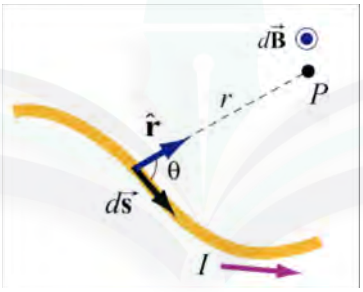


Figure : Magnetic field $d\vec{B}$ at point P due to a current-carrying element I $d\vec{s}$

The segments can be thought of as a vector quantity having a magnitude of the length of the segment and pointing in the direction of the current flow. The infinitesimal current source can then be written as I $d\vec{s}$.

Let r denote as the distance from the current source to the field point P and $\hat{r}$ the corresponding unit vector. The Biot–Savart law gives an expression for the magnetic field contribution, $d\vec{B}$, from the current source, I $d\vec{s}$,

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{s}\times r}{r^2}$$

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where μ_0 is a constant called the permeability of free space :

$\mu_0 = 4\pi \times 10^{-7}$ T.M/A here Tesla (T) is SI unit of $\vec{B}$

Notice that the expression is remarkably similar to the Coulomb's law for the electric field due to a charge element dq :

$$d\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{dq}{r^2}\hat{r}$$

Adding up these contributions to find the magnetic field at the point P requires integrating over the current source.

$$\vec{B} = \int d\vec{B} = \frac{\mu_0 I}{4\pi}\int \frac{d\vec{s}\times\hat{r}}{r^2}$$

The integral is a vector integral, which means that the expression for B is really three integrals, one for each component of $\vec{B}$. The vector nature of this integral appears in the cross product. Understanding how to evaluate this cross product and then perform the integral will be the key to learning how to use the Bio_Savart law.

Force on a Moving Charge in Magnetic Field

Consider a charge particle θ moving in a magnetic field B as shown in figure. At some instant its velocity is v which makes an angle θ with the direction of magnetic field.

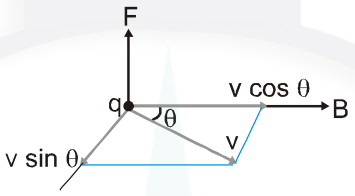


Figure 3.1

As we known that magnetic field exerts force on a moving charge particle. It is observed that the force acting on the charge is proportional to

(i) The magnitude of charge q on the particle

(ii) The magnitude B of the magnetic field

(iii) The component of velocity which is perpendicular to the magnetic field i.e. v sin θ

Combining the above three observations :

we have $F \propto qBv \sin\theta$

$\Rightarrow$ $F = kqBv \sin\theta$

where k is proportionally constant. Its value is chosen arbitrarily to be unity i.e. k = 1

$\Rightarrow$ $F = qBv \sin\theta$

Direction : The magnetic force acts in a direction perpendicular to both $\vec{v}$ and $\vec{B}$; that is, the magnetic force is perpendicular to the plane formed by $\vec{v}$ and $\vec{B}$. The direction of force can be calculated using right hand thumb rule.

These results show that the magnetic force on a particle is more complicated than the electric force. The magnetic force is distinctive because it depends on the velocity of the particle and because its direction is perpendicular to both $\vec{v}$ and $\vec{B}$. Despite this complicated behaviour, these observations can be summarized in a compact way by writing the magnetic force in the form

$$\vec{F} = q\vec{v}\times\vec{B}$$

where the direction of the magnetic force is that or $\vec{v}\times\vec{B}$ which, by definition of the cross product, is perpendicular to both $\vec{v}$ and $\vec{B}$.

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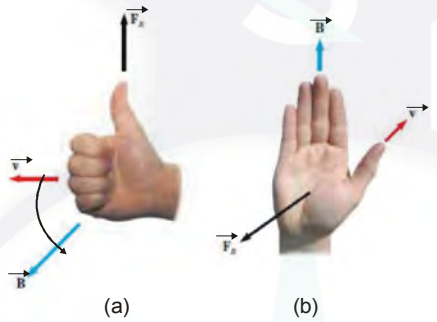
The S.I. unit of magnetic field is tesla (T), where 1 T = 1 N/Am.

Another unit is gauss (G). 1 T = 10^4 G.

1 T is a big unit. Earth's magnetic field is of the order or 10^{-5} T.

Right Hand Rules for Determining the Direction of the Magnetic Force Acting on a Moving Charged Particle

Figure reviews to right–hand rules for determining the direction of the cross product $\vec{v} \times \vec{B}$ and determining the direction of $\vec{F}_B$. The rule in Figure depends on our right-hand rule for the cross product. Point the four fingers of your right hand along the direction of $\vec{v}$ with the palm facing $\vec{B}$ and curl them toward $\vec{B}$. The extended thumb, which is at a right angle to the fingers, points in the direction of $\vec{v} \times \vec{B}$. Then $\vec{F}$ is in the direction of your thumb if q is positive and opposite to the direction of your thumb if q is negative.



Figure

An alternative rule is shown in figure **(b)**. Here the thumb points in the direction of $\vec{v}$ and the extended fingers in the direction of $\vec{B}$. Now, the force $\vec{F}_B$ on a positive charge extends outward from your palm. The advantage of this rule is that the force on the charge is in the direction that you would push on something with your hand outward from your palm. The force on a negative charge is in the opposite direction.

Note : If θ = 0° or θ = 180°, the F = 0. It means magnetic field does not extra a force on a charge particle moving parallel or antiparallel to the magnetic field.

F is maximum if θ = 90°, so force on the charge particle is maximum if velocity is perpendicular to the magnetic field.

If v = 0, then F = 0. A magnetic field does not exert force on a stationary charge particle.

There are important differences between electric and magnetic forces on charged particles :

(i) The electric force is always parallel or antiparallel to the direction of the electric field, whereas the magnetic force is perpendicular to the magnetic field.

(ii) the electric force acts on a charged particle independent of the particle's velocity, whereas the magnetic force acts on a charged particle only when the particle is in motion and the force is proportional to the velocity.

(iii) The electric force does work in displacing a charged particle, whereas the magnetic force does no work when a charged particle is displaced.

This last statement is true because when a charge moves in a magnetic field, the magnetic force is always perpendicular to the velocity. Hence, the work done by the magnetic force on the particle is zero.

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From the work–energy theorem, we conclude that the kinetic energy of a charged particle cannot be altered by a magnetic field alone. In their words, when a charge moves with a velocity, an applied magnetic field can alter the direction of the velocity vector, but it cannot change the speed of the particle.

Magnetic Field due to a Finite Straight Wire

A thin, straight wire carrying a current I is placed along the x-axis, as shown in Figure. Evaluate the magnetic field at point P due to the segment shown in figure.

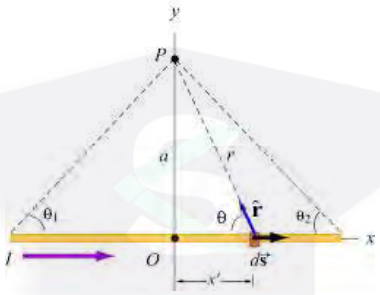


Figure : A thin straight wire carrying a current I

The contribution to the magnetic field due to $I\,d\vec{s}$

$$d\vec{B}=\frac{\mu_0 I}{4\pi}\frac{d\vec{s}\times\hat{r}}{r^2}=\frac{\mu_0 I}{4\pi}\frac{d\times\sin\theta}{r^2}\hat{k}$$

Which shows that the magnetic field at P will in the $+\hat{k}$ direction, or out of the page.

Simplify and carry out the integration.

The variables θ, x and r are not independent of each other. In order to complete the integration, let us rewrite the variables x and r in terms of θ. From Figure, we have

$$\begin{cases} r = a/\sin\theta = a\ \text{cosec}\ \theta \\ x = a\cot\theta \Rightarrow dx = -a\ \text{cosec}^2\theta d\theta \end{cases}$$

Upon substituting the above expressions, the differential contribution to the magnetic field is obtained as

$$dB=\frac{\mu_0 I}{4\pi}\frac{(-a\ \text{cosec}^2\theta d\theta)\sin\theta}{(a\ \text{cosec}\theta)^2}=\frac{\mu_0 I}{4\pi a}\sin\theta\, d\theta$$

Integrating over all angles subtended from $-\theta_1$ to θ_2 (a negative sign is needed for θ_1 in order to take into consideration the portion of the length extended in the negative x - axis from the origin), we obtain

$$dB=\frac{\mu_0 I}{4\pi a}\int_{-\theta_1}^{\theta_2}\sin\theta d\theta=\frac{\mu_0 I}{4\pi a}(\cos\theta_2+\cos\theta_1)$$

The first term involving θ_2 accounts for the contribution from the portion along the +x axis, while the second term involving θ_1 contains the contribution from the portion along the –x axis. The two terms add.

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Special Cases :

(i) Magnetic field on the perpendicular bisector of a finite straight wire of length 2L

In this case where $\theta_2 = \theta_1 = \theta$, the field point P is located along the perpendicular bisector. If the length of the rod is 2L, then $\cos\theta = L\sqrt{L^2 + a^2}$ and the magnetic field is

$$B = \frac{\mu_0 I}{2\pi a}\cos\theta = \frac{\mu_0 I}{2\pi a}\frac{L}{\sqrt{L^2+a^2}}$$

(ii) Magnetic field due to semi infinite straight wire

Here $\theta_1 = 90°$, $\theta_2 = 0°$ or $\theta_1 = 0°$, $\theta_2 = 90°$

$$B = \frac{\mu_0 I}{4\pi a}$$

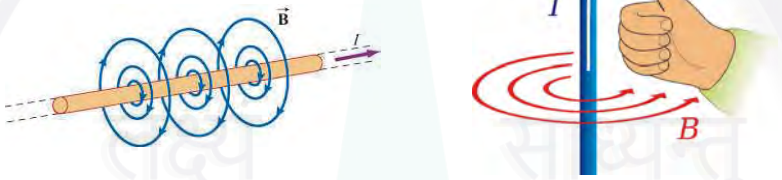
(iii) Magnetic field due to infinite straight wire

Here $\theta_1 = \theta_2 = 0°$

$$B = \frac{\mu_0 I}{2\pi a}$$

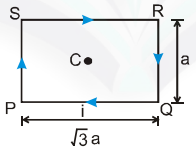
Direction of magnetic field of a straight wire

Note that in this limit, the system possesses cylindrical symmetry, and the magnetic field lines are circular, as shown in figure



In fact, the direction of the magnetic field due to a long straight wire can be determined by the right-hand rule (Figure). If you direct your right thumb along the direction of the current in the wire, then the fingers of your right hand curl in the direction of the magnetic field.

Ex. Find resultant magnetic field at 'C' in the figure shown.



Sol. It is clear that 'B' at 'C' due all the wires is directed ⊗. Also B at 'C' due PQ and SR is same.

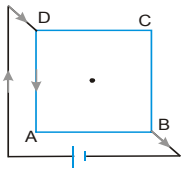
Also due to QR and PS is same

$\therefore \quad B_{res} = 2(B_{PQ} + B_{SP})$

$$B_{PQ} = \frac{\mu_0 i}{4\pi\frac{a}{2}}(\sin 60° + \sin 60°), \Rightarrow B_{sp} = \frac{\mu_0 i}{4\pi\frac{\sqrt{3}a}{2}}(\sin 30° + \sin 30°) \Rightarrow B_{res} = 2\left(\frac{\sqrt{3}\mu_0 i}{2\pi a} + \frac{\mu_0 i}{2\pi a\sqrt{3}}\right) = \frac{4\mu_0 i}{\sqrt{3}\pi a}$$

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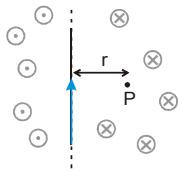
Ex. Figure shows a square loop made from a uniform wire. Find the magnetic field at the centre of the square if a battery is connected between the points B and D as shown in the figure



Sol. The current will be equally divided at D. The fields at the centre due to the currents in the wires DA and DC will be equal in magnitude and opposite in direction. The resultant of these two fields will be zero. Similarly, the resultant of the fields due to the wires AB and CB will be zero. Hence, the net field at the centre will be zero.

Special case :

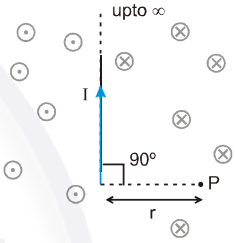
(i) If the wire is infinitely long then the magnetic field at 'P' (as shown in the figure) is given by (using $\theta_1 = \theta_2 = 90^\circ$ and the formula of 'B' due to straight wire)



$$B = \frac{\mu_0 I}{2\pi r} \Rightarrow B \propto \frac{I}{r}$$

The direction of $\vec{B}$ at various is as shown in the figure. The magnetic lines of force will be concentric circles around the wire (as shown earlier)

(ii) If the wire is infinitely long but 'P' is as shown in the figure. The direction of $\vec{B}$ at various points is as shown in the figure. At 'P'

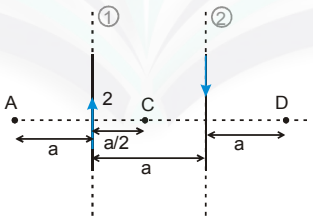


$$B = \frac{\mu_0 I}{4\pi r}$$

Ex. In the figure shown there are two parallel long wires (placed in the plane of paper) are carrying currents 2I and I consider points A, C, D on the line perpendicular to both the wires and also in the plane of the paper. The distances are mentioned. Find

(i) $\vec{B}$ at A, C, D

(ii) position of point on line A C D where $\vec{B}$ is O.



Sol. **(i)** Let us call $\vec{B}$ due to **(2)** and **(2)** as $\vec{B}_1$ and $\vec{B}_2$ respectively. Then

at A : $\vec{B}_1$ is $\odot$ and $\vec{B}_2$ is $\otimes$

$$B_1 = \frac{\mu_0 2I}{2\pi a} \text{ and } B_2 = \frac{\mu_0 I}{2\pi 2a}$$

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$\therefore \quad B_{res} = B_1 - B_2 = \frac{3}{4}\frac{\mu_0 I}{\pi a} \odot$ **Ans.**

at C : $\vec{B}_1$ is $\otimes$ and $\vec{B}_2$ also $\otimes$

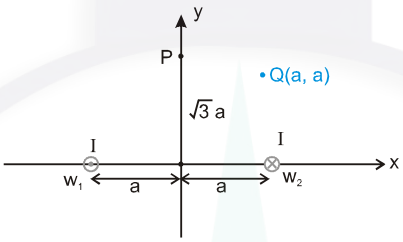
$\therefore \quad B_{res} = B_1 + B_2 = \frac{\mu_0 2I}{2\pi\frac{a}{2}} + \frac{\mu_0 I}{2\pi\frac{a}{2}} = \frac{6\mu_0 I}{2\pi a} = \frac{3\mu_0 I}{\pi a} \otimes$ **Ans.**

at D : $\vec{B}_1$ is $\otimes$ and $\vec{B}_2$ is $\odot$ and both are equal in magnitude.

$\therefore \quad B_{res} = 0$ **Ans.**

(ii) It is clear from the above solution that B = 0 at point 'D'.

Ex. In the figure shown two long wires W_1 and W_2 each carrying current I are placed parallel to each other and parallel to z-axis. The direction of current in W_1 is outward and in W_2 it is inwards. Find the $\vec{B}$ at 'P' and 'Q'.

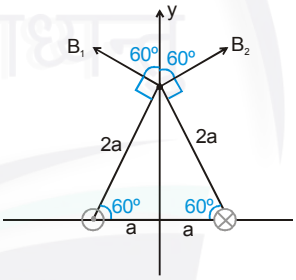


Sol. Let $\vec{B}$ due to W_1 be $\vec{B}_1$ and due to W_2 be $\vec{B}_2$.

By symmetry $\quad |\vec{B}_1| = |\vec{B}_2| = B$

$B_p = 2\,B\cos 60^\circ = B = \frac{\mu_0 I}{2\pi 2a} = \frac{\mu_0 I}{4\pi a}$

$\therefore \quad \vec{B_p} = \frac{\mu_0 I}{4\pi a}\hat{j}$ **Ans.**

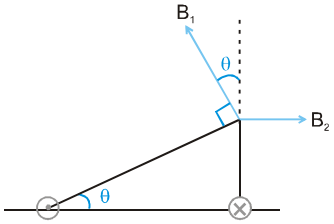


For θ $\quad B_1 = \frac{\mu_0 I}{2\pi\sqrt{5}a}, \quad \Rightarrow B_2 = \frac{\mu_0 I}{2\pi a}$

$\tan\theta = \frac{a}{2a} = \frac{1}{2} \Rightarrow \vec{B} = (B_1\cos\theta\,\hat{j}) + (B_2 - B_1\sin\theta)\hat{i}$

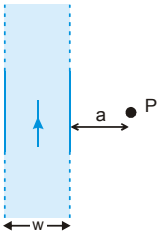
$\sin\theta = \frac{1}{\sqrt{5}} \quad \Rightarrow \vec{B} = \frac{\mu_0 I}{5\pi a}\hat{j} + \left(\frac{\mu_0 I}{2\pi a} - \frac{\mu_0 I}{10\pi a}\right)\hat{i}$

$\cos\theta = \frac{2}{\sqrt{5}} \quad \Rightarrow \vec{B} = \frac{2\mu_0 I}{5\pi a}\hat{i} + \frac{\mu_0 I}{5\pi a}\hat{j}$



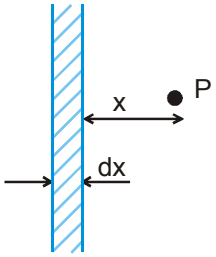
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Ex. In the figure shown a large metal sheet of width 'w' carries a current I (uniformly distributed in its width 'w'. Find the magnetic field at point 'P' which lies in the plane of the sheet.



Sol. To find 'B' at 'P' the sheet can be considered as collection of large number of infinitely long wires. Take a long wire distance 'x' from 'P' and of width 'dx'. Due to this the magnetic field at 'P' is 'dB'

$$dB = \frac{\mu_0\left(\frac{I}{w}dx\right)}{2\pi x} \otimes$$



due to each such wire $\vec{B}$ will be directed inwards

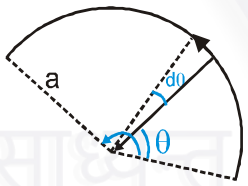
$$\therefore\ B_{res} = \int dB = \frac{\mu_0 I}{2\pi w}\int_{x=a}^{a+w}\frac{dx}{x} \int_{x=a}^{a+w}\frac{dx}{x} = \frac{\mu_0 I}{2\pi w}\cdot \ln\frac{a+w}{a}$$ **Ans.**

Magnetic Field due to a current carrying Arc at its centre

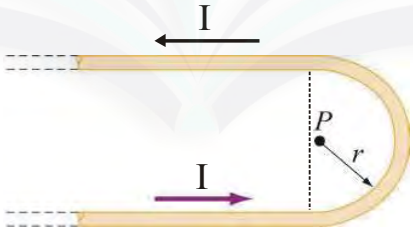
$$dl = ad\theta$$

$$dB = \frac{\mu_0}{4\pi}\frac{I(ad\theta)\sin 90°}{a^2} = \frac{\mu_0 I}{4\pi a}d\theta$$

$$B = \int dB = \frac{\mu_0 I}{4\pi a}\int_{\theta}^{\beta} d\theta \Rightarrow B = \frac{\mu_0 I}{4\pi R}(\beta)$$



Ex. An infinitely long current-carrying wire is bent into a hairpin-like shape shown in figure. Find the magnetic field at the point P which lies at the centre of the half-circle.

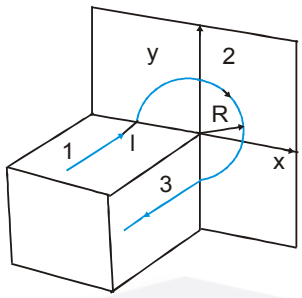


Sol. The total magnitude of the magnetic field is

$$\vec{B} = \vec{B}_1 + \vec{B}_2 + \vec{B}_3 = 2\vec{B}_1 + \vec{B}_2 = \frac{\mu_0 I}{4\pi r}\hat{k} + \frac{\mu_0 I}{4r}\hat{k} = \frac{\mu_0 I}{4\pi r}(2+\pi)\hat{k}$$

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Ex. Find the magnetic induction at the point O if the wire carrying a current I A has the shape shown in Fig. The radius of the curved part of the wire is R, the linear parts of the wire are very long.



Sol. $\vec{B} = \vec{B}_1 + \vec{B}_2 + \vec{B}_3 = \frac{\mu_0 I}{4\pi r}(-\hat{j}) + \frac{\mu_0 I}{4\pi r}\left(\frac{3\pi}{2}\right)(\hat{k}) + \frac{\mu_0 I}{4\pi r}(-\hat{i})$

Ex. A battery is connected between two points A and B on the circumference of a uniform conducting ring of radius r and resistance R. One of the arcs AB of the ring subtends an angle q at the centre. Magnetic field due to current at the centre of ring is

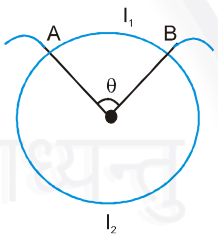
Sol. For a current flowing into a circular arc, magnetic induction in the centre

$$B = \frac{\mu_{0I}}{4\pi}\int \frac{dl \times r}{r^3} = \frac{\mu_{0I}}{4\pi}\int \frac{r^2 d\theta}{r^3} = \left(\frac{\mu_{0I}}{4\pi r}\right)\theta$$

The total current is divided into two arcs

$$I_1 = \frac{E}{R_1}$$

$$= \frac{E}{(R/2\pi r)I_1} = \frac{E}{(R/2\pi r)(r\theta)} = \frac{2\pi E}{R\theta}$$



Similarly $I_1\theta = \frac{2\pi E}{R} = \text{constant}$

$$I_2 = \frac{E}{R_2} = \frac{E}{(R/2\pi r)I_2}$$

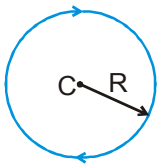
$$= \frac{E}{(R/2\pi r)\{r(2\pi - \theta)\}} = \frac{2\pi E}{R(2\pi - \theta)} = \text{constant}$$

$$B = B_1 - B_2 = \frac{\mu_0}{4\pi r}\left(\frac{2\pi E}{R} - \frac{2\pi E}{R}\right) = \theta$$

$\vec{B}$ due to Circular Loop

At centre : Due to each $\vec{d\ell}$ element of the loop $\vec{B}$ at 'c' is inwards (in this case).

$\therefore$ $\overrightarrow{B_{res}}$ at 'c' is $\otimes$.



$B = \frac{\mu_0 NI}{2R}$,

N = No. of turns in the loop.

$= \frac{\ell}{2\pi R}$; ℓ = length of the loop.

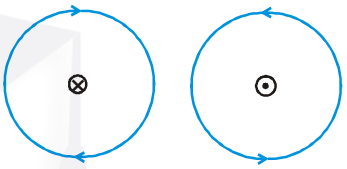
N can be fraction $\left(\frac{1}{4}, \frac{1}{3}, \frac{11}{3}\text{ etc.}\right)$ or integer.

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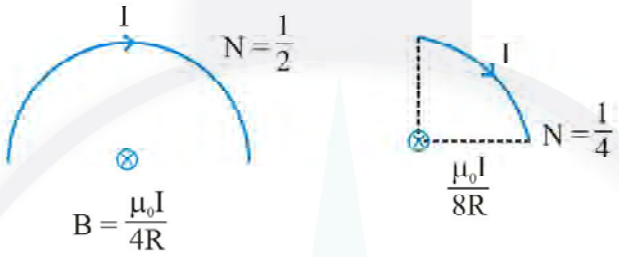
Direction of $\vec{B}$: The direction of the magnetic field at the centre of a circular wire can be obtained using the right-hand thumb rule. If the fingers are curled along the current, the stretched thumb will point towards the magnetic field (figure).



Another way to find the direction is to look into the loop along its axis. If the current is in anticlockwise direction, the magnetic field is towards the viewer. If the current is in clockwise direction, the field is away from the viewer.



Semicircular and Quarter of a circle :



Magnetic Field due to a Circular Current Loop at a point on its axis

Consider a circular loop of radius a carrying a current i. We have to find the magnetic field at a Point P on the axis of the loop at a distance d from its centre O. In figure

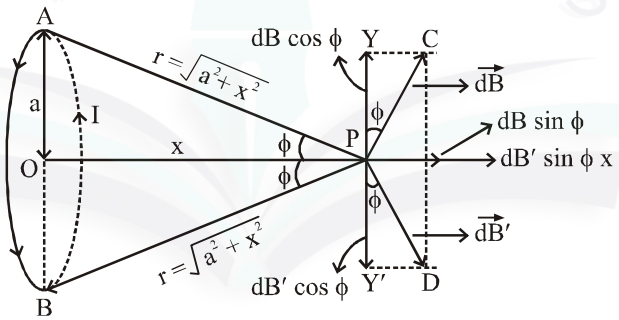


Figure shows the geometry for calculating the magnetic field at a point on the axis of a circular current loop a distance x from its center. We first consider the current element at the top of the loop. Here, as everywhere around the loop, $Id\vec{\ell}$ is tangent to the loop and perpendicular to the vector $\vec{r}$ from the current element to the field point P. The magnetic field $d\vec{B}$ due to this element is in the direction shown in the figure, perpendicular to $\vec{r}$ and also perpendicular to $Id\vec{\ell}$. The magnitude of $d\vec{B}$ is

$$dB = \frac{\mu_0}{4\pi r}\frac{Id\ell \sin 90}{r^2}$$

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When we sum around all the current elements in the loop, the components of $d\vec{B}$ perpendicular to the axis of the loop, such as dB_y in Figure sum to zero, leaving only the components dB_x that are parallel to From Figure, we have

$$B_x = \int dB \sin\phi = \int \sin\phi \frac{\mu_0 I}{4\pi r^2} d\ell = \frac{\mu_0 I}{4\pi r^2} \sin\phi \int d\ell = \frac{\mu_0 I}{4\pi r^2} \frac{a}{r} (2\pi a) = \frac{\mu_0 I (2\pi a^2)}{4\pi r^2}$$

using the facts that

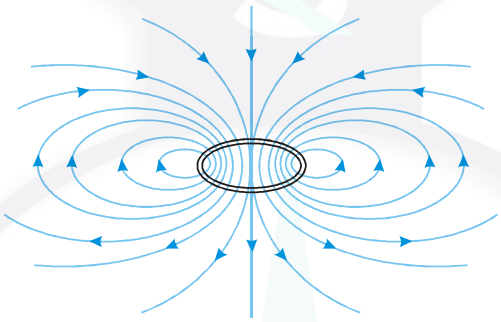
$r^2 + x^2 + a^2$

we get

$$B = \frac{\mu_0 I (2\pi a^2)}{4\pi (a^2 + x^2)^{3/2}}$$

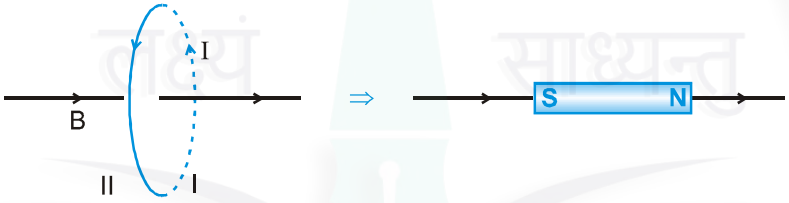
Note : If loop has N close turns then field becomes N times the field die to one turn.

Magnetic field lines due to a circular current

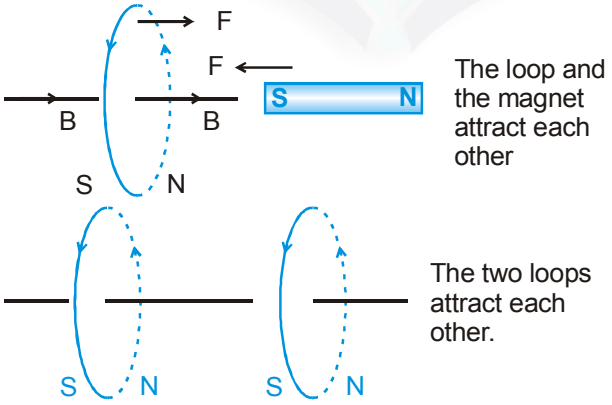


A loop as a magnet :

The pattern of the magnetic field is comparable with the magnetic field produced by a bar magnet.



The side 'I' (the side from which the $\vec{B}$ emerges out) of the loop acts as 'NORTH POLE' and side II (the side in which the $\vec{B}$ enters) acts as the 'SOUTH POLE'. It can be verified by studying force on one loop due to a magnet or a loop.



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Mathematically

$$B_{axis} = \frac{\mu_0 NIR^2}{2(R^2 + x^2)^{3/2}} \cong \frac{\mu_0 NIR^2}{2x^3} \quad \text{for } x >> R \; = 2\left(\frac{\mu_0}{4\pi}\right)\left(\frac{IN\pi R^2}{x^3}\right)$$

it is similar to B_{axis} due to magnet $= 2\left(\frac{\mu_0}{4\pi}\right)\frac{m}{x^3}$

Magnetic dipole moment of the loop

$M = IN\pi R^2$

$M = INA$ for any other shaped loop.

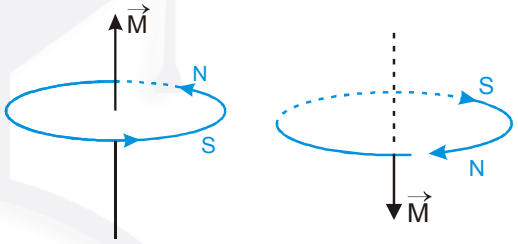
Unit of M is Amp. m^2

Unit of m (pole strength) = Amp. m $\{\because$ in magnet $M = m\ell\}$

$\vec{M} = IN\vec{A}$,

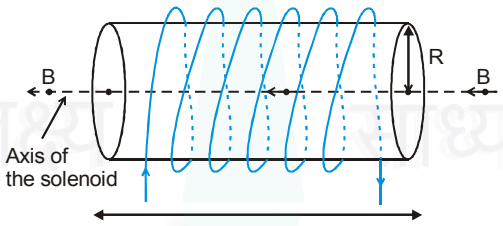
$\vec{A}$ = unit normal vector for the loop.

To be determined by right hand rule which is also used to determine direction of $\vec{B}$ on the axis. It is also from 'S' side to 'N' side of the loop.



Solenoid

(i) Solenoid contains large number of circular loops wrapped around a non-conducting cylinder. (it may be a hollow cylinder or it may be a solid cylinder)

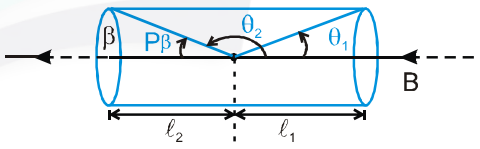


(ii) The winding of the wire is uniform direction of the magnetic field is same at all points of the axis.

(iii) $\vec{B}$ on axis (turns should be very close to each others).

$$B = \frac{\mu_0 ni}{2}(\cos\theta_1 - \cos\theta_2)$$

where n : number of turns per unit length.



$$\cos\theta_1 = \frac{\ell_1}{\sqrt{\ell_1^2 + R^2}} \; ; \quad \cos\beta = \frac{\ell_2}{\sqrt{\ell_2^2 + R^2}} \quad = -\cos\theta_2$$

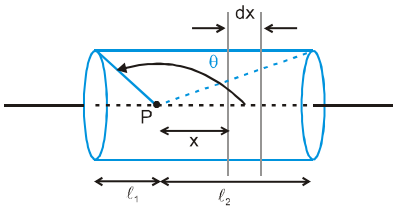
$$B = \frac{\mu_0 ni}{2}\left[\frac{\ell_1}{\sqrt{\ell_1^2 + R^2}} + \frac{\ell_2}{\sqrt{\ell_2^2 + R^2}}\right] = \frac{\mu_0 ni}{2}(\cos\theta_1 + \cos\beta)$$

Note : Use right hand rule for direction (same as the direction due to loop).

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Derivation

Take an element of width dx at a distance x from point P. [point P is the point on axis at which we are going to calculate magnetic field. Total number of turns in the element dn = ndx where n : number of turns per unit length.



$$dB = \frac{\mu_0 i R^2}{2(R^2 + x^2)^{3/2}} (ndx)$$

$$B = \int dB = \int_{-\ell_1}^{\ell_2} \frac{\mu_0 i R^2 \, ndx}{2(R^2 + x^2)^{3/2}} = \frac{\mu_0 ni}{2}\left[\frac{\ell_1}{\sqrt{\ell_1^2 + R^2}} + \frac{\ell_2}{\sqrt{\ell_2^2 + R^2}}\right] = \frac{\mu_0 ni}{2}[\cos\theta_1 - \cos\theta_2]$$

(iv) For 'Ideal Solenoid' :

***Inside** (at the mid point)

$\ell >> R$ or length is infinite

$\theta_1 \to 0$

$\theta_2 \to \pi$

$$B = \frac{\mu_0 ni}{2} [1 - (-1)]$$

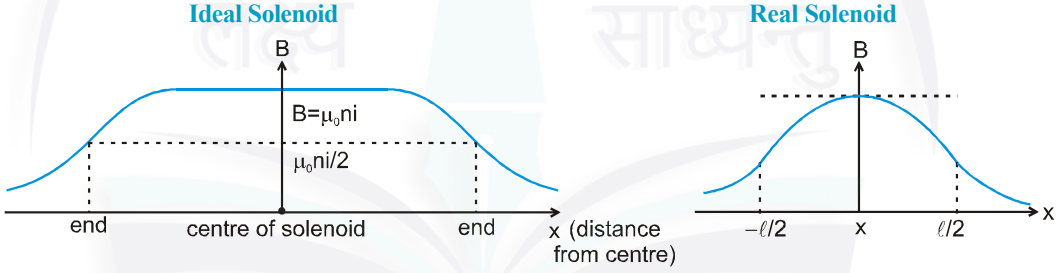
$B = \mu_0 ni$

If material of the solid cylinder has relative permeability 'μ_r' then $B = \mu_0 \mu_r ni$

At the ends $B = \frac{\mu_0 ni}{2}$

(v) Comparison between ideal and real solenoid :

(a)



Ex. A solenoid of length 0.4 m and diameter 0.6 m consists of a single layer of 1000 turns of fine wire carrying a current of 5.0×10^{-3} ampere. Find the magnetic field on the axis at the middle and at the ends of the solenoid.

(Given $\mu_0 = 4\pi \times 10^{-7} \frac{V - s}{A - m}$).

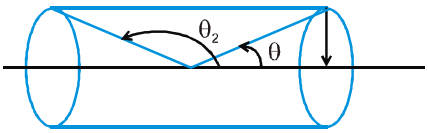
Sol. $B = \frac{1}{2}\mu_0 ni [\cos\theta_1 - \cos\theta_2]$

$\Rightarrow$ $n = \frac{1000}{0.4} = 2500$ per meter

$i = 5 \times 10^{-3}$ A.

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(i) $\cos\theta_1 = \dfrac{0.2}{\sqrt{(0.3)^2+(0.2)^2}} = \dfrac{0.2}{\sqrt{0.13}}$

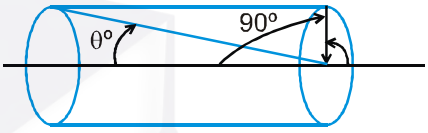


$$\cos\theta_2 = \frac{-0.2}{\sqrt{0.13}}$$

$$\Rightarrow \quad B = \frac{1}{2} \times (4 \times \pi \times 10^{-7}) \times 2500 \times 5 \times 10^{-3} \frac{2\times 0.2}{\sqrt{0.13}} = \frac{\pi \times 10^{-5}}{\sqrt{13}} T$$

(ii) At the end

$$\cos\theta_1 = \frac{0.4}{\sqrt{(0.3)^2+(0.4)^2}} = 0.8$$



$$\cos\theta_2 = \cos 90^\circ = 0$$

$$B = \frac{1}{2} \times (4 \times \pi \times 10^{-7}) \times 2500 \times 5 \times 10^{-3} \times 0.8$$

$$\Rightarrow \quad B = 2\pi \times 10^{-6} \text{ Wb/m}^2$$

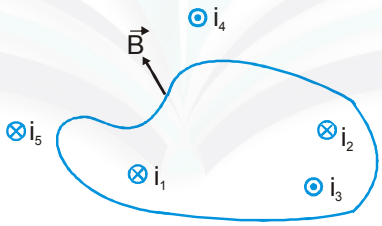
Ampere's Law :

Like Gauss's law in electrostatics, this law provides us a simple method to find magnetic fields in cases of symmetry.

Ampere's law gives another method to calculate the magnetic field due to a given current distribution.

Statement : The circulation $\oint \vec{B}.d\vec{l}$ of the resultant magnetic field (of a closed circuit or an infinite wire containing steady current) along a closed path (called amperian path) is equal to μ_0 times total current crossing the area bounded by the closed curve provided the electric field inside the loop remains constant.

Thus, $$\oint \vec{B}.d\vec{l} = \mu_0 i$$



In figure, the positive side is going into the plane of the diagram so that i_1 and i_2 are positive and i_3 is negative. Thus, the total current crossing the area is $i_1 + i_2 - i_3$. Any current outside the area is not included in writing the right - hand side of equation. The magnetic field $\vec{B}$ on the left-hand side is the resultant field due to all the currents existing anywhere.

Ampere's law may be derived from the Biot-Savart law may be derived from the Ampere's law. Thus, the two are equivalent in scientific content. However, Ampere's law is useful under contain symmetrical conditions.

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Justification of Ampere's Law

Let us consider a long straight wire carrying a current I in upward direction. Now take a circular path of radius symmetric to the wire. Let us now divide a circular path of radius r into a large number of small length vectors $\Delta\vec{s} = \Delta s\hat{\phi}$, where $\hat{\phi}$ point along the tangential direction with magnitude Δs (Figure)

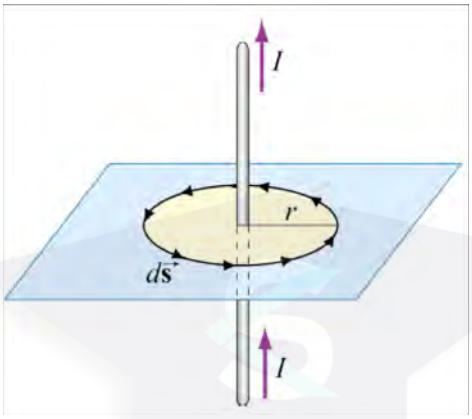


Figure : Amperian loop

In the limit $\Delta\vec{s} \to \vec{0}$, we obtain

$$\oint \vec{B}.d\vec{s} = \vec{B}\oint ds = \left(\frac{\mu_0 I}{2\pi r}\right)(2\pi r) = \mu_0 I$$

The result above is obtained by choosing a closed path, or an "Amperian loop" that follows one particular magnetic field line. Let's consider a slightly more complicated Amperian loop, as that shown in Figure.

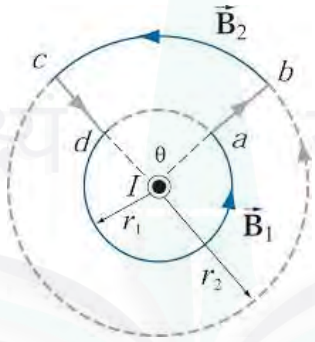


Figure : An Amperian loop involving two field lines

The line integral of the magnetic field around the contour abcda is

$$\oint_{abcda} \vec{B}.d\vec{s} = \oint_{ab} \vec{B}.d\vec{s} + \oint_{bc} \vec{B}.d\vec{s} + \oint_{cd} \vec{B}.d\vec{s} + \oint_{da} \vec{B}.d\vec{s} = 0 + B_2(r_2\theta) + 0 + B_1[r_1(2\pi - \theta)]$$

where the length of arc bc is $r_2\theta$ and $r_1(2\pi - \theta)$ for arc da. The first and the third integrals vanish since the magnetic field is perpendicular to the paths of integration. With

$B_1 = \frac{\mu_0 I}{2\pi r_1}$ and $B_2 = \frac{\mu_0 I}{2\pi r_2}$ the above expression become

$$\oint_{abcda} \vec{B}.d\vec{s} = \frac{\mu_0 I}{2\pi r^2}(r_2\theta) + \frac{\mu_0 I}{2\pi r_1}[r_1(2\pi - \theta)] = \frac{\mu_0 I}{2\pi}\theta + \frac{\mu_0 I}{2\pi}(2\pi - \theta) = \mu_0 I$$

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We see that the same result is obtained whether the closed path involves one or two magnetic field lines. As shown above example, in polar coordinates (r,φ) with current flowing in the +z axis, the magnetic field is given by $\vec{B} = (\mu_0 I / 2\pi r)\hat{\varphi}$. An arbitrary length element in the polar coordinates can be written as

$$d\vec{s} = dr\ \hat{r} + r d\phi\ \ \hat{\phi}$$

Which implies

$$\oint_{\text{closed path}} \vec{B} \cdot d\vec{s} = \oint_{\text{closed path}} \left(\frac{\mu_0 I}{2\pi r^2}\right) r d\varphi = \frac{\mu_0 I}{2\pi} \oint_{\text{closed path}} d\varphi = \frac{\mu_0 I}{2\pi}(2\pi) = \mu_0 I$$

In other words, the line integral of $\oint \vec{B} \cdot d\vec{s}$ around any closed Amperian loop is proportional to I_{enc}, the current encircled by the loop.

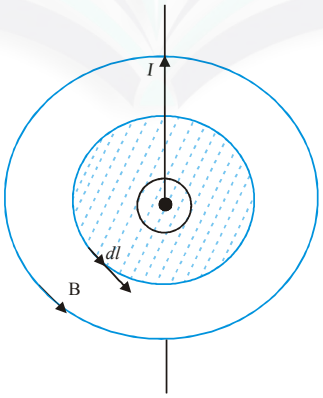
Figure : an Amperian loop of arbitary shape

The generalization to any closed loop of arbitary shape (see for example, Figure) that involves many magnetic field lines is known as Ampere's law :

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{enc}$$

Calculation of magnetic field due to long straight wire

Figure shows a long straight current i. we have to calculate the magnetic field at a point P which is at a distance r from the wire. Figure shows the situation in the plane perpendicular to the wire and passing through P. The current is perpendicular to the plane of the diagram and is coming out of it.



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Let us draw a circle passing through the point and with the axis as wire. We put an arrow to show the positive sense of the circle. The radius of the circle is r. The magnetic field due to the long, straight current at any point on the circle is along the tangent as shown in the figure. Same is the direction of the length-element dI there. By symmetry, all points of the circle are equivalent and hence the magnitude of the magnetic field should be the same at all these points. The circulation of magnetic field along the circle is

$$\oint \vec{B}.\vec{dl} = \oint Bdl = B\oint dl = B(2\pi r)$$

The current crossing the area bounded by the circle is

$$\sum I_{en} = +I$$

Thus, from Ampere's law,

$B(2\pi r) = \mu_0 I$

$\Rightarrow \quad B = \dfrac{\mu_0 I}{2\pi r}$

Magnetic field due to a current carrying thin long pipe

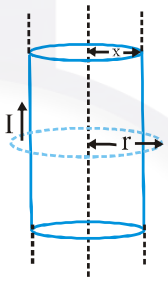
Case I : r > R

$$\oint \vec{B}.\vec{dl} = \oint B.dl = B\oint dl = B(2\pi r)$$

$$\sum I_{en} = +I$$

$\Rightarrow \quad B(2\pi r) = \mu_0 I$

$\Rightarrow \quad B = \dfrac{\mu_0 I}{2\pi r}$



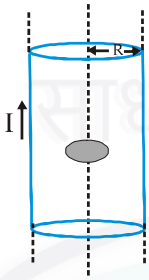
Case II : r < R

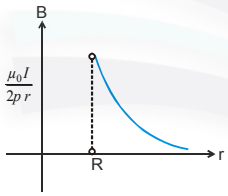
$$\oint \vec{B}.\vec{dl} = \oint Bdl = B\oint dl = B(2\pi r)$$

$$\sum I_{en} = 0$$

$\Rightarrow \quad B(2\pi r) = \mu_0 (0)$

$\Rightarrow \quad B = 0$





Magnetic field due to a current carrying rod having uniform current density

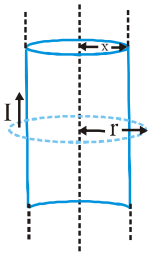
Case I : r > R

$$\oint \vec{B}.\vec{dl} = \oint B.dl = B\oint dl = B(2\pi r)$$

$$\sum I_{en} = +I$$

$\Rightarrow \quad B(2\pi r) = \mu_0 I$

$\Rightarrow \quad B = \dfrac{\mu_0 I}{2\pi r}$

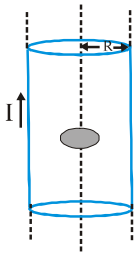


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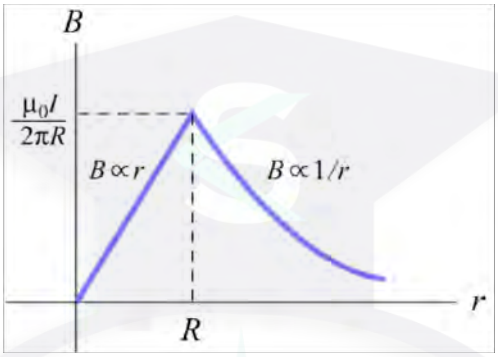
Case II : r < R

$$\oint \vec{B}.\vec{dl} = \oint Bdl = B\oint dl = B(2\pi r)$$

$$\sum I_{en} = \frac{I}{R^2}r^2$$



$$\Rightarrow \quad B(2\pi r) = \mu_0 \frac{1}{R^2}r^2 \Rightarrow B = \frac{\mu_0 I}{2\pi R^2}r$$



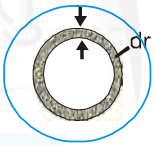
Magnetic Field Due to non uniform current density

Suppose that the current density in a wire of radius a varies with r according to $J = Kr^2$, where K is a constant and r is the distance from the axis of the wire. We have to find the magnetic field at a point distance r from the axis when (a) r < a and r > a

Choose a circular path centered on the axis of the conductor and apply Ampere's law

(a) To find the current passing through the area enclosed by the path integrate

$dI = JdA = (Kr^2)(2\pi r dr)$



$$\Rightarrow \quad I = \int dl = K\int_a^r 2\pi r^3 dr = \frac{K\pi r^4}{2}$$

Since $\oint \vec{B}.\vec{dl} = \mu_0 I$

$$\Rightarrow \quad B2\pi r = \mu_0 . \frac{\pi K r^4}{2} \Rightarrow B = \frac{\mu_0 K r^3}{4}$$

(b) If r > a, then net current through the Amperian loop is

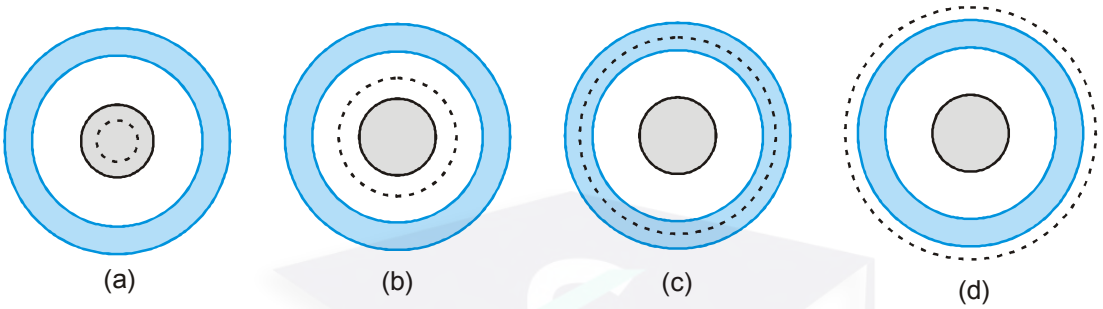
$$I = \int_a^r Kr^2 2\pi r dr = \frac{\pi K a^4}{2}$$

$$\Rightarrow \quad B = \frac{\mu_0 K a^4}{4r}$$

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Ex. Consider a coaxial cable which consists of an inner wire of radius a surrounded by an outer shell of inner and outer radii b and c respectively. The inner wire carries an electric current i_0 and the outer shell carries an equal current in same direction. Find the magnetic field at a distance x from the axis where **(a)** $x < a$, **(b)** $a < x < b$ **(c)** $b < x < c$ and **(d)** $x > c$. Assume that the current density is uniform in the inner wire and also uniform in the outer shell.

Sol.



A cross-section of the cable is shown in figure. Draw a circle of radius x with the centre at the axis of the cable. The parts a, b, c and d of the figure correspond to the four parts of the problem. By symmetry, the magnetic field at each point of a circle will have the same magnitude and will be tangential to it. The circulation of B along this circle is, therefore,

$$\oint \vec{B}.d\vec{\ell} = B2\pi x$$

in each of the four parts of the figure.

(a) The current enclosed within the circle in part b is i_0 so that

$$\frac{i_0}{\pi a^2} . \pi x^2 = \frac{i_0}{a^2} x^2 .$$

Ampere's law

$$\oint \vec{B}.d\vec{\ell} = \mu_0 i \text{ gives}$$

$$B.2\pi x = \frac{\mu_0 i_0 x^2}{a^2} \text{ or, } B = \frac{\mu_0 i_0 x}{2\pi a^2} .$$

The direction will be along the tangent to the circle.

(b) The current enclosed within the circle in part b is i_0 so that

$$B\ 2\pi x = \mu_0\ i_0 \quad \text{or,} \quad B = \frac{\mu_0 i_0}{2\pi x} .$$

(c) The area of cross-section of the outer shell is $\pi c^2 - \pi b^2$. The area of cross-section of the outer shell within the circle in part c of the figure is $\pi x^2 - \pi b^2$.

Thus, the current through this part is $\frac{i_0(x^2 - b^2)}{(c^2 - b^2)}$. This is in the same direction to the current i_0 in the inner wire.

Thus, the net current enclosed by the circle is

$$i_{net} = i_0 + \frac{i_0(x^2 - b^2)}{c^2 - b^2} = \frac{i_0(c^2 + x^2 - 2b^2)}{c^2 - b^2} .$$

From Ampere's law,

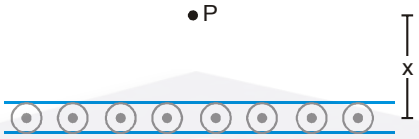
$$B\ 2\pi x = \frac{i_0(c^2 + x^2 - 2b^2)}{c^2 - b^2} \quad \text{or,} \quad B = \frac{\mu_0 i_0(c^2 + x^2 - 2b^2)}{2\pi x(c^2 - b^2)}$$

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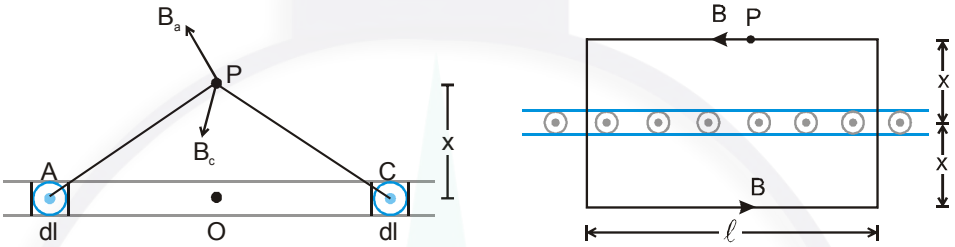
(d) The net current enclosed by the circle in part d of the figure is $2i_0$ and hence

$$B\,2\pi x = \mu_0 2i_0 \quad \text{or,} \quad B = \frac{\mu_0 i_0}{\pi x}.$$

Ex. Figure shows a cross-section of a large metal sheet carrying an electric current along its surface. The current in a strip of width dl is λdl where λ is a constant. Find the magnetic field at a point P at a distance y from the metal sheet.



Sol. Consider two strips A and C of the sheet situated symmetrically on the two sides of P (figure). The magnetic field at P due to the strip A is B_0 perpendicular to AP and that due to the strip C is B_C perpendicular to CP. The resultant of these two is parallel to the width AC of the sheet. The field due to the whole sheet will also be in this direction. Suppose this field has magnitude B.

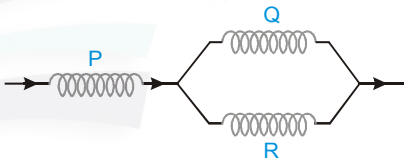


The field on the opposite side of the sheet at the same distance will also be B but in opposite direction. Applying Ampere's law to the rectangle shown in figure.

$$2B\ell = \mu_0 \lambda \ell \quad \text{or,} \quad B = \frac{1}{2}\mu_0 \lambda.$$

Note that it is independent of y.

Ex. Three identical long solenoids P, Q and R are connected to each other as shown in figure. If the magnetic field at the centre of P is 4 T, what would be the field at the centre of Q? Assume that the field due to any solenoid is confined within the volume of that solenoid only.



Sol. As the solenoids are identical, the currents in Q and R will be the same and will be half the current in P. The magnetic field within a solenoid is given by $B = \mu_0 ni$. Hence the field in Q will be equal to the field in R and will be half the field in P i.e., will be 2T.

Magnetic Field due to long Solenoid :

A solenoid is a long coil of wire tightly wound in the helical form. Figure 9.4.1 shows the magnetic field lines of a solenoid carrying a steady current *I*. We see that if the turns are closely spaced, the resulting magnetic field inside the solenoid becomes fairly uniform, provided that the length of the solenoid is much greater than its diameter. For an "ideal" solenoid, which is infinitely long with turns tightly packed, the magnetic field inside the solenoid is uniform and parallel to the axis, and vanishes outside the solenoid.

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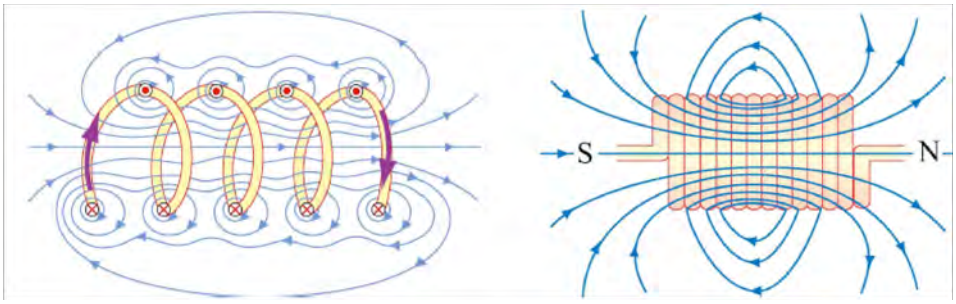


Figure : Magnetic field lines of a solenoid

We can use Ampere's law to calculate the magnetic field strength inside an ideal solenoid. The cross-sectional view of an ideal solenoid is shown in Figure. To compute $\vec{B}$, we consider a rectangular path of length *l* and width *w* and traverse the path in a counterclockwise manner. The line integral of $\vec{B}$ along this loop is

$$\oint \vec{B}.d\vec{s} = \underset{1}{\oint} \vec{B}.d\vec{s} + \underset{2}{\oint} \vec{B}.d\vec{s} + \underset{3}{\oint} \vec{B}.d\vec{s} + \underset{4}{\oint} \vec{B}.d\vec{s}$$
$$= 0 + 0 + B\ell + 0$$

In the above, the contributions along sides 2 and 4 are zero because $\vec{B}$ is perpendicular to $d\vec{s}$. In addition, $\vec{B} = \vec{0}$ along side 1 because the magnetic field is non-zero only inside the solenoid. On the other hand, the total current enclosed by the Amperian loop is I_{enc} = n/I, where *n* is the total number of turns per unit length. Applying Ampere's law yields

$$\oint \vec{B}.d\vec{s} = B\ell = \mu_0 n\ell I \qquad B = \mu_0 nI$$

Magnetic Field due to Toroid

Consider a toroid that consists of *N* turns, as shown in Figure. Find the magnetic field everywhere.

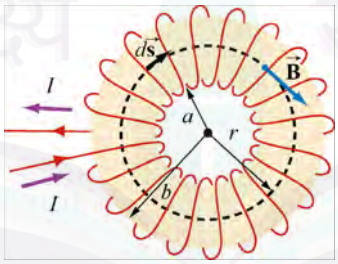


Figure : A toroid with *N* turns

One can think of a toroid as a solenoid wrapped around with its ends connected. Thus, the magnetic field is completely confined inside the toroid and the field points in the azimuthal direction (clockwise due to the way the current flows, as shown in Figure.)

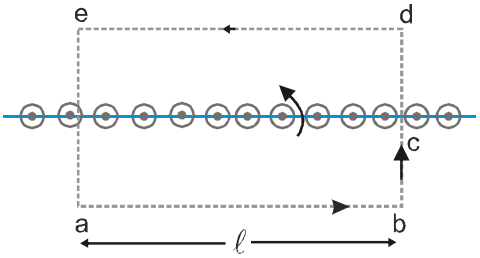
Applying Ampere's law, we obtain

$$\oint \vec{B}.d\vec{s} = \oint Bds = B\oint ds = B(2\pi r) = \mu_0 nI \quad \text{or} \quad B = \frac{\mu_0 NI}{2\pi r}$$

where *r* is the distance measured from the center of the toroid. Unlike the magnetic field of a solenoid, the magnetic field inside the toroid is non-uniform and decreases as $1/r$.

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Magnetic Field thin sheet of infinite dimension carrying a current of uniform linear current density i



$$\oint \vec{B}.\vec{dl} = \int_a^b \vec{B}.\vec{dl} + \int_b^c \vec{B}.\vec{dl} + \int_c^d \vec{B}.\vec{dl} + \int_d^e \vec{B}.\vec{dl} + \int_e^f \vec{B}.\vec{dl} + \int_f^g \vec{B}.\vec{dl}$$

$$= \int_a^b B.\cos\theta.dl + 0 + 0 + \int_d^e Bdl + 0 + 0 = \int_a^b Bdl + B\int_d^e dl = Bl + Bl = 2Bl$$

$$\sum I_{en} = il \Rightarrow \oint \vec{B}.\vec{dl} = \mu_0 \sum I_{en}$$

$$\Rightarrow 2BI = \mu_0 il \Rightarrow B = \frac{\mu_0 I}{2}$$

Magnetic Field of a Moving Point Charge :

Suppose we have an infinitesimal current element in the form of a cylinder of cross-sectional area A and length ds consisting of n charge carries per unit volume, all moving at a common velocity $\vec{v}$ along the axis of the cylinder. Let *l* be the current in the element, which we define as the amount of change passing through any cross-section of the cylinder per unit time. We see that the current I can be written as

$$nAq|\vec{v}| = I$$

The total number of charge carries in the current element is simply dN = nAds, so that the magnetic field $d\vec{B}$ due to the dN charge carries is given by

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{(nAq|\vec{v}|)d\vec{s}\times\hat{r}}{r^2} = \frac{\mu_0}{4\pi}\frac{(nAds)q\vec{v}\times\hat{r}}{r^2} = \frac{\mu_0}{4\pi}\frac{(dN)q\vec{v}\times\hat{r}}{r^2}$$

where r is the distance between the charge and the field point P as which the field is being measured, the unit vector $\hat{r} = \vec{r}/r$ points from the source of the field (the charge) to P. To differential length vector $d\vec{s}$ is defined to be parallel to $\vec{v}$. In case of a single charge, dN = 1, the above equation becomes

$$\vec{B} = \frac{\mu_0}{4\pi}\frac{q\vec{v}\times\hat{r}}{r^2}$$

Magnetic Force on Moving Charge

When a charge q moves with velocity $\vec{v}$, in a magnetic field $\vec{B}$, then the magnetic force experienced by moving charge is given by following formula :

$\vec{F} = q(\vec{v}\times\vec{B})$ Put q with sign.

$\vec{v}$: Instantaneous velocity

$\vec{B}$: Magnetic f

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(i) $\vec{F} \perp \vec{v}$ and also $\vec{F} \perp \vec{B}$

(ii) $\because \vec{F} \perp \vec{v}$ $\therefore$ power due to magnetic force on a charged particle is zero. (use the formula of power $P = \vec{F} . \vec{v}$ for its proof).

(iii) Since the $\vec{F} \perp \vec{B}$ so work done by magnetic force is zero in every part of the motion. The magnetic force cannot increase or decrease the speed (or kinetic energy) of a charged particle. Its can only change the direction of velocity.

(iv) On a stationary charged particle, magnetic force is zero.

(v) If $\vec{V} \| \vec{B}$, then also magnetic force on charged particle is zero. It moves along a straight line if only magnetic field is acting.

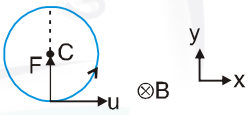
Ex. A charged particle of mass 5 mg and charge q = +2μC has velocity $\vec{v} = 2\hat{i} - 3\hat{j} + 4\hat{k}$. Find out the magnetic force on the charged particle and its acceleration at this instant due to magnetic field $\vec{B} = 3\hat{j} - 2\hat{k}$. $\vec{v}$ and $\vec{B}$ are in m/s and Wb/m^2 respectively.

Sol. $\vec{F} = q\vec{v} \times \vec{B} = 2 \times 10^{-6} (2\hat{i} - 3\hat{j} \times 4\hat{k}) \times (3\hat{j} - 2\hat{k}) = 2 \times 10^{-6} [-6\hat{i} + 4\hat{j} + 6\hat{k}]$ N

By Newton's Law $\vec{a} = \frac{\vec{F}}{m} = \frac{2 \times 10^{-6}}{5 \times 10^{-6}} (-6\hat{i} + 4\hat{j} + 6\hat{k}) = 0.8 (-3\hat{i} + 2\hat{j} + 3\hat{k})$ m/s^2

Motion of charged particles under the effect of magnetic force

- Particle released if v = 0 then $f_m = 0$
  $\therefore$ particle will remain at rest
- $\vec{V} \| \vec{B}$ here $\theta = 0$ or $\theta = 180^\circ$
  $\therefore F_m = 0$ $\therefore \vec{a} = 0$ $\therefore \vec{V}$ = const.
  $\therefore$ particle will move in a straight line with constant velocity
- Initial velocity $\vec{u} \perp \vec{B}$ and $\vec{B}$ = uniform



In this case $\because$ B is in z direction so the magnetic force in z-direction will be zero $\left(\because \overrightarrow{F_m} \perp \vec{B}\right)$.

Now there is no initial velocity in z-direction.

$\therefore$ particle will always move in xy plane.

$\therefore$ velocity vector is always $\perp \vec{B}$ $\therefore$ F_m = quB = constant

Now $quB = \frac{mu^2}{R} \Rightarrow R = \frac{mu}{qB}$ = constant.

The particle moves in a curved path whose radius of curvature is same every where, such curve in a plane is only a circle.

$\therefore$ path of the particle is circular.

$$R = \frac{mu}{qB} = \frac{p}{qB} = \frac{\sqrt{2mk}}{qB}$$

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Here p = linear momentum; k = kinetic energy

Now $v = \omega R \Rightarrow \omega = \frac{qB}{m} = \frac{2\pi}{T} = 2\pi f$

Time period $T = 2\pi m/qB$

frequency $f = qB/2\pi m$

Note : ω, f, T are independent of velocity.

Ex. A proton (p), α-particle and deuteron (D) are moving in circular paths with same kinetic energies in the same magnetic field. Find the ratio of their radii and time periods. (Neglect interaction between particles).

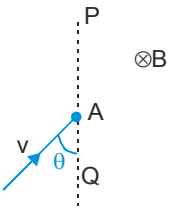
Sol. $R = \frac{\sqrt{2mK}}{qB}$

$\therefore \quad R_p : R_\alpha : R_D = \frac{\sqrt{2mK}}{qB} : \frac{\sqrt{2.4mK}}{2qB} : \frac{\sqrt{2.2mK}}{qB} = 1 : 1 : \sqrt{2}$

$T = 2\pi m/qB$

$\therefore \quad T_p : T_\alpha : T_D = \frac{2\pi m}{qB} : \frac{2\pi 4m}{2qB} : \frac{2\pi 2m}{qB} = 1 : 2 : 2$ **Ans.**

Ex. A positive charge particle of charge q, mass m enters into a uniform magnetic field with velocity v as shown in the figure. There is no magnetic field to the left of PQ.



Find

(i) Time spent,

(ii) Distance travelled in the magnetic field

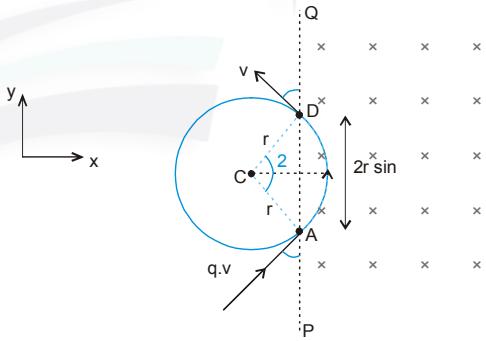
(iii) Impulse of magnetic force.

Sol. The particle will move in the field as shown

Angle subtended by the arc at the centre = 2θ

(i) Time spent by the charge in magnetic field

$\omega t = \theta \Rightarrow \frac{qB}{m} t = \theta \Rightarrow t = \frac{m\theta}{qB}$



(ii) Distance travelled by the charge in magnetic field :

$= r(2\theta) = \frac{mv}{qB} \cdot 2\theta$

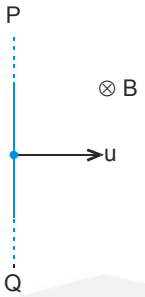
(iii) Impulse = change in momentum of the charge

$= (-mv \sin\theta \hat{i} + mv \cos\theta \hat{j}) - (mv \sin\theta \hat{i} + mv \cos\theta \hat{j})$

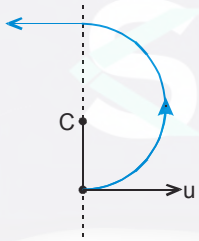
$= -2mv \sin\theta \hat{i}$

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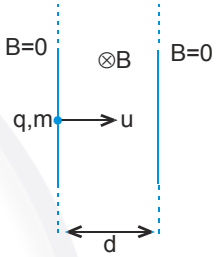
Ex. In the figure shown the magnetic field on the left on 'PQ' is zero and on the right of 'PQ' it is uniform. Find the time spent in the magnetic field.



Sol. The path will be semicircular time spent = $T/2 = \pi m/qB$

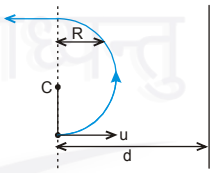


Ex. A uniform magnetic field of strength 'B' exists in a region of width 'd'. A particle of charge 'q' and mass 'm' is shot perpendicularly (as shown in the figure) into the magnetic field. Find the time spend by the particle in the magnetic field if



(i) $d > \frac{mu}{qB}$ **(ii)** $d < \frac{mu}{qB}$

Sol. **(i)** $d > \frac{mu}{qB}$ means $d > R$

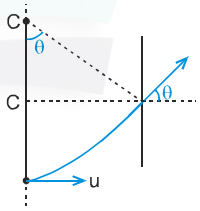


$\therefore \quad t = \frac{T}{2} = \frac{\pi m}{qB}$

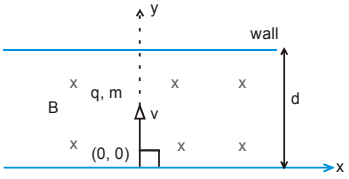
(ii) $\sin\theta = \frac{d}{R}$

$\theta = \sin^{-1}\left(\frac{d}{R}\right)$

$\omega t = \theta \Rightarrow t = \frac{m}{qB}\sin^{-1}\left(\frac{d}{R}\right)$



Ex. What should be the speed of charged particle so that it can't collide with the upper wall? Also find the coordinate of the point where the particle strikes the lower plate in the limiting case of velocity.

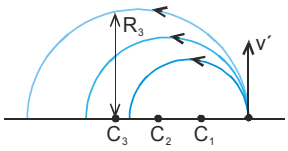


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Sol. **(i)** The path of the particle will be circular larger the velocity, larger will be the radius.

For particle not to s

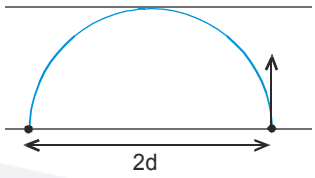
strike R < d



$\therefore \quad \frac{mv}{qB} < d \Rightarrow v < \frac{qBd}{m}$.

(ii) for limiting case $v = \frac{qBd}{m}$

R = d



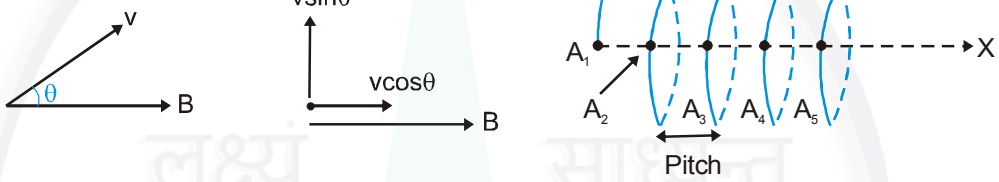
$\therefore$ coordinate = (–2d, 0, 0)

Helical path

If the velocity of the charge is not perpendicular to the magnetic field, we can break the velocity in two components – $v_{\parallel}$, parallel to the field and $v_{\perp}$, perpendicular to the field. The components $v_{\parallel}$ remains unchanged as the force $q\vec{v}\times\vec{B}$ is perpendicular to it. In the plane perpendicular to the field, the particle traces a circle of radius $r = \frac{mv_{\perp}}{qB}$ as given by equation. The resultant path is helix.

Complete analysis

Let a particle have initial velocity in the plane of the paper and a constant and uniform magnetic field also in the plane of the paper.



The particle starts from point A_1.

It completes its one revolution at A_2 and 2nd revolution at A_3 and so on. X-axis is the tangent to the helix points A_1, A_2, A_3,.....all are on the x-axis.

distance $A_1A_2 = A_3A_4 =$ ..... = v cosθ. T = pitch

where T = Time period

Let the initial position of the particle be (0,0,0) and v sin θ in +y direction. Then

in x : $F_x = 0$, $a_x = 0$, v_x = constant = v cosθ, x = (v cosθ)t

In y-z plane

From figure it is clear that

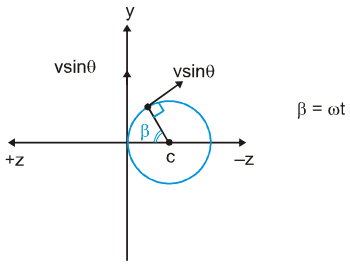
$y = R \sin\beta$, $v_y = v \sin\theta \cos\beta$

$z = -(R - R\cos\beta)$

$v_z = v \sin\theta \sin\beta$

acceleration towards centre = $(v\sin\theta)^2/R = \omega^2 R$

$\therefore \quad a_y = -\omega^2 R \sin\beta$, $a_z = -\omega^2 R \cos\beta$



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At any time : the position vector of the particle

(or its displacement w.r.t. initial position)

$\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$, x,y,z already found

velocity $\vec{v} = v_x\hat{i} + v_y\hat{j} + v_z\hat{k}$, v_x, v_y, v_z already found

$\vec{a} = a_x\hat{i} + a_y\hat{j} + a_z\hat{k}$, a_x, a_y,a_z already found

Radius $q(v\sin\theta)\,B = \dfrac{m(v\sin\theta)^2}{R} \Rightarrow R = \dfrac{mv\sin\theta}{qB} \Rightarrow \omega = \dfrac{v\sin\theta}{R} = \dfrac{qB}{m} = \dfrac{2\pi}{T} = 2\pi f.$

Ex. A charged particle P leaves the origin with speed $v = v_e$, at some inclination with the x-axis. There is uniform magnetic field B along the x-axis. P strikes a fixed target T on the x-axis for a minimum value of $B = B_0$. Find the condition so that P will also strike if you change magnetic field and speed.

Sol. Let d = distance of the tangent T from the point of projection. P will strike T if d an integral multiple of the pitch.

Pitch

$$\left(2\pi\frac{m}{qB_0}\right)v_0\cos\theta = N\left(2\pi\frac{m}{qB}\right)v\cos\theta$$

Here N is a natural number.

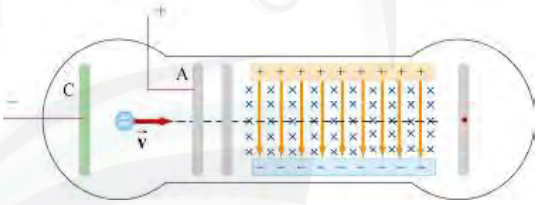
Lorentz Force

In the presence of both electric field $\vec{E}$ and magnetic field $\vec{B}$, the total force on a charged particle is

$$\vec{F} = q(\vec{E} + \vec{v} + \vec{B})$$

This is known as the Lorentz force.

Velocity Selector



By combining the two fields, particles which move with a certain velocity can be selected. This was the principle used by J.J. Thomson to measure the charge-to-mass ratio of the electrons. In figure the schematic diagram of Thomson's apparatus is depicted.

The electrons with charge q = –e and mass m are emitted from the cathode C and then accelerated toward slit A. Let the potential difference between A and C be $V_A - V_C = \Delta V$. The change in potential energy is equal to external work done in accelerating the electrons : $\Delta U - W_{ext} = q\Delta V = -e\Delta V$. By energy conservation, the kinetic energy gained is $\Delta K = -\Delta U = mv^2/2$. Thus, the speed of the electrons is given by

$$v = \sqrt{\frac{2e\Delta V}{m}}$$

If the electrons further pass through a region where there exists a downward uniform electric field, the electrons, being negatively charged, will be deflected upward. However, if in addition to the electric field, a magnetic field directed into the page is also applied, then the electrons will experience an additional downward magnetic force $-e\vec{v}\times\vec{B}$. When the two forces exactly cancel, the electrons will move in a straight path. From Eq., we see that

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when the condition for the cancellation of the two forces is given by eE = evB. which implies

$$v = \frac{E}{B}$$

In other words, only those particles with speed v = E/B will be able to move in a straight line. Combining the two equations, we obtain $\frac{e}{m} = \frac{E^2}{2(\Delta V)B^2}$

By measuring, E, ΔV and B, the charge-to-mass ratio can be readily determined. The most precise measurement to date is e/m = 1.758820174(71) × 10^{11} C/kg.

Mass Spectrometer

Various methods can be used to measure the mass of an atom. One possibility is through the use of a mass spectrometer. The basic feature of a Bainbridge mass spectrometer is illustrated in Figure. A particle carrying a charge +q is first sent through a velocity selector.

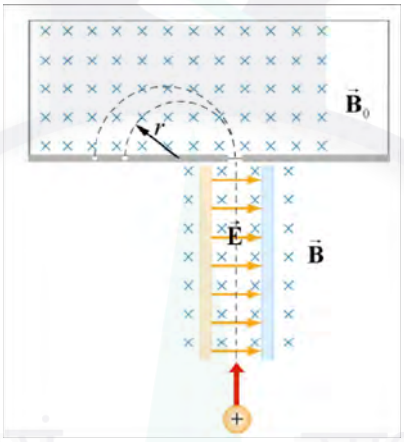


Figure : A Bainbridge mass spectrometer

The applied electric and magnetic field satisfy the relation E = vB so that the trajectory of the particle is a straight line. Upon entering a region where a second magnetic field $\vec{B}_0$ pointing into the page has been applied, the particle will move in a circular path with radius r and eventually strike the photographic plate. Using Eq., we have

$$r = \frac{mV}{qB_0}$$

Since v = E/B, the mass of the particle can be written as $m = \frac{qB_0 r}{v} = \frac{qB_0 Br}{E}$

Hall's Effect

In 1879, Edwin H.Hall, then a 24 -year-old graduate student at the Johns Hopkins University, showed that they can drift electrons in copper wire in presence of magnetic field. This Hall effect allows us to find

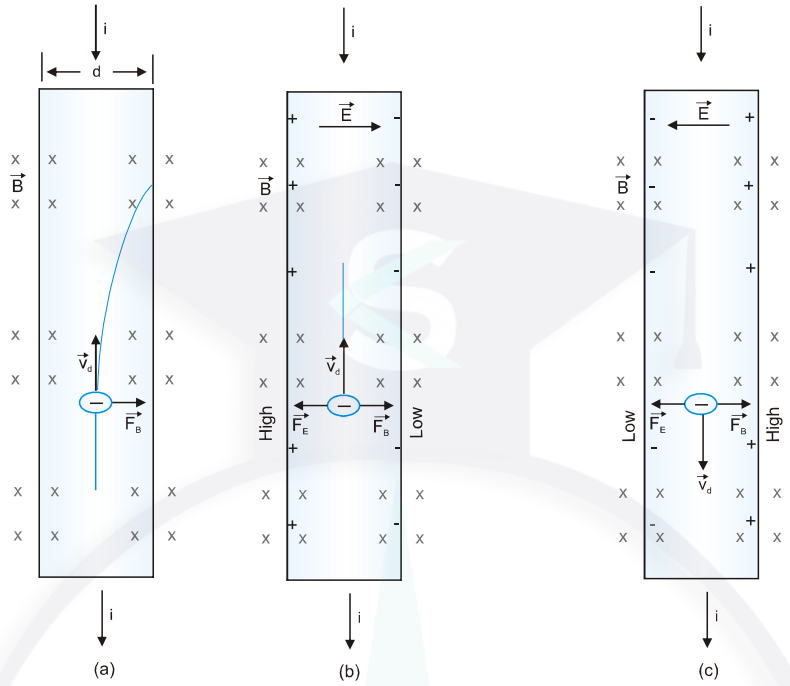
(a) If charge carries in a conductor are positively or negatively charged.

(b) The number of charge carries per unit volume of the conductor.

Consider a strip of current carrying wire kept in external magnetic field. Let the wire has width d, Cross-sectional area A, and charge carries per unit volume as n.

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Figure **(a)** shows a copper strip of width d, carrying a current i whose conventional direction is from the top of the figure to the bottom. The charge carries are electrons and, as we know, they drift (with drift speed vd) in the opposite direction, from bottom to top. At the instant shown in figure, an external magnetic field B, pointing into the plane of the figure, has just been turned on. We see that a magnetic force will act on each drifting electron, pushing it towards the right edge of the strip.



As time goes on, electrons move to the right, mostly piling up on the right edge of the strip, leaving uncompensated positive charges in fixed position at the left edge. The separation of positive charges on the left edge and negative charges on the right edge produces an electric field E within the strip, pointing from left to right in Fig. b. This field exerts an electric force FE on each electron, tending to push it to the left. Thus, this electron force on the electrons, which opposes the magnetic force on them, begins to build up.

Equilibrium quickly develops in which the electric force on each electron has increased enough to match the magnetic force. When this happens, as Fig. b shows, the force due to B and the force due to E are in balance. The drifting electrons then move along the strip toward the top of the page at velocity vd with no further collection of electrons on the right edge of the strip and thus no further increase in the electric field E.

$$eE = ev_dB \qquad \text{..... (2)}$$

$$v_d = \frac{J}{ne} = \frac{i}{neA} \qquad \text{..... (2)}$$

A Hall potential difference V is associated with the electric field across strip width d.

$$V = Ed \qquad \text{..... (3)}$$

From **(2)**, (2) and **(3)**

$$\frac{E}{B} = \frac{V}{Bd} = \frac{i}{neA}$$

$$\therefore \qquad n = \frac{idB}{eAV} \;\&\; v_d = \frac{i}{neV} = \frac{V}{Bd}$$

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By connecting a voltmeter across the width, we can measure the potential difference between the two edges of the strip. Moreover, the voltmeter can tell us which edge is at higher potential. For the situation of Fig. B, we would find that the left edge is at higher potential, which is consistent with our assumption that the charge carries are negatively charged.

It is also possible to use the Hall effect to measure directly the drift speed vd of the charge carries, which you may recall is of the order of centimeters per hour. In this clever experiment, the metal strip is moved mechanically through the magnetic field in a direction opposite that of the drift velocity of the charge carries. The speed of the moving strip is then adjusted until the Hall potential difference vanishes.

As this condition, with no hall effect, the velocity of the charge carries with respect to the laboratory frame must be zero, so the velocity of the strip must be equal in magnitude but opposite the direction of the velocity of the negative charge carries.

For a moment, let us make the opposite assumption, that the charge carries in current i are positively charged (Fig. c). Convince yourself that as these charge carries move from top to bottom in the strip, they are pushed to the right edge by F_B and thus that the right edge is at higher potential. Because that last statement is contradicted by our voltmeter reading, the charge carries must be negatively charged.

Ex. A non-relativistic proton beam passes without deviation through the region of space where there are uniform transverse mutually perpendicular electric and magnetic fields with E = –120 kV/m and B = 50mT. Then the beam strikes a grounded target. Find the force with which the beam acts on the target of the beam current is equal to I =0.80 mA.

Sol. $$F = \frac{dp}{dt} = v\frac{dm}{dt} = v\frac{dm}{dq}\frac{dq}{dt} = \frac{E}{B}\frac{m}{q}I = 20\ \mu N$$

Ex. A particle of mass m and charge q is released from the origin in a region occupied by electric field E and magnetic field B,

$$B = B_0\hat{j}, E = E_0\hat{i}$$

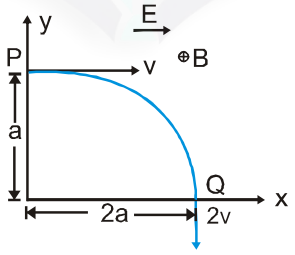
Find the speed of the particle.

Sol. Since the magnetic field does not perform any work, therefore, whatever has been gain in kinetic energy it is only because of the work done by electric field. Applying work-energy theorem.

$$W_E = \Delta K$$

$$qE_0 = \frac{1}{2}mv^2 - 0 \qquad \text{or} \qquad v = \sqrt{\frac{2qE_0}{m}}$$

Ex. A particle of charge +q and mass m moving under the influence of a uniform electric field $E\hat{i}$ and a uniform magnetic field $B\hat{k}$ follows a trajectory from P to Q as shown in figure. The velocities at P and Q are $v\hat{i}$ and $-2v\hat{i}$. Find **(a)** E **(b)** rate of work done by the electric field at P. **(C)** rate of work done by each the fields at Q.



Sol. Increase in Kinetic energy of particle

$$= \frac{1}{2}m(2v)^2 - \frac{1}{2}mv^2 = \frac{3}{2}mv^2$$

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Work done by the uniform electric field, E, in going from P to Q = (qE) × 2a = 2qEa

Hence, $2qEa = \frac{3}{2}mv^2$ or $E = \frac{3mv^2}{4qa}$

Rate of work done by the electric field at

P_{at} P = F. v = qE . v

$= qE\hat{i}.v\hat{i} = qEv \quad = q.\frac{3mv^2}{4qa}.v = \frac{3}{4}\frac{mv^2}{a}$

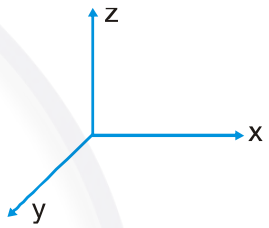
Q is

$P_{at}.Q = qE\hat{i}.(-2v\hat{j}) = 0$

At Q, rate of work done by both the fields is zero.

Ex. A particle of mass 1×10^{-26} kg and charge 1.6×10^{-19} C travelling with a velocity 1.28×10^6 ms^{-1} in the +x direction enters a region in which a uniform electric field E and uniform magnetic field of induction B are present such that $E_x = E_y = 0$, $E_x = -102.4$ kVm^{-1} and $B_x = B_z = 0$. $B_y = 8 \times 10^{-2}$ Wbm^{-2}. The particle enters this region at the origin at time t = 0. Determine the location (x, y and z coordinates) of the particle at $t = 5 \times 10^{-4}$ s. If the electric field is switched off at this instant (with the magnetic field still present), what will be the position of the particle at $t = 7.45 \times 10^{-6}$ s ?

Sol. Let $\hat{i}$, $\hat{j}$ and $\hat{k}$ be unit vector along the positive directions of x, y and z axes. Q = charge on the particle = 1.6×10^{-19} C $\vec{v}$ = velocity of the charged particle = (1.28×10^6) ms^{-1} $\hat{i}$



$\vec{E}$ = electric field intensity :

$= (-102.4 \times 10^3\ Vm^{-1})\ \hat{k}$

$\vec{B}$ = magnetic induction of the magnetic field

$= (8 \times 10^{-2}\ Wbm^{-2})\ \hat{j}$

$\therefore$ $\vec{F}_e$ = electric force on the charge $= q\vec{E} = [1.6 \times 10^{-19}\ (-102.4 \times 10^3)\ Nj\ \hat{k}$

$= 163.84 \times 10^{-16}\ N(-\hat{k})$

$\vec{F}_m$ = magnetic force on the charge = $q\vec{v} \times \vec{B}$

$= [1.6 \times 10^{-19}\ (1.28 \times 10^6)\ (8 \times 10^{-2})\ N]\ (\hat{i} \times \hat{j}) = (163.84 \times 10^{-16}\ N)(\hat{k})$

The two forces $\vec{F}_e$ and $\vec{F}_m$ are along z-axis and equal, opposite and collinear.

The net force on the charge is zero and hence the particle does not get deflected and continues to travel along x–axis.

(a) At time $t = 5 \times 10^{-6}$ s

$x = (5 \times 10^{-6})\ (1.28 \times 10^6) = 6.4$ m

$\therefore$ Coordinates of the particle = (6.4 m, 0, 0)

(b) When the electric field is switched off, the particle is in the uniform magnetic field perpendicular to its velocity only and has a uniform circular motion in the x–z plane (i.e. the plane of velocity and magnetic force), anticlockwise as seen along +y axis.

Now, $\frac{mv^2}{r} = qvB$ where r is the radius of the circle.

$\therefore$ $r = \frac{mv}{qB} = \frac{(1\times10^{-26})(1.28\times10^6)}{(1.6\times10^{-19})(8\times10^{-2})}$

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The length of the arc traced by the particle in $[(7.45 - 5) \times 10^{-6}$ s]

$= (v)(t) = (1.28 \times 10^{6})(2.45 \times 10^{-6})$

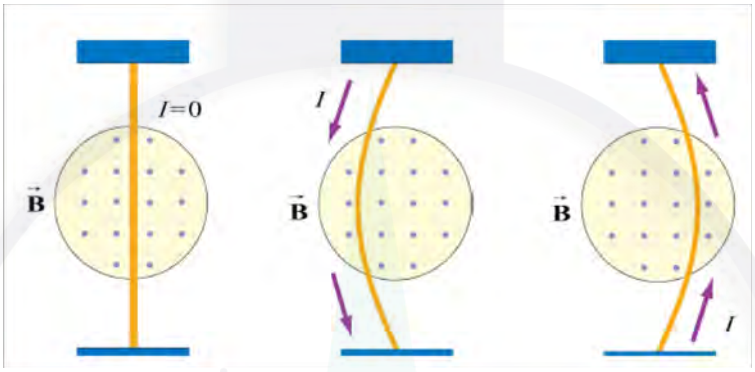
$= 3.136 \text{ m} = \pi m = \frac{1}{2}$ circumference

$\therefore$ The particle has the coordinates (6.4, 0, 2m) as (x, y, z)

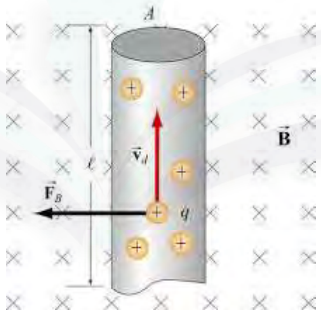
Magnetic Force on a Current-Carrying Wire :

We have just seen that a charged particle moving through a magnetic field experiences a magnetic force $\vec{F}_B$. Since electric current consists of a collection of charged particles in motion, when placed in a magnetic field, a current-carrying wire will also experience a magnetic force.

Consider a long straight wire suspended in the region between the two magnetic poles. The magnetic field points out the page and is represented with dots (.). It can be readily demonstrated that when a downward current passes through, the wire is deflected to the left. However, when the current is upward, the deflection is rightward, as shown in figure.



To calculate the force exerted on the wire, consider a segment of wire of length ℓ and cross-sectional area A, as shown in Figure. The magnetic field points into the page, and is represented with crosses (X).



The charges move at an average drift velocity $\vec{v}_d$. Since the total amount of charge in this segment is $Q_{tot} = q(nA\ell)$, where n is the number of charges per unit volume, the total magnetic force on the segment is

$$\vec{F}_B = Q_{tot}\vec{v}_d \times \vec{B} = qnA\ell\ (\vec{v}_d \times \vec{B}) = I(\vec{\ell} \times \vec{B})$$

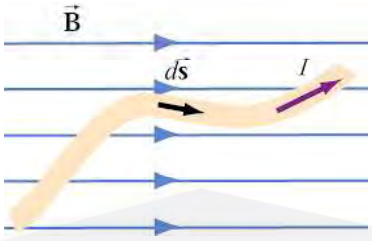
where I - nqv_dA and $\vec{\ell}$ is a length vector with a magnitude ℓ and directed along the direction of the electric current.

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Special Case - 1 :

Wire of arbitary shape placed in uniform magnetic field

For a wire of arbitary shape, the magnetic force can be obtained by summing over the forces acting on the small segments that make up the wire. Let the differential segment be denoted as $d\vec{s}$ (Figure)



The magnetic force acting on the segment is : $d\vec{F}_B = Id\vec{s} \times B$

Thus, the total force is : $\vec{F}_B = I\int_a^b d\vec{s} \times B$

where a and b represent the endpoints of the wire.

As an example, consider a curved wire carrying a current I in a uniform magnetic field $\vec{B}$, as shown in Figure.

Using the magnetic force on the wire is given by

$$\vec{F}_B = \left(I\int_a^b d\vec{s} \right) \times \vec{B} = I\vec{\ell} \times \vec{B}$$

where $\vec{\ell}$ is the length vector directed from a to b. However, if the wire forms a closed loop of arbitary shape (Figure), then the force on the loop becomes

$$\vec{F}_B = I\left(\oint d\vec{s}\right) \times \vec{B}$$

Special Case - 2 :

Magnetic force on a closed loop in uniform magnetic field.

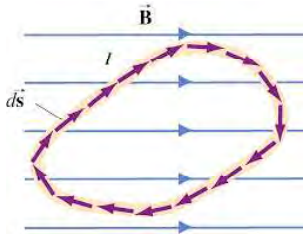
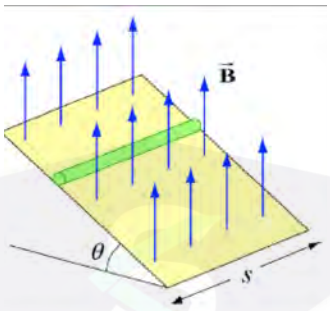


Figure : A closed loop carrying a current I in a uniform magnetic field

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Since the drift of differential length elements $d\vec{s}$ from a closed polygon, and their vector sum is zero, i.e. $\oint d\vec{s} = 0$. The net magnetic force on a closed loop is $\vec{F}_B = \vec{0}$.

Ex. A conducting bar of length is placed on a frictionless inclined plane which is titled at an angle q from the horizontal, as shown in figure.

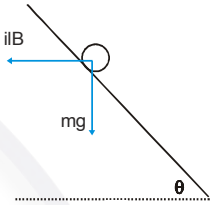


A uniform magnetic field is applied in the vertical direction. To prevent the bar from sliding down, a voltage source is connected to the ends of the bar with current flowing through. Determine the magnitude and the direction of the current such that the bar will remain stationary.

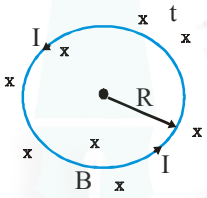
Sol. For equilibrium

$I\ell B\cos\theta = mg\sin\theta$

$\Rightarrow \quad I = \dfrac{mg\sin\theta}{\ell B\cos\theta}$



Ex. A current (I) carrying circular wire of radius R is placed in a magnetic field B perpendicular to its plane. Find the tension T along the circumference of the wire.

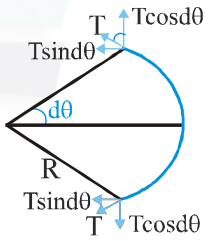


Sol. For small element portion

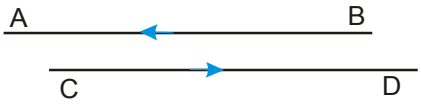
$2T = d\theta\, IB$

$2Td\theta = 2RIBd\theta$

$T = IRB$



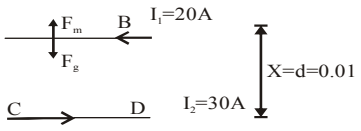
Ex. A long horizontal wire AB, which is free to move in a vertical plane and carries a steady current of 20 A, is in equilibrium at a height of 0.01 m over another parallel long wire CD which is fixed in a horizontal plane and carries a steady current of 30 A, as shown in figure. Show that when AB is slightly depressed, it executes simple harmonic motion. Find the period of oscillation.



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Sol. Let m be the mass per unit length of wire AB. At a height x about the wire CD, magnetic force per unit length on wire AB will be given by

$$F_m = \frac{\mu_0 i_1 i_2}{2\pi x} \text{ (upwards)} \qquad \text{..... (i)}$$



Wt. per unit of wire AB is

$F_g = mg$ (downwards)

At x = d, wire is in equilibrium

i.e., $F_m = F_g \Rightarrow \frac{\mu_0}{2\pi}\frac{i_1 i_2}{d} = mg$

$\Rightarrow \quad \frac{\mu_0 i_1 i_2}{2\pi d^2} = \frac{mg}{d}$ ..... (ii)

When AB is depressed, x decreases therefore, F_m will increase, while F_g remains the same. Let AB is displaced by dx downwards. Differentiating equation (i) w.r.t. x, we get

$$dF_m = \frac{\mu_0}{2\pi}\frac{i_1 i_2}{x^2}.dx \qquad \text{..... (iii)}$$

i.e., restoring force, F = d $\qquad$ $F_m \propto -dx$

Hence the motion of wire is simple harmonic. From equation (ii) and (iii), we can write

$$dF_m = -\left(\frac{mg}{d}\right).dx \qquad (x = d)$$

$\therefore$ Acceleration of wire, $a = -\left(\frac{g}{d}\right).dx$

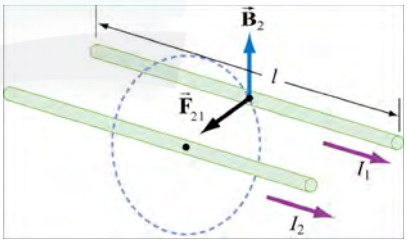
Hence period of oscillations

$$T = 2\pi\sqrt{\frac{dx}{a}} = 2\pi\sqrt{\frac{\text{disp.}}{\text{acc.}}}$$

$\Rightarrow \quad T = 2\pi\sqrt{d/g} = 2\pi\sqrt{\frac{0.01}{9.8}} \Rightarrow T = 0.2$ s

Force Between Two Parallel Wires :

We have already seen that a current-carrying wire produces a magnetic field. In addition, when placed in a magnetic field, a wire carrying a current will experience a net force. Thus, we expect two current-carrying wires to exert forces on each other. Consider two parallel wires separated by a distance α and carrying currents I_1^2 and I_2^2 in the $+\xi$-direction, as shown in Figure.



The magnetic force $\vec{F}_{12}$, exerted by wire 2 on wire 1 may be computed as follows. Using the result from the previous example, the magnetic field lines due to I_2^2 going in the $+\xi$ direction are circles concentric with wire 2, with the field $\vec{B}_2$ pointing in the tangential direction. Thus, at an arbitrary point Π on wire 1, we have $\vec{B}_2 = -(\mu_0 I_2 / 2\pi a)\hat{j}$ which points in the direction perpendicular to wire 1, as depicted in Figure. Therefore,

$$\vec{F}_{12} = I_1 \vec{\ell} \times \vec{B}_2 = (\ell\hat{i}) \times \left(-\frac{\mu_0 I_2}{2\pi a}\hat{j}\right) = -\frac{\mu_0 I_1 I_2 \ell}{2\pi a}\hat{k}$$

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Clearly $\vec{F}_{12}$ points toward wire 2. The conclusion we can draw from this simple calculation is that two parallel wires carrying currents in the same direction will attract each other. On the other hand, if the currents flow in opposite directions, the resultant force will be repulsive.

Definition of Ampere

Consider two parallel wires separated by 1 m and carrying a current of 1A each. Then $i_1 = i_2 = 1A$ and $d = 1m$, so that from equation

$$\frac{dF}{dl} = 2\times10^{-7}\ \text{N/m}$$

This is used to formally define the unit 'ampere' of electric current. If two parallel, long wires, kept 1 m apart in vacuum, carry equal currents in the same direction and there is a force of attraction of 2×10^{-7} newton per metre of each wire, the current in each wire is said to be 1 ampere.

Magnetic Moment

Magnetic field (at large distances) due to current in circular current loop is very similar in behaviour to the electric field of an electric dipole. We know that the magnetic field on the axis of a circular loop, of a radius R, carrying a steady current I.

$$B = \frac{\mu_0 I(2\pi a^2)}{4\pi(a^2+x^2)^{3/2}}$$

its direction is along the axis and given by the right-hand thumb rule. Here, x is the distance along the axis from the centre of the loop.

For $x >> R$, we may drop the R^2 term in the denominator. Thus

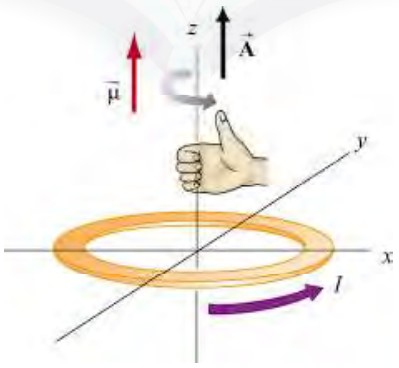
$$B = 2\left(\frac{\mu_0}{4\pi}\right)\left(\frac{IA}{x^2}\right)$$

Where $A = \pi R^2$ = area of the loop

The expression is very similar to an expression obtained earlier for the electric field of a dipole. The similarly may be seen if we can define the magnetic dipole moment $\vec{\mu}$ as

$$\vec{\mu} = I\vec{A}$$

The direction of $\vec{\mu}$ is the same as the area vector $\vec{A}$ (perpendicular to the plane of the loop) and is determined by the right-hand rule (Figure). The SI unit for the μαγνετιχ διπολε μομεντ ισ αμπερε–μετερ^2 (A.μ^2).

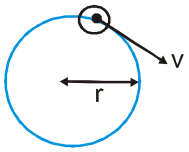


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Ex. Find the magnetic moment of an electron orbiting in a circular orbit of radius r with a speed v.

Sol. Magnetic moment $\mu = iA$

we can write $i = \frac{e}{T} = \frac{e}{\frac{2\pi r}{v}} = \frac{ev}{2\pi r}$



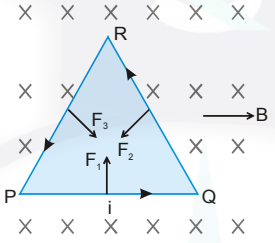
A = area of the loop = pr^2

$$\Rightarrow \quad \mu = (I)\left(\frac{ev}{2\pi r}\right)(\pi r^2)$$

$$\Rightarrow \quad \mu = \frac{evr}{2}$$

Ex. A wire is bent in the form of an equilateral triangle PQR of side 20 cm and carries a current of 2.5 A. It is placed in a magnetic field B of magnitude 2.0 T directed perpendicularly to the plane of the loop. Find the forces on the three sides of the triangle.

Sol. : Suppose the field and the current have directions as shown in figure. The force on PQ is



$\vec{F}_1 = i\vec{\ell} \times \vec{B}$ or, $F_1 = 2.5\ A \times 20\ cm \times 2.0\ T = 1.0\ N$

The rule of vector product shows that the force F_1 is perpendicular to PQ and is directed towards the inside of the triangle.

The forces $\vec{F}_2$ and $\vec{F}_3$ on QR and RP can also be obtained similarly. Both the forces are 1.0 N directed perpendicularly to the respective sides and towards the inside of the triangle.

The three forces $\vec{F}_1$, $\vec{F}_2$ and $\vec{F}_3$ will have zero resultant, so that there is no net magnetic force on the triangle. This result can be generalised. Any closed current loop, placed in a homogeneous magnetic field, does not experience a net magnetic force.

Ex. Figure shows two long metal rails placed horizontally and parallel to each other at a separation y. A uniform magnetic field B exists in the vertically upward direction. A wire of mass m can slide on the rails. The rails are connected to a constant current source which drives a current i in the circuit. The friction coefficient between the rails and the wire is μ.

(a) What soluble the minimum value of μ which can prevent the wire from sliding on the rails?

(b) Describe the motion of the wire if the value of μ is half the value found in the previous part

Sol. **(a)** The force on the wire due to the magnetic field is

$$\vec{F} = i\vec{\ell} \times \vec{B}$$

or, $F = iyB$

It acts towards right tin the given figure. If the wire does not slide on the rails, the force of friction by the rails should be equal to F. If μ_0 be the minimum coefficient of friction which can prevent sliding, this force is also equal to μ_0 mg. Thus,

$$\mu_0 mg = iyB$$

or, $$\mu_0 = \frac{iyB}{mg}$$

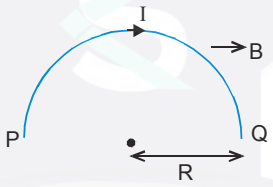
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(b) If the friction coefficient is $\mu = \frac{\mu_0}{2} = \frac{iyB}{2mg}$, the wire will slide towards right. The frictional force by the rails is

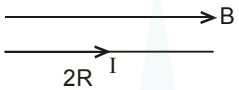
$$f = \mu mg = \frac{iyB}{2} \text{ towards left.}$$

The resultant force is $iyB - \frac{iyB}{2} = \frac{iyB}{2}$ towards right. The acceleration will be $a = \frac{iyB}{2m}$. The wire will slide towards right with this acceleration.

Ex. In the figure shown a semicircular wire is placed in a uniform $\vec{B}$ directed toward right. Find the resultant magnetic force and torque on it.



Sol. The wire is equivalent to

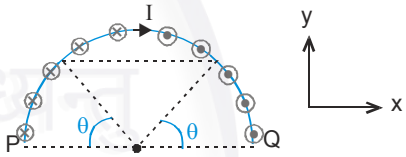


$\because$ $\theta = 0$

$\therefore$ $F_{res} = 0$ **Ans.**

forces on individual parts are marked in the figure by $\otimes$ and $\odot$.

By symmetry their will be pair of forces forming couples.

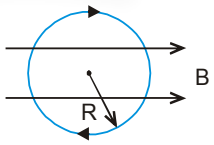


$$\tau = \int_0^{\pi/2} i(Rd\theta)B\sin(90-\theta).2R\cos\theta$$

$$\tau = \frac{i\pi R^2}{2}B$$

$\Rightarrow$ $\vec{\tau} = \frac{i\pi R^2}{2}B(-\hat{j})$ **Ans.**

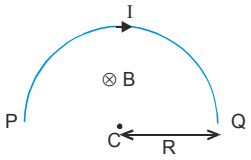
Ex. Find the resultant magnetic force and torque on the loop.



Sol. : $\overrightarrow{F_{res}} = 0$, ($\because$ loop)

and $\vec{\tau} = i\pi R^2 B(-\hat{j})$ using the above method

Ex. In the figure shown find the resultant magnetic force and torque about 'C', and 'P'.



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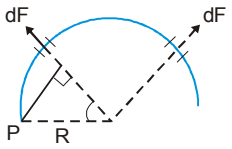
Sol. $\vec{F}_{nett} = I \cdot 2R \cdot B$

$\because$ wire is equivalent to

P ⟶ Q
2R

Force on each element is radially outward : $\tau_c = 0$

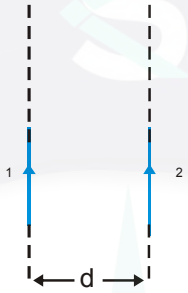
point about



$$P = \int_0^{\pi} [i(Rd\theta)B\sin 90^0]\ R\sin\theta$$

$= 2IBR^2$ **Ans.**

Ex. Prove that magnetic force per unit length on each of the infinitely long wire due to each other is $\mu_0 I_1 I_2/2\pi d$. Here it is attractive also.

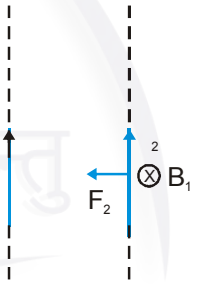


Sol. On (2), B due to **(i)** is = $\frac{\mu_0 I_1}{2\pi d} \otimes$

$\therefore$ F on (2) on 1m length

$= I_2 \cdot \frac{\mu_0 I_1}{2\pi d} \cdot 1$ towards left it is attractive

$= \frac{\mu_0 I_1 I_2}{2\pi d}$ (hence proved)



Similarly on the other wire also.

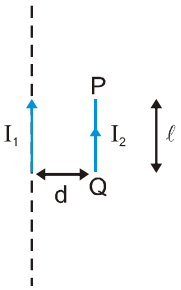
Note :

- Definition of ampere (fundamental unit of current) using the above formula.
  If $I_1 = I_2 = 1A$, $d = 1m$ then $F = 2 \times 10^{-7}$ N

$\therefore$ "When two very long wires carrying equal currents and separated by 1m distance exert on each other a magnetic force of 2×10^{-7} N on 1m length then the current is 1 ampere."

- The above formula can also be applied if to one wire is infinitely long and the other is of finite length. In this case the force per unit length on each wire will not be same.

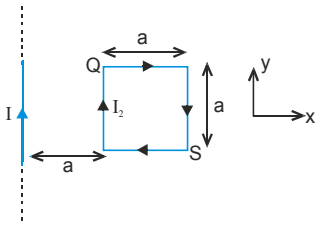
  Force per unit length on PQ = $\frac{\mu_0 I_1 I_2}{2\pi d}$ (attractive)



- If the currents are in the opposite direction then the magnetic force on the wires will be repulsive.

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Ex. Find the magnetic force on the loop 'PQRS' due to the loop wire.

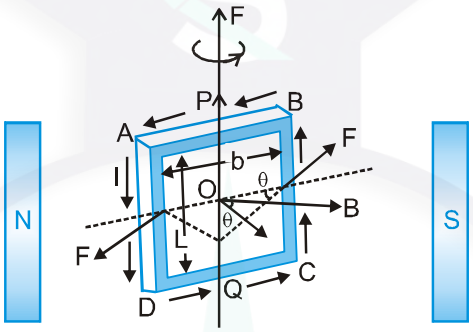


Sol. $F_{res} = \frac{\mu_0 I_1 I_2}{2\pi a} a(-\hat{i}) + \frac{\mu_0 I_1 I_2}{2\pi(2a)} a(\hat{i})$

$= \frac{\mu_0 I_1 I_2}{4\pi}(-\hat{i})$

Torque on a Current Loop :

When a current-carrying coil is placed in a uniform magnetic field the net force on it is always zero. However, as its different parts experience forces in different directions so the loop may experience a torque (or couple) depending on the orientation of the loop and the axis of rotation. For this, consider a rectangular coil in a uniform field B which is free to rotate about a vertical axis PQ and normal to the plane of the coil making an angle θ with the field direction as shown in figure **(A)**.



Axis of rotation
(A)

The arms AB and CD will experience forces B(NI)b vertically up and down respectively. These two forces together will give zero net force and zero torque (as are collinear with axis of rotation), so will have no effect on the motion of the coil.

Now the forces on the arms AC and BD will be BINL in the direction out of the page and into the page respectively, resulting in zero net force, but an anticlockwise couple of value

$\tau = F \times \text{Arm} = BINL \times (b \sin\theta)$

i.e. $\tau = BIA \sin\theta$ with $A = NLb$ .....**(i)**

Now treating the current–carrying coil as a dipole of moment $\vec{M} = I\vec{A}$ Eqn. **(i)** can be written in vector form as

$\vec{\tau} = \vec{M} \times \vec{B}$ [with $\vec{M} = I\vec{A} = NIA\vec{n}$ .....**(ii)**]

This is the required result and from this it is clear that :

(1) Torque will be minimum (= 0) when $\sin\theta = \text{min} = 0$, i.e., $\theta = 0^\circ$, i.e. 180° i.e., the plane of the coil is perpendicular to magnetic field i.e. normal to the coil is collinear with the field [fig. **(A)** and **(C)**]

(2) Torque will be maximum (= BINA) when $\sin\theta = \text{max} = 1$, i.e., $\theta = 90^\circ$ i.e. the plane of the coil is parallel to the field i.e. normal to the coil is perpendicular to the field. [fig.**(B)**].

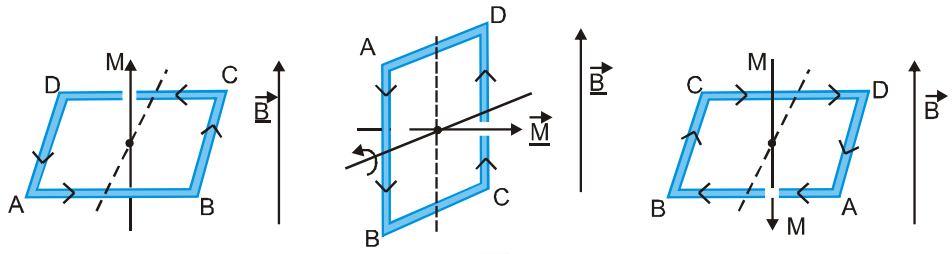
(3) By analogy with dielectric or magnetic dipole in a field, in case of current–carrying in a field.

$U = -\vec{M} \bullet \vec{B}$ with $F = -\frac{dU}{dr}$

and $W = MB(1 - \cos\theta)$

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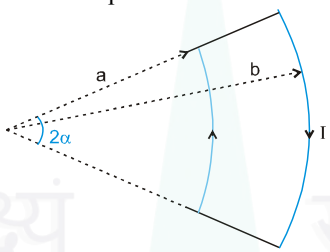
The values of U and W for different orientations of the coil in the field are shown in fig.



$\theta = 0^\circ$ ($\vec{M}$ is parallel to $\vec{B}$)	$\theta = 90^\circ$ ($\vec{M}$ is $\perp$ to $\vec{B}$)	$\theta = 180^\circ$ ($\vec{M}$ is antiparallel to $\vec{B}$)
$\tau = 0 = \min$	$\tau = MB = \max$	$\tau = 0$
$W = 0 = \min$	$W = MB$	$W = 2MB = \max$
$U = -MB = \min$	$U = 0$	$U = MB = \max$
Stable equilibrium	No equilibrium	Unstable equilibrium
(A)	(B)	(C)

(4) Instruments such as electric motor, moving coil galvanometer and tangent galvanometers etc. are based on the fact that a current–carrying coil in a uniform magnetic field experiences a torque (or couple).

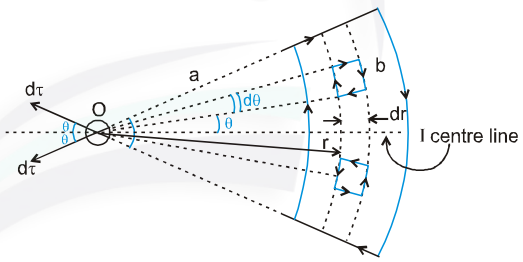
Ex. A loop with current I is in the field of a long straight wire with current I_0. The plane of the loop is perpendicular to the straight wire. Find torque acting on the loop.



Sol. : $d\vec{s} = (r d\theta\, dr)$ (inwards)

$d\vec{M} = (rI\, d\theta\, dr)$ (inwards)

$\vec{B} = \dfrac{\mu_0 I_0}{2\pi r}$ (tangential clockwise)



$d\tau = |d\vec{M} \times \vec{B}| = \dfrac{\mu_0 I I_0\, d\theta\, dr}{2\pi}$ (towards centre)

$\therefore \quad \tau = \int_{-\alpha}^{\alpha} \int_a^b d\tau \cos\theta$

$= \dfrac{\mu_0 I I_0}{2\pi} \int_{-\alpha}^{\alpha} \int_a^b \cos\theta\, d\theta\, dr$

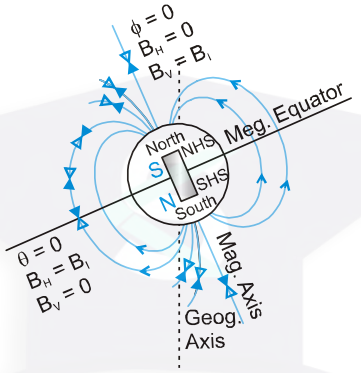
$= \dfrac{\mu_0 I I_0 (b-a)\sin\alpha}{\pi}$ (to the left) **Ans.**

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Terrestrial Magnetism (Earth's Magnetism) :

Introduction :

The idea that earth is magnetised was first suggested towards the end of the sixteenth century by Dr William Gilbert. The origin of earth's magnetism is still a mater of conjecture among scientists but it is agreed upon that the earth behaves as a magnetic dipole inclined at a small angle (11.5°) to the earth's axis of rotation with its south pole pointing north. The lines of force of earth's magnetic field are shown in figure which are parallel to the earth's surface near the equator and perpendicular to it near the poles. While discussing magnetism of the earth one should keep in mind that:



(a) The **magnetic meridian** at a place is not a line but a vertical plane passing through the axis of a freely suspended magnet, i.e., it is a plane which contains the place and the magnetic axis.

(b) The **geographical meridian** at a place is a vertical plane which passes through the line joining the geographical north and south, i.e., it is a plane which contains the place and earth's axis of rotation, i.e., geographical axis.

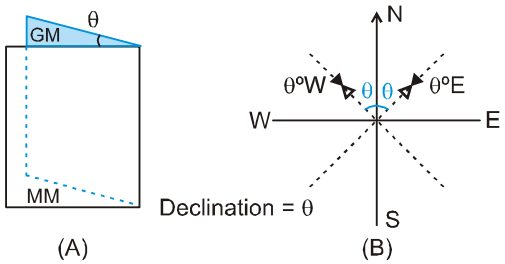
(c) The **magnetic Equator** is a great circle (a circle with the centre at earth's centre) on earth's surface which is perpendicular to the magnetic axis. The magnetic equator passing through Trivandrum in South India divides the earth into two hemispheres. The hemisphere containing south polarity of earth's magnetism is called the northern hemisphere (NHS) while the other, the southern hemisphere (SHS).

(d) The magnetic field of earth is not constant and changes irregularly from place to place on the surface of the earth and even at a given place it varies with time too.

Elements of the Earth's Magnetism :

The magnetism of earth is completely specified by the following three parameters called elements of earth's magnetism :

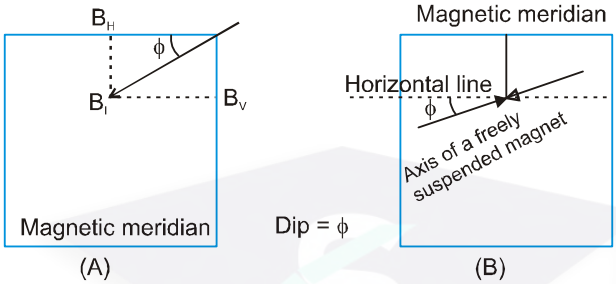
(a) Variation or Declination θ : At a given place the angle between the geographical meridian and the magnetic meridian is called declination, i.e., at a given place it is the angle between the geographical north south direction and the direction indicated by a magnetic compass needle, Declination at a place is expressed at θ° E or θ° W depending upon whether the north pole of the compass needle lies to the east (right) or to the west (left) of the geographical north-south direction. The declination at London is 10°W means that at London the north pole of a compass needle points 10°W, i.e., left of the geographical north.



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(b) Inclination or Angle of Dip ϕ : It is the angle which the direction of resultant intensity of earth's magnetic field subtends with horizontal line in magnetic meridian at the given place. Actually it is the angle which the axis of a freely suspended magnet (up or down) subtends with the horizontal in magnetic meridian at a given place.

Here, it is worthy to note that as the northern hemisphere contains south polarity of earth's magnetism, in it the north pole of a freely suspended magnet (or pivoted compass needle) will dip downwards, i.e., towards the earth while the opposite will take place in the southern hemisphere.



Angle of dip at a place is measured by the instrument called Dip-Circle in which a magnetic needle is free to rotate in a vertical plane which can be set in any vertical direction. Angle of dip at Delhi is 42°.

(c) Horizontal Component of Earth's Magnetic Field BH : At a given place it is defined as the component of earth's magnetic field along the horizontal in the magnetic meridian. It is represented by B_H and is measured with the help of a vibration or deflection magnetometer. At Delhi the horizontal component of the earth's magnetic field is 35 μT, i.e., 0.35 G.

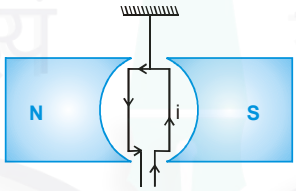
If at a place magnetic field of earth is B_I and angle of dip ϕ, then in accordance with figure **(a)**.

$$B_H = B_I \cos\phi \quad \text{and} \quad B_v = B_I \sin\phi \qquad \text{....(2)}$$

So that, $$\tan\phi = \frac{B_v}{B_H} \quad \text{and} \quad I = \sqrt{B_H^2 + B_v^2} \qquad \text{....(2)}$$

Moving coil galvanometer

A galvanometer is used to detect the current and has moderate resistance.



Principle

When a current carrying coil is placed in a magnetic field, it experiences a torque given by $\tau = NiAB \sin\theta$ where θ is the angle between normal to plane of coil and direction of magnetic field. In actual arrangement the coil is suspended between the cylindrical pole pieces of a strong magnet.

The cylindrical pole pieces give the field radial such that $\sin\theta = 1$ (always). So torque $\tau = NiAB$ If C is torsional rigidity (i.e., restoring couple per unit twist of the suspension wire), then for deflection θ of coil $\tau = C\theta$. In equilibrium we have external couple = Restoring couple i.e. $C\theta = NiAB$ or $\theta = \frac{NAB}{C}i$ i.e., $\theta \propto i$

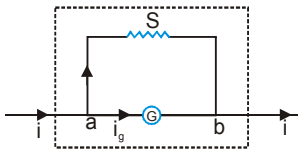
In words the deflection produced is directly proportional to current in the coil.

The quantity $\frac{\theta}{i} = \frac{NAB}{C}$ is called the current sensitivity of the galvanometer. Obviously for greater sensitivity of galvanometer the number of turns N, area of coil A and magnetic field B produced by pole pieces should be larger and torsional rigidity C should be smaller. That is why the suspension wire is used of phosphor bronze for which torsional rigidity C is smaller.

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Conversion of Galvanometer into Ammeter

An ammeter is a low resistance galvanometer; used to measure current directly in amperes and is always connected in series with the circuit. To convert a galvanometer into ammeter, a low resistance, called shunt, is connected in parallel to the galvanometer as shown in figure.



Let i_g be the current in galvanometer for its full scale deflection and G the resistance of galvanometer. Let i is the range of ammeter and i_s the current in shunt S. Then potential difference across a and b is

$$V_{ab} = i_g G = i_S S. \qquad \text{...(i)}$$

At junction a, $i = i_S + i_g$ i.e., $i_S = i - i_g$

Therefore from (i) $i_g G = (i - i_g)S$ or $i_g(S+G) = iS$ i.e., $i_g = \frac{S}{S+G} i$ ...(ii)

This is the working equation for conversion of galvanometer into ammeter. Here $i_g < i$.

From (ii) shunt required $S = \frac{i_g G}{i - i_g}$. If $i_g << i$, $S = \left(\frac{i_g}{i}\right) G$

The resistance of ammeter R_A so formed is given by $\frac{1}{R_A} = \frac{1}{G} + \frac{1}{S} \Rightarrow R_A = \frac{SG}{S+G}$ ....(iii)

Note: Equation (ii) may also be used to increase the range of given ammeter. Here G will be resistance of given ammeter, S shunt applied, i_g its initial range and i the new range desired.

Conversion of Galvanometer into Voltmeter

A voltmeter is a high resistance galvanometer and is connected between two points across which potential difference, is to be measured i.e., voltmeter is connected in parallel with the circuit. To convert a galvanometer into voltmeter, a high resistance R in series is connected to the galvanometer.



If V is range of voltmeter, then $i_g = \frac{V}{R+G}$ or resistance in series $R = \frac{V}{i_g} - G$ ...(i)

This is working equation for conversion of galvanometer into voltmeter.

The resistance of voltmeter so formed is $R_V = R + G$ ...(ii)

Note: Equation (i) may also be used to increase the range of voltmeter. If V_0 is initial range and V is new range of voltmeter, then $i_g = \frac{V_0}{G} = \frac{V}{R+G}$

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TIPS &FORMULAS

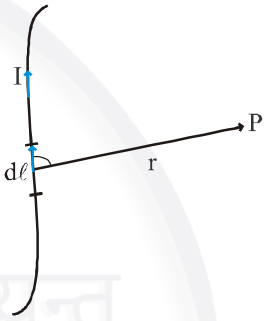
A static charge produced only electric field and only electric field can exert a force on it. A moving charge produced both electric field and magnetic field can exert force on it. A current carrying conductor produces only magnetic field and only magnetic field can exert a force on it.

Magnetic charge (i.e. current), produces a magnetic field. It can not produce electric field as net charge on a current carrying conductor is zero. A magnetic field is detected by its action current carrying conductors (or moving charges) and magnetic needles (compass). The vector quantity $\vec{B}$ known as **MAGNETIC INDUCTION** is introduced to characterise a magnetic field. It is a vector quantity which may be defined is term of the force it produces on electric currents. Lines of magnetic induction may be drawn in the same way as lines of electric field. The number of line per unit area crossing a small area perpendicular to the direction of the induction bring numerically equal to $\vec{B}$. The number of lines of $\vec{B}$ crossing a given area is referred to as the **magnetic flux** linked with that area. For this reason $\vec{B}$ is also called **magnetic flux density.**

1. Magnetic Induction Produced by a Current (Biot-Savart Law) :

The magnetic induction dB produced by an element dl carrying a current I are a distance r is given by :

$$dB = \frac{\mu_0\mu_r}{4\pi}\frac{Id\ell\sin\theta}{r^2} \Rightarrow \overrightarrow{dB} = \frac{\mu_0\mu_r}{4\pi}\frac{I\left(d\vec{\ell}\times\vec{r}\right)}{r^3}$$



here the quantity $Id\ell$ is called as current element strength.

μ = permeability of the medium = $\mu_0\mu_r$

μ_0 = permeability of free space

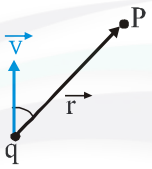
μ_r = relative permeability of the medium (Dimensionless quantity).

Unit of μ_0 & μ is NA^{-2} or Hm^{-1} ;

$\mu_0 = 4\pi\times10^{-7}\ Hm^{-1}$

2. Magnetic Induction Due to a Moving Charge :

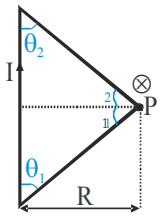
$$dB_p = \frac{\mu_0 qv\sin\theta}{4\pi r^2}$$



In vector form it can be written as $\overrightarrow{dB} = \frac{\mu_0}{4\pi}\frac{q\left(\vec{v}\times\vec{r}\right)}{r^3}$

3. Magnetic Induction Due to a Current Carrying Straight Conductor

(a) Magnetic induction due to a current carrying straight wire

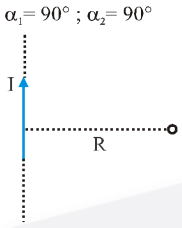


$$B = \frac{\mu_0 I}{4\pi R}\left(\cos\theta_1+\cos\theta_2\right) = \frac{\mu_0 I}{4\pi R}\left(\sin\alpha_1+\sin\alpha_2\right)$$

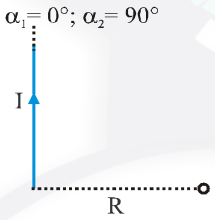
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If the wire is very long $\theta_1 \cong \theta_2 \cong 0^\circ$ then , $B = \frac{\mu_0 I}{2\pi R}$

(b) **Magnetic induction due to a infinity long wire** $B = \frac{\mu_0 I}{2\pi R} \otimes$

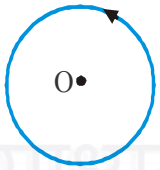


4. **Magnetic Induction due to semi infinite straight conductor** $B = \frac{\mu_0 I}{4\pi R} \otimes$



5. **Magnetic Field Due to a Flat Circular Coil Carrying A Current :**

(a) At its centre $B = \frac{\mu_0 NI}{2R} \odot$



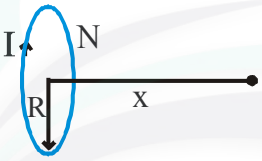
where

N = total number of turns in the coil

I = current in the coil

R = Radius of the coil

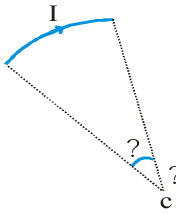
(b) On the axis $B = \frac{\mu_0 NIR^2}{2\left(x^2 + R^2\right)^{3/2}}$



where x = distance of the point from the centre.

It is maximum at the centre $B_C = \frac{\mu_0 NI}{2R}$

(c) **Magnetic Induction due to Flat Circular Arc :** $B = \frac{\mu_0 I\theta}{4\pi R}$



6. **Magnetic field due to infinite long solid cylindrical conductor of radius R**

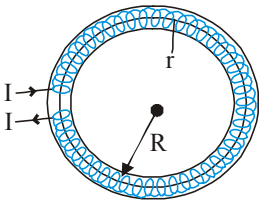
(i) For $r \geq R : B = \frac{\mu_0 I}{2\pi r}$ **(ii)** For $r < R : B = \frac{\mu_0 Ir}{2\pi R^2}$

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7. Magnetic Induction Due to Solenoid

$B = \mu_0 nI$, direction along axis.

where $n \rightarrow$ number of turns per meter ; $I \rightarrow$ current

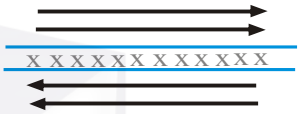


8. Magnetic Induction due to Toroid : $B = \mu_0 nI$

where $n = \dfrac{N}{2\pi R}$ (no. of turns per m)

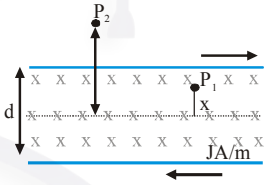
N = total turns R >> r

9. Magnetic Induction due to Current Carrying Sheet



$B = \dfrac{1}{2}\mu_0 I$ where I = Linear current density (A/m)

10. Magnetic Induction Due to Thick Sheet



At point P_2 $\quad B_{out} = \dfrac{1}{2}\mu_0 Jd$

At point P_1 $\quad B_{in} = \mu_0 Jx$

11. GILBERT'S MAGNETISM (EARTH'S MAGNETIC FIELD) :

(a) The line of earth's magnetic induction lies in a vertical plane coinciding with the magnetic North- South direction at that place. This plane is called the **Magnetic Meridian.** Earth's magnetic axis is slightly inclined to the geometric axis of earth and this angle varies from 10.5^0 to 20^0. The Earth's Magnetic poles are opposite to the geometric poles i.e. at earth's north pole, its magnetic south pole is situated and vice versa.

(b) On the magnetic meridian plane, the magnetic induction vector of the earth at any point, generally inclined to the horizontal at an angle called the **Magnetic Dip** at that place , such that $\vec{B}$ = total magnetic induction of the earth at that point.

$\vec{B}_v$ = the vertical component of $\vec{B}$ in the magnetic meridian plane = B sin θ

$\vec{B}_H$ = the horizontal component of $\vec{B}$ in the magnetic meridian plane = B cos θ.

$\dfrac{B_V}{B_H} = \tan\theta$

(c) At a given place on the surface of the earth, the magnetic meridian and the geographic meridian may not coincide. The angle between them is called **"DECLINATION AT THAT PLACE"**

12. AMPERES LAW

$\oint \vec{B}.\vec{d\ell} = \mu \sum I$ where $\sum I$ = algebraic sum of all the currents.

13. MOTION OF A CHARGE IN UNIFORM MAGNETIC FIELD :

(a) When $\vec{v}$ is || to $\vec{B}$: Motion will be in a straight line and $\vec{F} = 0$

(b) When $\vec{v}$ is $\perp$ to $\vec{B}$: Motion will be in circular path with radius

$R = \dfrac{mv}{qB}$ and angular velocity $\omega = \dfrac{qB}{m}$ and F = qvB.

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(c) When $\vec{v}$ is at $\angle\theta$ to $\vec{B}$: Motion will be helical with radius

$R_k = \frac{mv\sin\theta}{qB}$ and pitch $P_H = \frac{2\pi mv\cos\theta}{qB}$ and $F = qvB\sin\theta$.

14. LORENTZ FORCE :

An electric charge 'q' moving with a velocity $\vec{v}$ through a magnetic field of magnetic induction $\vec{B}$ experiences a force $\vec{F}$, given by $\vec{F} = q\vec{v}\times\vec{B}$. There fore, if the change moves in a space where both electric and magnetic fields are superposed.

$\vec{F}$ = net electromagnetic force on the charge = $q\vec{E} + q\vec{v}\times\vec{B}$

This force is called the **Lorentz Force**

15. MOTION OF CHARGE IN COMBINED ELECTRIC FIELD & MAGNETIC FIELD

When $\vec{v}\|\vec{B}$ & $\vec{v}\|\vec{E}$, motion will be uniformly accelerated in straight line as $F_{magnetic} = 0$ and $F_{electrostatic} = qE$

So the particle will be either speeding up or speeding down

When $\vec{v}\|\vec{B}$ & $\vec{v}\perp\vec{E}$, motion will be uniformly accelerated in a parabolic path

When $\vec{v}\perp\vec{B}$ & $\vec{v}\perp\vec{E}$, the particle may more undeflected & undeivated with same uniform speed if $v = \frac{E}{B}$ (This is called as velocity selector condition

16. Magnetic Force on a Straight Current Carrying Wire : $\vec{F} = I\left(\vec{L}\times\vec{B}\right)$

I = current in the straight conductor

$\vec{L}$ = length of the conductor in the direction of the current in it

$\vec{B}$ = magnetic induction. (Uniform throughout the length of conductor)

Note : In general force is $\vec{F} = \int I\left(d\vec{\ell}\times\vec{B}\right)$

17. Magnetic Interaction Force Between Two Parallel Long Straight Currents :

When two long straight linear conductors are parallel and carry a current in each, they magnetically interact with each other, one experiences a force.

This force is of :

(i) Repulsion if the currents are anti-parallel (i.e. in opposite direction) or

(ii) Attraction if the currents are parallel (i.e. in the same direction)

This force per unit length on either conductor is given by $F = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{r}$.

Where r = perpendicular distance between the parallel conductors.

18. Magnetic Torque on a Closed Circuit :

When a plane closed current circuit of 'N' turns and of area 'A' per turn carrying a current I is placed in uniform magnetic field, it experience a zero net force, but experience a torque given by $\vec{\tau} = NI\vec{A}\times\vec{B} = \vec{M}\times\vec{B} = BINA\sin\theta$ where $\vec{A}$ = area vector outward from the face of the circuit where the current is anticlockwise,

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$\vec{B}$ = magnetic induction of the uniform magnetic field

$\vec{M}$ = magnetic moment of the current circuit = IN $\vec{A}$

Note : This expression can be used only if $\vec{B}$ is uniform otherwise calculate will be used.

19. Moving Coil Galvanometer :

It consists of a plane coil of many turns suspended in a radial magnetic field. When a current is passes in the coil it experiences a torque which produces a twist in the suspension.

The deflection is directly proportional to the torque $\therefore$ NIAB = Kθ

$I = \left(\frac{K}{NAB}\right)\theta$; K = elastic torsional constant of the suspension

$I = Cq \quad C = \frac{K}{NAB}$ = Galvanometer Constant

20. Force Experienced by a Magnetic Dipole in a Non-Uniform Magnetic Field :

$$\left|\vec{F}\right| = \left|M\frac{\partial B}{\partial r}\right|$$

where M = magnetic dipole moment.

21. Force on a Random shaped conductor in a uniform magnetic field

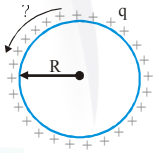


(a) Magnetic force on a closed loop in a uniform $\vec{B}$ is zero.

(b) Force experienced by a wire of any shape is equivalent to force on a wire joining points A & B in a uniform magnetic field.

22. Magnetic moment of a rotating charge :

If a charge q is rotating at an angular velocity ω, its equivalent current is given as



$I = \frac{q\omega}{2\pi}$ & its magnetic moment is $M = I\pi R^2 = \frac{1}{2}q\omega R^2$.

Note : The ratio of magnetic moment to angular momentum of a uniform rotating object which is charged uniformly is always a constant. Irrespective of the shape of conductor M/L = q/2m

23. Magnetic dipole

(a) Magnetic moment M = m × 2*l* where m = pole strength of the magnet.

(b) Magnetic field at axial point (or End-on) of dipole $\vec{B} = \frac{\mu_0 2\vec{M}}{4\pi r^3}$

(c) Magnetic field at equatorial position (Broad-on) of dipole $\vec{B} = \frac{\mu_0}{4\pi^3}\frac{(-\vec{M})}{r^3}$

Magnetic Potential $V = \frac{\mu_0}{4\pi}\frac{M\cos\theta}{r^2}$

Magnetic field $B = \frac{\mu_0}{4\pi}\frac{M\sqrt{1+3\cos^2\theta}}{r^3}$

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(d) Torque on dipole placed in uniform magnetic field $\vec{\tau} = \vec{M} \times \vec{B}$

(e) Potential energy of dipole placed in an uniform field $U = -\vec{M}.\vec{B}$

24. **Intensity of magnetisation** $I = M / V$

25. **Magnetic induction** $B = \mu H = \mu_0 (H+1)$

26. **Magnetic permeability** $\mu = \frac{B}{H}$

27. **Magnetic suspectibility** $\chi_m = \frac{I}{H} = \mu - 1$

28. **Curie law**

- For paramagnetic materials $\chi_m \propto \frac{1}{T}$

29. **Curie Wires law**

- For Ferromagnetic materials $\chi_m \propto \frac{1}{T - T_c}$

  Where T_c = curie temperature

30. A charged particle moves perpendicular to magnetic field. Its kinetic energy will remain constant but momentum changes because magnetic force acts perpendicular to velocity of particle.

31. If a unit north pole rotates around a current carrying wire then work has to be done because magnetic field produced by current is always non-conservative in nature.

32. In a conductor, free electrons keep on moving but no magnetic force acts on a conductor in a magnetic field because in a conductor, the average thermal velocity of electrons is zero.

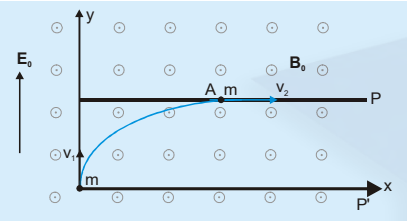
33. Magnetic force between two charges is generally much smaller then the electric force between them because speeds of charges are much smaller than the free space speed of light.

Note : $\frac{F_{magnetic}}{F_{electric}} = \frac{v^2}{c^2}$

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SOLVED EXAMPLE

Ex.1 There are constant electric field $E_0\hat{j}$ & magnetic field $B\hat{k}$ present between plates P and P'. A particle of mass m is projected from plate P' along y axis with velocity v_1. After moving on the curved path, it passes through point A just grazing the plate P with velocity v_2. The magnitude of impulse (i.e. $\vec{F}\Delta t = \Delta\vec{p}$) provided by magnetic force during the motion of particle from origin to point A is :–

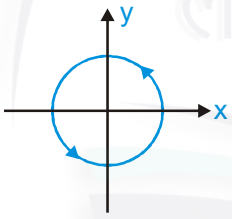


(A) $m|v_2 - v_1|$ (B) $m\sqrt{v_1^2 + v_2^2}$

(C) mv_1 (D) mv_2

Sol. Electric force is only responsible for the change in momentum along y–axis. Therefore impulse provide by magnetic force is $J_B = mv_2$.

Ex.2 Current i = 2.5 A flows along the circle $x^2 + y^2 = 9$ cm^2 (here x & y in cm) as shown. Magnetic field at point (0, 0, 4 cm) is



(A) $(36\pi \times 10^{-7}\,T)\hat{k}$

(B) $(36\pi \times 10^{-7}\,T)(-\hat{k})$

(C) $\left(\frac{9\pi}{5} \times 10^{-7}\,T\right)\hat{k}$

(D) $\left(\frac{9\pi}{5} \times 10^{-7}\,T\right)(-\hat{k})$

Sol. Magnetic field on the axis of a circular loop

$$B = \left(\frac{\mu_0}{4\pi}\right) \times \frac{2\pi i R^2}{(R^2 + z^2)^{3/2}}$$

$$= 10^{-7} \times \frac{2\pi \times 2.5 \times 3^2 \times 10^{-4}}{125 \times 10^{-6}}\hat{k}$$

$$= \left(\frac{9\pi}{25} \times 10^{-5}\,T\right)\hat{k} = (36\pi \times 10^{-7}\,T)\hat{k}$$

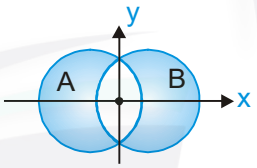
Ex.3 Three identical charge particles A, B and C are projected perpendicular to the uniform magnetic field with velocities v_1, v_2 and v_3 ($v_1 < v_2 < v_3$) respectively such that T_1, T_2 and T_3 are their respective time period of revolution and r_1, r_2 and r_3 are respective radii of circular path described. Then

(A) $\frac{r_1}{T_1} > \frac{r_2}{T_2} > \frac{r_3}{T_3}$ (B) $T_1 < T_2 < T_3$

(C) $\frac{r_1}{T_1} < \frac{r_2}{T_2} < \frac{r_3}{T_3}$ (D) $r_1 = r_2 = r_3$

Sol. $T = \frac{2\pi m}{qB}$ & $r = \frac{mv}{qB} \Rightarrow \frac{r}{T} \propto v$

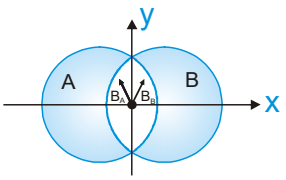
Ex.4 Two cylindrical straight and very long non magnetic conductors A and B, insulated from each other, carry a current I in the positive and the negative z–direction respectively. The direction of magnetic field at origin is



(A) $-\hat{i}$ (B) $+\hat{i}$

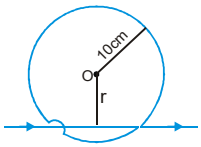
(C) $\hat{j}$ (D) $-\hat{j}$

Sol.



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Ex.5 An infinitely long straight wire is bent as shown in figure. The circular portion has a radius of 10 cm with its center O at a distance r from the straight part. The value of r such that the magnetic field at the center O of the circular portion is zero will be :-



(A) $\frac{10}{\pi}$ cm **(B)** $\frac{20}{\pi}$ cm

(C) $\frac{1}{5\pi}$ cm **(D)** $\frac{5}{\pi}$ cm

Sol. $B_{\text{circular loop}} = -B_{\text{wire}} \Rightarrow \frac{\mu_0 I}{2\times 10} = \frac{\mu_0 I}{2\pi r}$

$\Rightarrow r = \frac{10}{\pi}$ cm

Ex.6 A conducting coil is bent in the form of equilateral triangle of side 5 cm. Current flowing through it is 0.2 A. The magnetic moment of the triangle is :-

(A) $\sqrt{3}\times 10^{-2}$ A–m^2 **(B)** 2.2×10^{-4} A–m^2

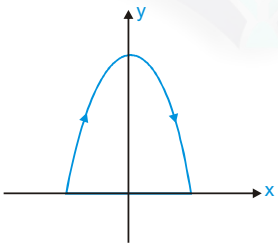
(C) 2.2×10^{-2} A–m^2 **(D)** $\sqrt{3}\times 10^{-4}$ A–m^2

Sol. Magnetic moment of current carrying triangular loop M = IA

$$M = 0.2\left(\frac{1}{2}\times 5\times 10^{-2}\times\frac{\sqrt{3}\times 5\times 10^{-2}}{2}\right)$$

$= 2.2\times 10^{-4}$ A-m^2

Ex.7 A wire carrying a current of 4A is bent in the form of a parabola $x^2 + y = 16$ as shown in figure, where x and y are in meter. The wire is placed in a uniform magnetic field $\vec{B} = 5\hat{k}$ tesla. The force acting on the wire is



(A) $80\,\hat{j}$ N

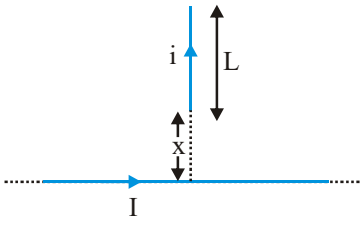
(B) $-\,80\,\hat{j}$ N

(C) $-160\,\hat{j}$ N

(D) $160\,\hat{j}$ N

Sol. **(C)** $\vec{F} = I(\vec{\ell}\times\vec{B}) = 4(8\hat{i}\times 5\hat{k}) = -160\,\hat{j}$ N

Ex.8 The magnetic force between wires as shown in figure is :-



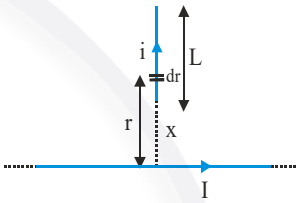
(A) $\frac{\mu_0 i l^2}{2\pi}\ell n\left(\frac{x+L}{2x}\right)$

(B) $\frac{\mu_0 i l^2}{2\pi}\ell n\left(\frac{2x+L}{2x}\right)$

(C) $\frac{\mu_0 i l}{2\pi}\ell n\left(\frac{x+L}{x}\right)$

(D) None of these

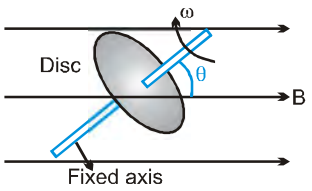
Sol. Magnetic field at dr, $B = \frac{\mu_0 I}{2\pi r}$



Force on small element at a distance r of wire of length L is $dF = i(dr)\left(\frac{\mu_0 I}{2\pi r}\right)$

$$F = \frac{\mu_0 i I}{2\pi}\int_x^{x+L}\frac{dr}{r} = \frac{\mu_0 i I}{2\pi}\ell n\left(\frac{x+L}{x}\right)$$

Ex.9 A disc of radius r and carrying positive charge q is rotating with angular speed ω in a uniform magnetic field B about a fixed axis as shown in figure, such that angle made by axis of disc with magnetic field is θ. Torque applied by axis on the disc is



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(A) $\frac{q\omega r^2 B\sin\theta}{2}$, clockwise

(B) $\frac{q\omega r^2 B\sin\theta}{4}$, anticlockwise

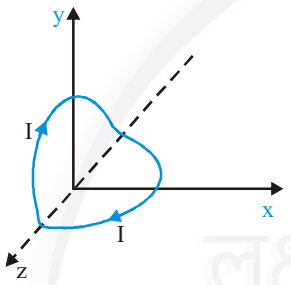
(C) $\frac{q\omega r^2 B\sin\theta}{2}$, anticlockwise

(D) $\frac{q\omega r^2 B\sin\theta}{4}$, clockwise

Sol. $\frac{M}{L}=\frac{q}{2m} \Rightarrow M=\frac{q}{2m}\times\frac{mr^2}{2}\omega$

$\Rightarrow \tau=\left|\vec{M}\times\vec{B}\right|=\frac{q\omega r^2 B\sin\theta}{4}(\text{clockwise})$

Ex.10 A circular current carrying loop of radius R is bent about its diameter by 90° and placed in a magnetic field $\vec{B}=B_0(\hat{i}+\hat{j})$ as shown in figure.



(A) The torque acting on the loop is zero

(B) The magnetic moment of the loop is $\frac{I\pi R^2}{2}\left(-\hat{i}-\hat{j}\right)$

(C) The angular acceleration of the loop is non zero.

(D) The magnetic moment of the loop is $\frac{I\pi R^2}{2}\left(-\hat{i}+\hat{j}\right)$

Sol. $\vec{M}=\frac{I\pi R^2}{2}\left(-\hat{i}-\hat{j}\right);\ \vec{\tau}=\vec{M}\times\vec{B}=0$

Ex.11 A particle of mass m and charge q is thrown from origin at t = 0 with velocity $2\hat{i}+3\hat{j}+4\hat{k}$ units in a region with uniform magnetic field $2\hat{i}$ units. After time $t=\frac{\pi m}{qB}$, an electric field $\vec{E}$ is switched on, such that particle moves on a straight line with constant speed. $\vec{E}$ may be

(A) $-8\hat{j}+6\hat{k}$ units **(B)** $-6\hat{i}-9\hat{k}$ units

(C) $-12\hat{j}+9\hat{k}$ units **(D)** $8\hat{j}-6\hat{k}$ units

Sol. At $t=\frac{\pi n}{qB}$, $\vec{v}=2\hat{i}-3\hat{j}-4\hat{k}$; For net force to be zero $q\vec{v}\times\vec{B}+q\vec{E}=0 \Rightarrow \vec{E}=-\vec{v}\times\vec{B}=-8\hat{j}+6\hat{k}$

Ex.12 A particle of specific charge $\frac{q}{m}=\pi\times10^{10}\,C\,kg^{-1}$ is projected from the origin along the positive x–axis with a velocity of 10^5 ms^{-1} in a uniform magnetic field $\vec{B}=-2\times10^{-3}\hat{k}$ tesla. Choose correct alternative(s)

(A) The centre of the circle lies on the y–axis

(B) The time period of revolution is 10^{-7} s.

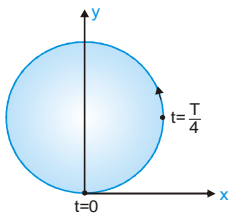
(C) The radius of the circular path is $\frac{5}{\pi}$ mm

(D) The velocity of the particle at $t=\frac{1}{4}\times10^{-7}$s is $10^5\hat{j}$ m/s

Sol. $\vec{F}=q(\vec{v}\times\vec{B})$, $\vec{v}=10^5\hat{i}$, $\vec{B}=-2\times10^{-3}\hat{k}$

$\Rightarrow$ Force will be in y–direction

$\Rightarrow$ Motion of particle will be in xy plane



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Time period

$$T = \frac{2\pi m}{qB} = \frac{2\pi}{\pi \times 10^{10} \times 2 \times 10^{-3}} = 10^{-7}\,s$$

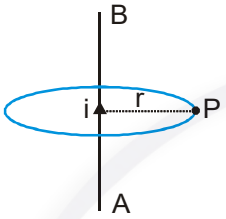
$$\text{Radius of path} = \frac{mv}{qB} = \frac{10^5}{\pi \times 10^{10} \times 2 \times 10^{-3}}$$

$$= \frac{5}{\pi} \times 10^{-3}\,m = \frac{5}{\pi}\,mm$$

$$\text{At } t = \frac{T}{4} = \frac{10^{-7}}{4}\,s.$$

Velocity of particle will be in +y direction.

Ex.13 In the given figure, B is magnetic field at P due to shown segment AB of an infinite current carrying wire. A loop is taken as shown in figure. Which of the following statement(s) is/are correct.



(A) $\oint \vec{B} \cdot \overrightarrow{d\ell} = \mu_0 i$

(B) $B = \frac{\mu_0 i}{2\pi r}$

(C) Magnetic field at P will be tangential

(D) None of these

Sol. Magnetic field at P is tangential.

Ex.14 A current–carrying ring is placed in a magnetic field. The direction of the field is perpendicular to the plane of the ring–

(A) There is no net force on the ring.

(B) The ring will tend to expand.

(C) The ring will tend to contract.

(D) Either **(B)** or **(C)** depending on the directions of the current in the ring and the magnetic field.

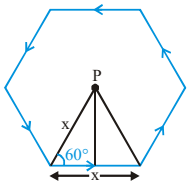
Sol. Net force = 0 and ring will tend to expand/contracts depending on I & B.

Ex.15 Column-I gives some current distributions and a point P in the space around these current distributions. Column-II gives some expressions of magnetic field strength. Match column-I to corresponding field strength at point P given in column-II

Column – I	Column – II
(A) A conducting loop shaped as regular hexagon of side x, carrying current i. P is the centroid of hexagon	**(P)** $\frac{3\mu_0 i}{32\pi x}$
(B) A cylinder of inner radius x and outer radius 3x, carrying current i. Point P is at a distance 2x from the axis of the cylinder	**(Q)** $\frac{\sqrt{3}\mu_0 i}{\pi x}$
(C) Two coaxial hollow cylinders of radii x and 2x, each carrying current i, but in opposite direction. P is a point at distance 1.5x from the axis of the cylinders	**(R)** $\frac{\mu_0 i}{2x}$
(D) Magnetic field at the centre of an n-sided regular polygon, of circumcircle of radius x, carrying current i, $n \to \infty$, P is centroid of the polygon.	**(S)** $\frac{\mu_0 i}{3\pi x}$
	(T) Zero

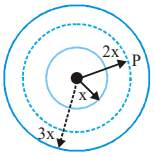
Sol. **For A:** $B_P = 6 \times \frac{\mu_0 i}{4\pi(x\sin 60°)}[\sin 30° + \sin 30°]$

$$= \frac{\sqrt{3}\mu_0 i}{\pi x}$$

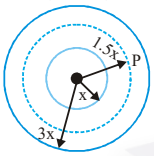


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For B: $B_P = \dfrac{\mu_0\left(\frac{3}{8}i\right)}{2\pi(2x)} = \dfrac{3\mu_0 i}{32\pi x}$



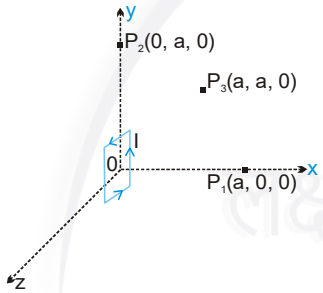
For C : $B_P = \dfrac{\mu_0 i}{2\pi(1.5x)} = \dfrac{\mu_0 i}{3\pi x}$



For D : If $n \to \infty$, n sided polygon $\to$ circle

so $B = \dfrac{\mu_0 i}{2x}$

Ex.16 A very small current carrying square loop (current I) of side 'L' is placed in y-z plane with centre at origin of the coordinate system (shown in figure). In column–I the coordinate of the points are given & in column–II magnitude of strength of magnetic field is given. Then



Column I	Column II
(A) At point O (0, 0, 0)	(P) $\dfrac{\mu_0 IL^2}{2\pi a^3}$
(B) At point P_1 (a, 0, 0) (here a >> L)	(Q) $\dfrac{2\sqrt{2}\mu_0 I}{\pi L}$
(C) At point P_2 (0, a, 0) (here (a >> L)	(R) $\dfrac{\mu_0\sqrt{5}IL^2}{16\pi a^3}$
(D) At point P_3 (a, a, 0) (here a >> L)	(S) $\dfrac{\mu_0 IL^2}{4\pi a^3}$
	(T) $\dfrac{\mu_0\sqrt{5}IL^2}{4\pi a^3}$

Sol. **For A :** $B_{P_1} = 4\times\dfrac{\mu_0 I}{4\pi(L/2)}\left[\sin\dfrac{\pi}{4}+\sin\dfrac{\pi}{4}\right]$

$$= \frac{2\sqrt{2}\mu_0 I}{\pi L}$$

For B: $B_{P_2} = \dfrac{2kM}{r^3} = \dfrac{2\left(\frac{\mu_0}{4\pi}\right)(IL^2)}{a^3} = \dfrac{\mu_0 IL^2}{2\pi a^3}$

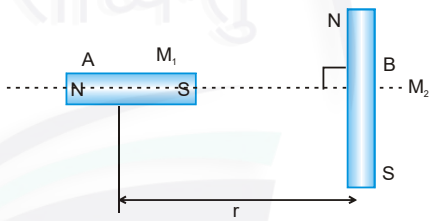
For C : $B_{P_3} = \dfrac{kM}{r^3} = \dfrac{\left(\frac{\mu_0}{4\pi}\right)(IL^2)}{a^3} = \dfrac{\mu_0 IL^2}{4\pi a^3}$

For D : $B_{P_4} = \dfrac{kM}{r^3}\sqrt{1+3\cos^2\theta}$

where $\cos\theta = \dfrac{1}{\sqrt{2}}$

$$\Rightarrow B_{P_4} = \frac{\left(\frac{\mu_0}{4\pi}\right)(IL^2)}{(a\sqrt{2})^3}\sqrt{1+3\left(\frac{1}{2}\right)} = \frac{\mu_0\sqrt{5}IL^2}{16\pi a^3}$$

Ex.17 Two short magnet A and B of magnetic dipole moments M_1 and M_2 respectively are placed as shown. The axis of 'A' and the equatorial line of 'B' are the same. Find the magnetic force on one magnet due to the other.



Sol. Magnetic field due to magnet B :

$$B = \frac{\mu_0}{4\pi}\cdot\frac{M_2}{r^3}$$

Magnetic force acting on magnet A :

$$F = M_1\frac{dB}{dr} = -3\left(\frac{\mu_0}{4\pi}\right)\frac{M_1M_2}{r^4}$$

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Ex.18 A bar magnet has a pole strength of 3.6 A-m and magnetic length 8 cm. Find the magnetic field at (a) a point on the axis at a distance of 6 cm from the centre towards the north pole and (b) a point on the perpendicular bisector at the same distance.

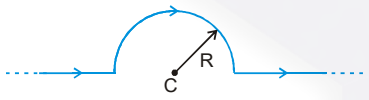
Sol. $M = 3.6 \times 8 \times 10^2\ A.m^2$

(a) $B = \frac{\mu_0}{4\pi} \cdot \frac{2Mr}{(r^2 - a^2)^2} = 8.6 \times 10^{-4}\ T.$

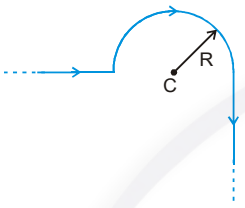
(b) $B = \frac{\mu_0}{4\pi} \cdot \frac{M}{(r^2 + a^2)^{3/2}} = 7.7 \times 10^{-5}\ T$

Ex.19 Find 'B' at centre 'C' in the following cases :

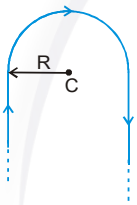
(i)



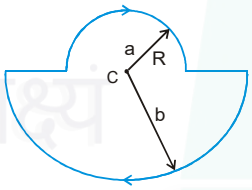
(ii)



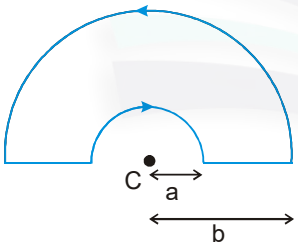
(iii)



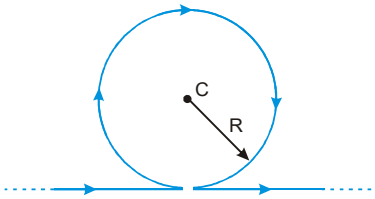
(iv)



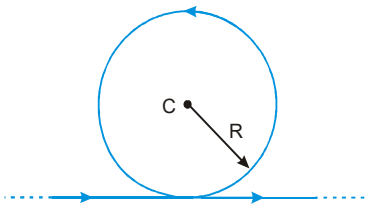
(v)



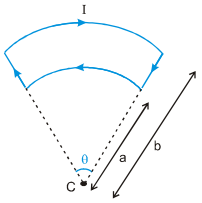
(vi)



(vii)



(viii)



Sol.

(i) $B = \frac{\mu_0 I}{2R} \times \frac{1}{2} = \frac{\mu_0 I}{4R}$

(ii) $B = B_1 + B_2 = \left(\frac{\mu_0 I}{2R} \times \frac{1}{2}\right) + \left(\frac{\mu_0}{4\pi} \cdot \frac{I}{R}\right)$

$= \frac{\mu_0 I}{4R}\left(1 + \frac{1}{\pi}\right)$

(iii) $B = B_1 + B_2 + B_3 = 2B_1 + B_2 = \left(2 \times \frac{\mu_0}{4\pi}\frac{I}{R}\right)$

$+ \left(\frac{\mu_0 I}{2R} \times \frac{1}{2}\right) = \frac{\mu_0 I}{2R}\left(\frac{1}{2} + \frac{1}{\pi}\right)$

(iv) $B = B_1 + B_2 = \frac{\mu_0}{2a} \times \frac{1}{2} + \frac{\mu_0}{2b} \times \frac{1}{2}$

$= \frac{\mu_0 I}{4}\left(\frac{1}{a} + \frac{1}{b}\right)$

(v) $B = B_1 - B_2 = \left(\frac{\mu_0 I}{2a} \times \frac{1}{2} - \frac{\mu_0 I}{2b} \times \frac{1}{2}\right)$

$= \frac{\mu_0 I}{4}\left(\frac{1}{a} - \frac{1}{b}\right)$

(vi) $B = B_1 - B_2 = \frac{\mu_0 I}{2R} - \frac{\mu_0 I}{2\pi R} = \frac{\mu_0 I}{2R}\left(1 - \frac{1}{\pi}\right)$

(vii) $B = B_1 + B_2 = \frac{\mu_0 I}{2R} + \frac{\mu_0 I}{2\pi R} = \frac{\mu_0 I}{2R}\left(1 + \frac{1}{\pi}\right)$

(viii) $B = B_1 - B_2 = \frac{\mu_0 I}{2a} - \frac{\mu_0 I}{2b} \times \frac{\theta}{2\pi}$

$= \frac{\mu_0 I\theta}{4\pi}\left(\frac{1}{a} - \frac{1}{b}\right)$

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Exercise # 1 SINGLE OBJECTIVE NEET LEVEL

1. A length L of wire carries a steady current I. It is bent first to form a circular plane coil of one turn. The same length is now bent more sharply to give a double loop of smaller radius. The magnetic field at the centre caused by the same current is

(A) A quarter of its first value

(B) Unaltered

(C) Four times of its first value

(D) A half of its first value

2. A vertical straight conductor carries a current vertically upwards. A point P lies to the east of it at a small distance and another point Q lies to the west at the same distance. The magnetic field at P is

(A) Greater than at Q

(B) Same as at Q

(C) Less than at Q

(D) Greater or less than at Q depending upon the strength of the current

3. If a copper rod carries a direct current, the magnetic field associated with the current will be

(A) Only inside the rod

(B) Only outside the rod

(C) Both inside and outside the rod

(D) Neither inside nor outside the rod

4. If a long hollow copper pipe carries a direct current, the magnetic field associated with the current will be

(A) Only inside the pipe

(B) Only outside the pipe

(C) Neither inside nor outside the pipe

(D) Both inside and outside the pipe

5. The magnetic field $d\vec{B}$ due to a small current element $d\vec{l}$ at a distance $\vec{r}$ and element carrying current i is, or Vector form of Biot-savart's law is

(A) $d\vec{B} = \frac{\mu_0}{4\pi} i \left(\frac{d\vec{l} \times \vec{r}}{r}\right)$ **(B)** $d\vec{B} = \frac{\mu_0}{4\pi} i^2 \left(\frac{d\vec{l} \times \vec{r}}{r}\right)$

(C) $d\vec{B} = \frac{\mu_0}{4\pi} i^2 \left(\frac{d\vec{l} \times \vec{r}}{r^2}\right)$ **(D)** $d\vec{B} = \frac{\mu_0}{4\pi} i \left(\frac{d\vec{l} \times \vec{r}}{r^3}\right)$

6. A charge q *coulomb* moves in a circle at n revolutions per second and the radius of the circle is r *metre*. Then magnetic field at the centre of the circle is

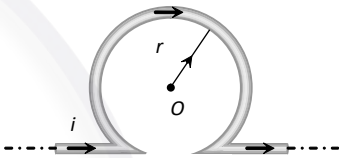
(A) $\frac{2\pi q}{nr} \times 10^{-7}$ *N/amp/metre*

(B) $\frac{2\pi q}{r} \times 10^{-7}$ *N/amp/metre*

(C) $\frac{2\pi nq}{r} \times 10^{-7}$ *N/amp/metre*

(D) $\frac{2\pi q}{r}$ *N/amp/metre*

7. An infinitely long straight conductor is bent into the shape as shown in the figure. It carries a current of i *ampere* and the radius of the circular loop is r *metre*. Then the magnetic induction at its centre will be



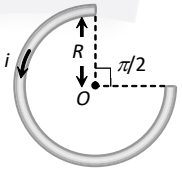
(A) $\frac{\mu_0}{4\pi}\frac{2i}{r}(\pi + 1)$

(B) $\frac{\mu_0}{4\pi}\frac{2i}{r}(\pi - 1)$

(C) Zero

(D) Infinite

8. A current i *ampere* flows in a circular arc of wire whose radius is R, which subtend an angle $3\pi/2$ radian at its centre. The magnetic induction B at the centre is



(A) $\frac{\mu_0 i}{R}$ **(B)** $\frac{\mu_0 i}{2R}$

(C) $\frac{2\mu_0 i}{R}$ **(D)** $\frac{3\mu_0 i}{8R}$

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9. A current *i ampere* flows along the inner conductor of a coaxial cable and returns along the outer conductor of the cable, then the magnetic induction at any point outside the conductor at a distance *r metre* from the axis is

(A) ∞ **(B)** Zero

(C) $\frac{\mu_0}{4\pi}\frac{2i}{r}$ **(D)** $\frac{\mu_0}{4\pi}\frac{2\pi i}{r}$

10. A straight section PQ of a circuit lies along the X-axis from $x=-\frac{a}{2}$ to $x=\frac{a}{2}$ and carries a steady current i. The magnetic field due to the section PQ at a point $X=+a$ will be

(A) Proportional to a **(B)** Proportional to a^2

(C) Proportional to $1/a$ **(D)** Zero

11. A proton moving with a constant velocity passes through a region of space without any change in its velocity. If $\vec{E}$ and $\vec{B}$ represent the electric and magnetic fields respectively, then this region of space may have

(A) $E=0, B=0$ **(B)** $E=0, B\neq 0$

(C) $E\neq 0, B=0$ **(D)** $E\neq 0, B\neq 0$

12. A uniform electric field and a uniform magnetic field are produced, pointed in the same direction. An electron is projected with its velocity pointing in the same direction

(A) The electron will turn to its right

(B) The electron will turn to its left

(C) The electron velocity will increase in magnitude

(D) The electron velocity will decrease in magnitude

13. Two particles X and Y having equal charges, after being accelerated through the same potential difference, enter a region of uniform magnetic field and describes circular path of radius R_1 and R_2 respectively. The ratio of mass of X to that of Y is

(A) $\left(\frac{R_1}{R_2}\right)^{1/2}$ **(B)** $\frac{R_2}{R_1}$

(C) $\left(\frac{R_1}{R_2}\right)^{2}$ **(D)** $\frac{R_1}{R_2}$

14. A beam of ions with velocity $2\times10^5\ m/s$ enters normally into a uniform magnetic field of $4\times10^{-2}\ tesla$. If the specific charge of the ion is $5\times10^7\ C/kg$, then the radius of the circular path described will be

(A) $0.10\ m$ **(B)** $0.16\ m$

(C) $0.20\ m$ **(D)** $0.25\ m$

15. The radius of curvature of the path of the charged particle in a uniform magnetic field is directly proportional to

(A) The charge on the particle

(B) The momentum of the particle

(C) The energy of the particle

(D) The intensity of the field

16. An electron has mass $9\times10^{-31}\ kg$ and charge $1.6\times10^{-19}\ C$ is moving with a velocity of $10^6\ m/s$, enters a region where magnetic field exists. If it describes a circle of radius $0.10\ m$, the intensity of magnetic field must be

(A) $1.8\times10^{-4}\ T$ **(B)** $5.6\times10^{-5}\ T$

(C) $14.4\times10^{-5}\ T$ **(D)** $1.3\times10^{-6}\ T$

17. A proton (mass m and charge $+e$) and an α – particle (mass $4m$ and charge $+2e$) are projected with the same kinetic energy at right angles to the uniform magnetic field. Which one of the following statements will be true

(A) The α-particle will be bent in a circular path with a small radius that for the proton

(B) The radius of the path of the α-particle will be greater than that of the proton

(C) The α-particle and the proton will be bent in a circular path with the same radius

(D) The α-particle and the proton will go through the field in a straight line

18. A charged particle moving in a magnetic field experiences a resultant force

(A) In the direction of field

(B) In the direction opposite to that field

(C) In the direction perpendicular to both the field and its velocity

(D) None of the above

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19. If the direction of the initial velocity of the charged particle is perpendicular to the magnetic field, then the orbit will be

or

The path executed by a charged particle whose motion is perpendicular to magnetic field is

(A) A straight line **(B)** An ellipse

(C) A circle **(D)** A helix

20. If the direction of the initial velocity of the charged particle is neither along nor perpendicular to that of the magnetic field, then the orbit will be

(A) A straight line **(B)** An ellipse

(C) A circle **(D)** A helix

21. Two free parallel wires carrying currents in opposite direction

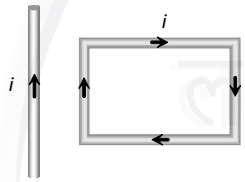
(A) Attract each other

(B) Repel each other

(C) Neither attract nor repel

(D) Get rotated to be perpendicular to each other

22. A rectangular loop carrying a current i is situated near a long straight wire such that the wire is parallel to the one of the sides of the loop and is in the plane of the loop. If a steady current I is established in wire as shown in figure, the loop will



(A) Rotate about an axis parallel to the wire

(B) Move away from the wire or towards right

(C) Move towards the wire

(D) Remain stationary

23. A circular coil of radius 4 *cm* and of 20 turns carries a current of 3 *amperes*. It is placed in a magnetic field of intensity of 0.5 $weber/m^2$. The magnetic dipole moment of the coil is

(A) 0.15 $ampere-m^2$ **(B)** 0.3 $ampere-m^2$

(C) 0.45 $ampere-m^2$ **(D)** 0.6 $ampere-m^2$

24. A conducting circular loop of radius r carries a constant current i. It is placed in a uniform magnetic field $\vec{B}$, such that $\vec{B}$ is perpendicular to the plane of the loop. The magnetic force acting on the loop is

(A) $ir\vec{B}$ **(B)** $2\pi ri\vec{B}$

(C) Zero **(D)** $\pi ri\vec{B}$

25. Two thin long parallel wires separated by a distance b are carrying a current i *amp* each. The magnitude of the force per unit length exerted by one wire on the other is

(A) $\frac{\mu_0 i^2}{b^2}$ **(B)** $\frac{\mu_0 i^2}{2\pi b}$

(C) $\frac{\mu_0 i}{2\pi b}$ **(D)** $\frac{\mu_0 i}{2\pi b^2}$

26. Through two parallel wires A and B, 10 and 2 *ampere* of currents are passed respectively in opposite direction. If the wire A is infinitely long and the length of the wire B is 2 m, the force on the conductor B, which is situated at 10 *cm* distance from A will be

(A) 8×10^{-5} N **(B)** 4×10^{-7} N

(C) 4×10^{-5} N **(D)** $4\pi\times10^{-7}$ N

27. If two streams of protons move parallel to each other in the same direction, then they

(A) Do not exert any force on each other

(B) Repel each other

(C) Attract each other

(D) Get rotated to be perpendicular to each other

28. A straight wire carrying a current i_1 amp runs along the axis of a circular current . Then the force of interaction between the two current carrying conductors is

(A) ∞ **(B)** Zero

(C) $\frac{\mu_0}{4\pi}\frac{2i_1i_2}{r}$ N/m **(D)** $\frac{2i_1i_2}{r}$ N/m

29. Two parallel wires are carrying electric currents of equal magnitude and in the same direction. They exert

(A) An attractive force on each other

(B) A repulsive force on each other

(C) No force on each other

(D) A rotational torque on each other

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30. Two long and parallel wires are at a distance of 0.1 *m* and a current of 5 *A* is flowing in each of these wires. The force per unit length due to these wires will be

(A) 5×10^{-5} N / m **(B)** 5×10^{-3} N / m

(C) 2.5×10^{-5} N / m **(D)** 2.5×10^{-4} N / m

31. An iron rod of length *L* and magnetic moment *M* is bent in the form of a semicircle. Now its magnetic moment will be

(A) M **(B)** $\frac{2M}{\pi}$

(C) $\frac{M}{\pi}$ **(D)** $M\pi$

32. Unit of magnetic flux density (or magnetic induction) is

(A) *Tesla* **(B)** *Weber/metre*^{2}

(C) *Newton/ampere-metre* **(D)** All of the above

33. Magnetic intensity for an axial point due to a short bar magnet of magnetic moment *M* is given by

(A) $\frac{\mu_0}{4\pi}\times\frac{M}{d^3}$ **(B)** $\frac{\mu_0}{4\pi}\times\frac{M}{d^2}$

(C) $\frac{\mu_0}{2\pi}\times\frac{M}{d^3}$ **(D)** $\frac{\mu_0}{2\pi}\times\frac{M}{d^2}$

34. A magnet is placed in iron powder and then taken out, then maximum iron powder is at

(A) Some away from north pole

(B) Some away from south pole

(C) The middle of the magnet

(D) The end of the magnet

35. A magnet of magnetic moment *M* and pole strength *m* is divided in two equal parts, then magnetic moment of each part will be

(A) M **(B)** M/ 2

(C) M/4 **(D)** 2M

36. Points *A* and *B* are situated along the extended axis of 2 *cm* long bar magnet at a distance *x* and 2*x cm* respectively. From the pole nearer to the points, the ratio of the magnetic field at A and B will be

(A) 4 : 1 exactly **(B)** 4 : 1 approx.

(C) 8 : 1 exactly **(D)** 8 : 1 approx.

37. If a magnet of pole strength *m* is divided into four parts such that the length and width of each part is half that of initial one, then the pole strength of each part will be

(A) m/4 **(B)** m/2

(C) m/8 **(D)** 4m

38. The distance of two points on the axis of a magnet from its centre is 10 *cm* and 20 *cm* respectively. The ratio of magnetic intensity at these points is 12.5 : 1. The length of the magnet will be

(A) 5 *cm* **(B)** 25 *cm*

(C) 10 *cm* **(D)** 20 *cm*

39. Ratio of magnetic intensities for an axial point and a point on broad side-on position at equal distance *d* from the centre of magnet will be **or** The magnetic field at a distance *d* from a short bar magnet in longitudinal and transverse positions are in the ratio

(A) 1 : 1 **(B)** 2 : 3

(C) 2 : 1 **(D)** 3 : 2

40. The magnetism of magnet is due to

(A) The spin motion of electron

(B) Earth

(C) Pressure of big magnet inside the earth

(D) Cosmic rays

41. A very small magnet is placed in the magnetic meridian with its south pole pointing north. The null point is obtained 20 *cm* away from the centre of the magnet. If the earth's magnetic field (horizontal component) at this point be 0.3 *gauss*, the magnetic moment of the magnet is

(A) 8.0×10^2 *e.m.u.* **(B)** 1.2×10^3 *e.m.u.*

(C) 2.4×10^3 *e.m.u.* **(D)** 3.6×10^3 *e.m.u.*

42. Intensity of magnetic field due to earth at a point inside a hollow steel box is

(A) Less than outside **(B)** More than outside

(C) Same **(D)** Zero

43. Earth's magnetic field always has a horizontal component except at or Horizontal component of earth's magnetic field remains zero at

(A) Equator **(B)** Magnetic poles

(C) A latitude of 60° **(D)** An altitude of 60°

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44. A dip needle in a plane perpendicular to magnetic meridian will remain

(A) Vertical

(B) Horizontal

(C) In any direction

(D) At an angle of dip to the horizontal

45. At magnetic poles of earth, angle of dip is

(A) Zero **(B)** 45°

(C) 90° **(D)** 180°

46. The correct relation is

(A) $\boldsymbol{B} = \frac{B_V}{B_H}$ **(B)** $\boldsymbol{B} = B_V \times B_H$

(C) $|\boldsymbol{B}| = \sqrt{B_H^2 + B_V^2}$ **(D)** $\boldsymbol{B} = B_H + B_V$

(Where B_H = Horizontal component of earth's magnetic field; B_V = Vertical component of earth's magnetic field and B = Total intensity of earth's magnetic field)

47. At a certain place, the horizontal component of earth's magnetic field is $\sqrt{3}$ times the vertical component. The angle of dip at that place is

(A) 60° **(B)** 45°

(C) 90° **(D)** 30°

48. The vertical component of earth's magnetic field is zero at or The earth's magnetic field always has a vertical component except at the

(A) Magnetic poles **(B)** Geographical poles

(C) Every place **(D)** Magnetic equator

49. The angle between the magnetic meridian and geographical meridian is called

(A) Angle of dip

(B) Angle of declination

(C) Magnetic moment

(D) Power of magnetic field

50. The lines of forces due to earth's horizontal component of magnetic field are

(A) Parallel straight lines **(B)** Concentric circles

(C) Elliptical **(D)** Parabolic

51. Time period of a freely suspended magnet does not depend upon

(A) Length of the magnet

(B) Pole strength of the magnet

(C) Horizontal component of earth's magnetic field

(D) Length of the suspension thread

52. Magnetic moments of two bar magnets may be compared with the help of

(A) Deflection magnetometer

(B) Vibration magnetometer

(C) Both of the above

(D) None of the above

53. The time period of oscillation of a freely suspended bar magnet with usual notations is given by

(A) $T = 2\pi\sqrt{\frac{I}{MB_H}}$ **(B)** $T = 2\pi\sqrt{\frac{MB_H}{I}}$

(C) $T = \sqrt{\frac{I}{MB_H}}$ **(D)** $T = 2\pi\sqrt{\frac{B_H}{MI}}$

54. In sum and difference method in vibration magnetometer, the time period is more if

(A) Similar poles of both magnets are on same sides

(B) Opposite poles of both magnets are on same sides

(C) Both magnets are perpendicular to each other

(D) Nothing can be said

55. At a certain place a magnet makes 30 oscillations per minute. At another place where the magnetic field is double, its time period will be

(A) 4 *sec* **(B)** 2 *sec*

(C) $\frac{1}{2}$ sec **(D)** $\sqrt{2}$ sec

56. Vibration magnetometer is used for comparing

(A) Magnetic fields **(B)** Earth's field

(C) Magnetic moments **(D)** All of the above

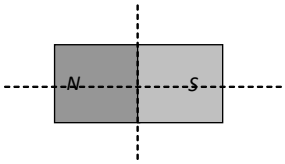
57. Two magnets of same size and mass make respectively 10 and 15 *oscillations per minute* at certain place. The ratio of their magnetic moments is

(A) 4 : 9 **(B)** 9 : 4

(C) 2 : 3 **(D)** 3 : 2

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58. Time period for a magnet is *T*. If it is divided in four equal parts along its axis and perpendicular to its axis as shown then time period for each part will be



(A) 4T $_{4T}$ **(B)** T/4
(C) T/2 **(D)** T

59. Keeping dissimilar poles of two magnets of equal pole strength and length same side, their time period will be
(A) Zero **(B)** One second
(C) Infinity **(D)** Any value

60. Time period in vibration magnetometer will be infinity at
(A) Magnetic equator **(B)** Magnetic poles
(C) Equator **(D)** At all places

61. Magnets cannot be made from which of the following substances
(A) Iron **(B)** Nickel
(C) Copper **(D)** All of the above

62. The magnetic moment of atomic neon is
(A) Zero **(B)** $\mu B / 2$
(C) μB **(D)** $3\mu B / 2$

63. Which of the following is most suitable for the core of electromagnets
(A) Soft iron **(B)** Steel
(C) Copper-nickel alloy **(D)** Air

64. Demagnetisation of magnets can be done by
(A) Rough handling
(B) Heating
(C) Magnetising in the opposite direction
(D) All the above

65. A ferromagnetic material is heated above its curie temperature. Which one is a correct statement
(A) Ferromagnetic domains are perfectly arranged
(B) Ferromagnetic domains becomes random
(C) Ferromagnetic domains are not influenced
(D) Ferromagnetic material changes itself into diamagnetic material

66. If a diamagnetic substance is brought near north or south pole of a bar magnet, it is
(A) Attracted by the poles
(B) Repelled by the poles
(C) Repelled by the north pole and attracted by the south pole
(D) Attracted by the north pole and repelled by the south pole

67. The material of permanent magnet has
(A) High retentivity, low coercivity
(B) Low retentivity, high coercivity
(C) Low retentivity, low coercivity
(D) High retentivity, high coercivity

68. The permanent magnet is made from which one of the following substances
(A) Diamagnetic **(B)** Paramagnetic
(C) Ferromagnetic **(D)** Electromagnetic

69. Temperature above which a ferromagnetic substance becomes paramagnetic is called
(A) Critical temperature **(B)** Boyle's temperature
(C) Debye's temperature **(D)** Curie temperature

70. When a magnetic substance is heated, then it
(A) Becomes a strong magnet
(B) Losses its magnetism
(C) Does not effect the magnetism
(D) Either (A) or (C)

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Exercise # 2 SINGLE OBJECTIVE AIIMS LEVEL

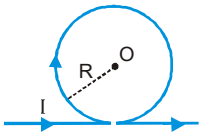
1. Two concentric coils each of radius equal to 2π cm are placed at right angles to each other. 3A and 4A are the currents flowing in each coil respectively. The magnetic induction in Wb/m^2 at the centre of the coils will be : –

($\mu_0 = 4\pi \times 10^{-7}$ Wb/Am)

(A) 12×10^{-5} **(B)** 10^{-5}

(C) 5×10^{-5} **(D)** 7×10^{-5}

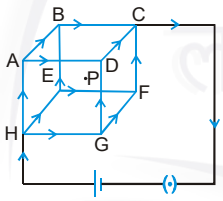
2. An infinitely long straight conductor is bent into the shape as shown in figure. It carries a current I ampere and the radius of the circular loop is r meter. Then the magnetic induction at the centre of the circular part is :–



(A) Zero **(B)** ∞

(C) $\frac{\mu_0}{4\pi}\frac{2I}{r}(\pi+1)$ **(D)** $\frac{\mu_0}{4\pi}\frac{2I}{r}(\pi-1)$

3. A steady current is set up in a cubic network composed of wires of equal resistance and length d as shown in figure. What is the magnetic field at the centre P due to the cubic network ?



(A) $\frac{\mu_0}{4\pi}\cdot\frac{2I}{d}$ **(B)** $\frac{\mu_0}{4\pi}\cdot\frac{3I}{\sqrt{2}d}$

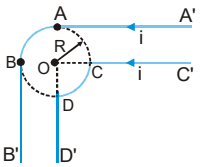
(C) 0 **(D)** $\frac{\mu_0}{4\pi}\cdot\frac{8\pi I}{d}$

4. If the intensity of magnetic field at a point on the axis of current coil is half of that at the centre of the coil, then the distance of that point from the centre of the coil will be :–

(A) $\frac{R}{2}$ **(B)** R

(C) $\frac{3R}{2}$ **(D)** 0.766R

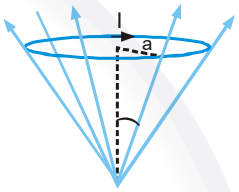
5. All straight wires are very long. Both AB and CD are arcs of the same circle, both subtending right angles at the centre O. Then the magnetic field at O is–



(A) $\frac{\mu_0 i}{4\pi R}$ **(B)** $\frac{\mu_0 i}{4\pi R}\sqrt{2}$

(C) $\frac{\mu_0 i}{2\pi R}$ **(D)** $\frac{\mu_0 i}{2\pi R}(\pi+1)$

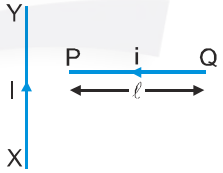
6. A circular current loop of radius a is placed in a radial field B as shown. The net force acting on the loop is



(A) zero **(B)** 2πBaIcosθ

(C) 2πaIBsinθ **(D)** None

7. A conductor PQ carries a current 'i' is placed perpendicular to a long conductor XY carrying a current I. The direction of force on PQ will be :–



(A) towards right

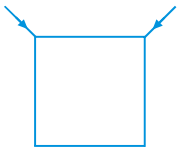
(B) towards left

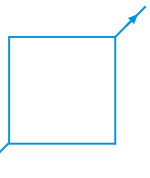
(C) upwards

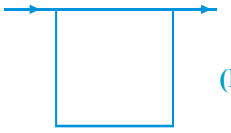
(D) downwards

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8. Current flows through uniform, square frames as shown. In which case is the magnetic field at the centre of the frame not zero?

(A) 

(B) 

(C) 

(D) 

9. A wire PQRST carrying current I = 5A is placed in uniform magnetic field B = 2T as shown in fig. If the length of part QR = 4 cm and SR = 6 cm then the magnetic force on SR edge of the wire is :–



(A) 0.4 N **(B)** 0.6 N

(C) zero **(D)** 6 N

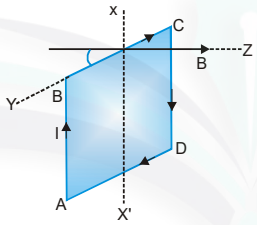
10. The square loop ABCD, carrying a current I, is placed in a uniform magnetic field B, as shown. The loop can rotate about the axis XX'. The plane of the loop makes an angle θ (θ < 90°) with the direction of B. Through what angle will the loop rotate by itself before the torque on it becomes zero –

(A) θ

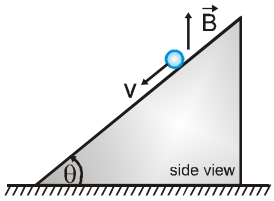
(B) 90° – θ

(C) 90° + θ

(D) 180° – θ



11. A conducting rod of length ℓ and mass m is moving down a smooth inclined plane of inclination θ with constant velocity v in fig. A current I is flowing in the conductor in a direction perpendicular to paper inwards. A vertically upward magnetic field $\vec{B}$ exists in space. Then magnitude of magnetic field $\vec{B}$ is



(A) $\frac{mg}{i\ell}\sin\theta$ **(B)** $\frac{mg}{i\ell}\tan\theta$

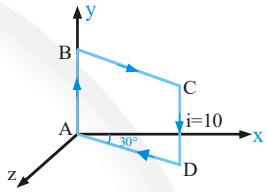
(C) $\frac{mg\cos\theta}{i\ell}$ **(D)** $\frac{mg}{i\ell\sin\theta}$

12. The unit of electric current 'Ampere' is the amount of current flowing through each of two parallel wire 1m. apart and of infinite length will give rise to a force between them equal to :–

(A) 1 N/m **(B)** 2×10^{-7} N/m

(C) 1×10^{-2} N/m **(D)** $4\pi\times10^{-7}$ N/m

13. Figure shows a square current carrying loop ABCD of side 10 cm and current i = 10 A. The magnetic moment $\vec{M}$ of the loop is



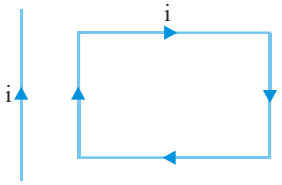
(A) $(0.05)\left(\hat{i}-\sqrt{3}\hat{k}\right)$ A – m^2

(B) $(0.05)\left(\hat{j}+\hat{k}\right)$ A – m^2

(C) $(0.05)\left(\sqrt{3}\hat{i}+\hat{k}\right)$ A – m^2

(D) $\left(\hat{i}+\hat{k}\right)$ A – m^2

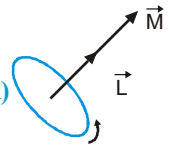
14. A rectangular loop carrying a current i is situated near a long straight wire such that the wire is parallel to one of the sides of the loop and is in the plane of the loop. If steady current I is established in the wire as shown in the figure, the loop will :

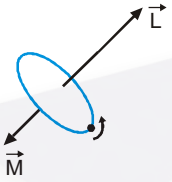


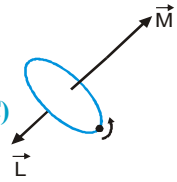
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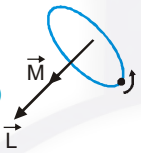
(A) rotate about an axis parallel to the wire
(B) move away from the wire
(C) move towards the wire
(D) remain stationary

15. A negatively charged particle is revolving in a circle of radius r. Out of the following which one figure represents the correct directions of $\vec{L}$ and $\vec{M}$ ($\vec{L}$ is angular momentum of particle; $\vec{M}$ is magnetic moment of the particle).

(A) 

(B) 

(C) 

(D) 

16. A helium nucleus is moving in a circular path of radius 0.8m. If it takes 2 sec to complete one revolution. Find out magnetic field produced at the centre of the circle.

(A) $\mu_0 \times 10^{-19}$ T
(B) $\frac{10^{-19}}{\mu_0}$ T
(C) 2×10^{-19} T
(D) $\frac{2 \times 10^{-19}}{\mu_0}$ T

17. An electron is moving along +x direction. To get it moving on an anticlockwise circular path in x–y plane, a magnetic field applied along

(A) +y–direction
(B) +z–direction
(C) –y–direction
(D) –z–direction

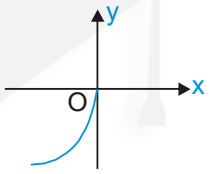
18. Two proton beams are moving with equal speed v in same direction. The ratio of electric force and magnetic force between them is – (Where c_0 is speed of light in vacuum)

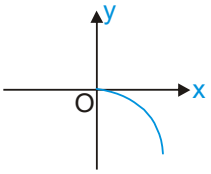
(A) $\frac{c_0^2}{v^2}$
(B) $\frac{v^2}{c_0^2}$
(C) $\frac{c_0}{v}$
(D) $\frac{v}{c_0}$

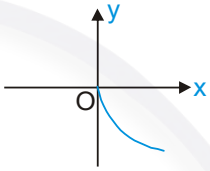
19. In a region a uniform magnetic field acts in horizontal plane towards north. If cosmic particles (80% protons) falling vertically downwards, then they are deflected towards

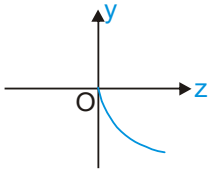
(A) North
(B) South
(C) East
(D) West

20. In a region of space uniform electric field is present as $\vec{E} = E_0\hat{j}$ and uniform magnetic field is present as $\vec{B} = B_0\hat{k}$. An electron is released from rest at origin. Which of the following best represents the path followed by electron after release.

(A) 

(B) 

(C) 

(D) 

21. Two particles X and Y having equal charges, after being accelerated through the same potential difference, enter a region of uniform magnetic field and describe circular paths of radii R_1 and R_2 respectively. The ratio of the mass of X to that of Y is :

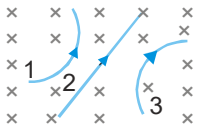
(A) $(R_1/R_2)^{1/2}$
(B) R_2/R_1
(C) $(R_1/R_2)^2$
(D) R_1/R_2

22. A charged particle moves through a magnetic field perpendicular to its direction. Then–

(A) the momentum changes but the kinetic energy is constant
(B) both momentum and kinetic energy of the particle are not constant
(C) both momentum and kinetic energy of the particle are constant
(D) kinetic energy changes but the momentum is constant

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23. The charges 1, 2, 3 are moves in uniform transverse magnetic field then :–



(A) particle '1' positive and particle 3 negative

(B) particle 1 negative and particle 3 positive

(C) particle 1 negative and particle 2 neutral

(D) particle 1 and 3 are positive and particle 2 neutral

24. A charged particle moves in a magnetic field $\vec{B} = 10\hat{i}$ with initial velocity $\vec{u} = 5i + 4\hat{j}$. The path of the particle will be

(A) straight line **(B)** circle

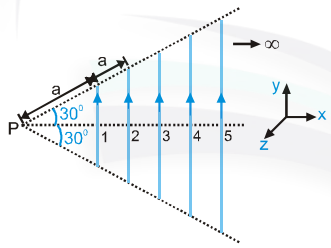
(C) helical **(D)** None

25. A proton, a deuteron and an α–particle having the same kinetic energy are moving in circular trajectories in a constant magnetic field. If r_p, r_d and r_α denote respectively the radii of the trajectories of these particles, then:

(A) $r_\alpha = r_p < r_d$ **(B)** $r_\alpha > r_d < r_p$

(C) $r_\alpha = r_d > r_p$ **(D)** $r_p = r_d = r_\alpha$

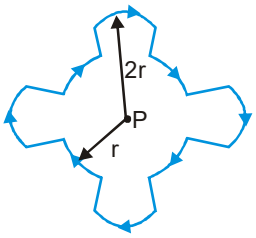
26. Infinite number of straight wires each carrying current I are equally placed as shown in the figure. Adjacent wires have current in opposite direction. Net magnetic field at point P is



(A) $\frac{\mu_0 I}{4\pi}\frac{\ell n2}{\sqrt{3}a}\hat{k}$ **(B)** $\frac{\mu_0 I}{4\pi}\frac{\ell n4}{\sqrt{3}a}\hat{k}$

(C) $\frac{\mu_0 I}{4\pi}\frac{\ell n4}{\sqrt{3}a}\left(-\hat{k}\right)$ **(D)** zero

27. A current I flows a closed path in the horizontal plane of the circle as shown in the figure. The path consists of eight cars with alternating radii r and 2r. Each segment of arc subtends equal angle at the common centre P. The magnetic field produced by current path at point P is



(A) $\frac{3}{8}\frac{\mu_0 I}{r}$; perpendicular to the plane of the paper and directed inward

(B) $\frac{1}{8}\frac{\mu_0 I}{r}$; perpendicular to the plane of the paper and directed outward

(C) $\frac{1}{8}\frac{\mu_0 I}{r}$; perpendicular to the plane of the paper and directed inward

(D) $\frac{3}{8}\frac{\mu_0 I}{r}$ perpendicular to the plane of the paper and directed outward

28. A particle of charge -16×10^{-18} C moving with velocity 10 ms^{-1} along the x–axis enters region where a magnetic field of induction B is along the y–axis and an electric field of magnitude 10^4 V/m is along the negative z–axis If the charged particle continues moving along the x–axis, the magnitude of B is–

(A) 10^3 Wb/m^2 **(B)** 10^5 Wb/m^2

(C) 10^{16} Wb/m^2 **(D)** 10^{-3} Wb/m^2

29. Equal current i is flowing in three infinitely long wires along positive x, y and z directions. The magnitude of magnetic field at a point (0, 0, –a) would be

(A) $\frac{\mu_0 i}{2\pi a}\left(\hat{j} - \hat{i}\right)$ **(B)** $\frac{\mu_0 i}{2\pi a}\left(\hat{j} + \hat{i}\right)$

(C) $\frac{\mu_0 i}{2\pi a}\left(\hat{i} - \hat{j}\right)$ **(D)** $\frac{\mu_0 i}{2\pi a}\left(\hat{i} + \hat{j} + \hat{k}\right)$

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30. Two mutually perpendicular conductors carrying currents I_1 and I_2 lie in one plane. Locus of the point at which the magnetic induction is zero, is a

(A) circle with centre as the point of intersection of the conductor

(B) parabola with vertex as the point of intersection of the conductors

(C) straight line passing through the point of intersection of the conductors

(D) rectangular hyperbola

31. An electron (mass = 9.1×10^{-31}; charge = -1.6×10^{-19} C) experiences no deflection if subjected to an electric field of 3.2×10^5 V/m and a magnetic field of 2.0×10^{-3} Wb/m^2. Both the fields are normal to the path of electron and to each other. If the electric field is removed, then the electron will revolve in an orbit of radius

(A) 45 m **(B)** 4.5 m

(C) 0.45 m **(D)** 0.045 m

32. An electron is projected with velocity v_0 in a uniform electric field E perpendicular to the field. Again it is projected with velocity v_0 perpendicular to a uniform magnetic field B. If r_1 is initial radius of curvature just after entering in the electric field and r_2 is initial radius of curvature just after entering in magnetic field then the ratio r_1/r_2 is equal to

(A) $\frac{Bv_0^2}{E}$ **(B)** $\frac{B}{E}$

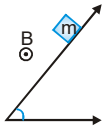
(C) $\frac{Ev_0}{B}$ **(D)** $\frac{Bv_0}{E}$

33. A uniform magnetic field $\vec{B} = B_0\hat{j}$ exists in a space. A particle of mass m and charge q is projected towards negative x–axis with speed v from the a point (d, 0, 0). The maximum value v for which the particle does not hit y–z plane is

(A) $\frac{2Bq}{dm}$ **(B)** $\frac{Bqd}{m}$

(C) $\frac{Bq}{2dm}$ **(D)** $\frac{Bqd}{2m}$

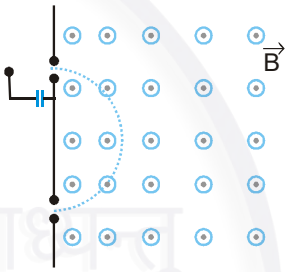
34. A block of mass m & charge q is released on a long smooth inclined plane magnetic field B is constant, uniform, horizontal and parallel to surface as shown. Find the time from start when block loses contact with the surface



(A) $\frac{m\cos\theta}{qB}$ **(B)** $\frac{m\,\mathrm{cosec}\,\theta}{qB}$

(C) $\frac{m\cot\theta}{qB}$ **(D)** None

35. A mass spectrometer is a device which select particle of equal mass. An iron with electric charge $q > 0$ starts at rest from a source S and is accelerated through a potential difference V. It passes through a hole into a region of constant magnetic field $\vec{B}$ perpendicular to the plane of the paper as shown in the figure. The particle is deflected by the magnetic field and emerges through the bottom hole at a distance d from the top hole. The mass of the particle is



(A) $\frac{qBd}{V}$ **(B)** $\frac{qB^2d^2}{4V}$

(C) $\frac{qB^2d^2}{8V}$ **(D)** $\frac{qBd}{2V}$

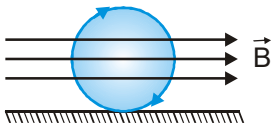
36. A conducting ring of mass 2 kg and radius 0.5 m is placed on a smooth horizontal plane. The ring carries a current i = 4A. A horizontal magnetic field B = 10 T is switched on at time t = 0 as shown in figure. The initial angular acceleration of the ring will be

(A) 40π rad/s^2

(B) 20π rad/s^2

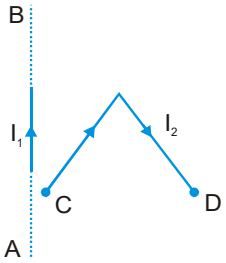
(C) 5π rad/s^2

(D) 15π rad/s^2



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37. In the figure shown a current I_1 is established in the long straight wire AB. Another wire CD carrying current I_2 is placed in the plane of the paper. The line joining the ends of this wire is perpendicular to the wire AB. The force on the wire CD is



(A) zero **(B)** towards left
(C) directed upwards **(D)** none of these

38. The dimensional formula for the physical quantity $\frac{E^2\mu_0\varepsilon_0}{B^2}$ is (E = electric field and B = magnetic field)

(A) $L^0M^0T^0$ **(B)** $L^1M^0T^{-1}$
(C) $L^{-1}M^0T^1$ **(D)** $L^{1/2}M^0T^{-1/2}$

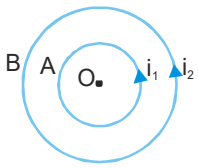
39. Two thick wires and two thin wires, all of the same materials and same length form a square in the three different ways P, Q and R as shown in fig with current direction shown, the magnetic field at the centre of the square is zero in cases



(A) in P only **(B)** in P and Q only
(C) in Q and R only **(D)** P and R only

40. A and B are two concentric circular conductors of centre O and carrying current i_1 and i_2 as shown in the diagram. If ratio of their radii is 1:2 and ratio of the flux densities at O due to A and B is 1:3 then the value of $\frac{i_1}{i_2}$ will be :–

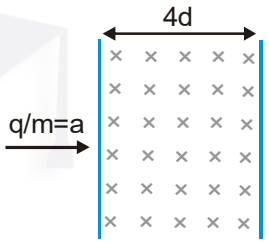
(A) $\frac{1}{2}$
(B) $\frac{1}{3}$
(C) $\frac{1}{4}$
(D) $\frac{1}{6}$



41. A moving coil galvanometer has 150 equal divisions. Its current sensitivity is 10 divisions per milli ampere and voltage sensitivity is 2 divisions per millivolt. In order that each division reads 1 V, the resistance in Ohm's needed to be connected in series with the coil will be–

(A) 10^3 **(B)** 10^5
(C) 99995 **(D)** 9995

42. If a charged particle of charge to mass ratio $q/m = \alpha$ is entering in a magnetic field of strength B at a speed $v = (2\alpha d)(B)$, then which of the following is correct?



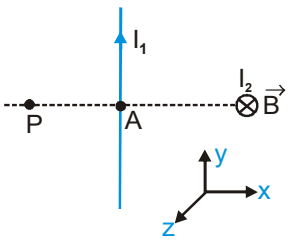
(A) Angle subtended by charged particle at the centre of circular path is 2π.

(B) The charge will move on a circular path and will come out from magnetic field at a distance 4d from the point of insertion

(C) The time for which particle will be in the magnetic field is $\frac{2\pi}{\alpha B}$

(D) The charged particle will subtend an angle of 90° at the centre of circular path

43. Two infinitely long linear conductors are arranged perpendicular to each other and are in mutually perpendicular planes as shown in figure. If I_1=2A along the y–axis and I_2 = 3A along –ve z–axis and AP = AB = 1cm. The value of magnetic field strength $\vec{B}$ at P is



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(A) $(3 \times 10^{-5}\ T)\hat{j} + (-4 \times 10^{-5}\ T)\hat{k}$

(B) $(3 \times 10^{-5}\ T)\hat{j} + (4 \times 10^{-5}\ T)\hat{k}$

(C) $(4 \times 10^{-5}\ T)\hat{j} + (3 \times 10^{-5}\ T)\hat{k}$

(D) $(-3 \times 10^{-5}\ T)\hat{j} + (4 \times 10^{-5}\ T)\hat{k}$

44. A uniform magnetic field of 1.5 T exists in a cylindrical region of radius 10.0 cm, it's direction being parallel to the axis along east to west. A current carrying wire in north south direction passes through this region. The wire intersects the axis and experience a force of 1.2 N downward. If the wire is turned from North South to north east–south west direction, then magnitude and direction of force is–

(A) 1.2 N, upward

(B) $1.2\sqrt{2}$ N, downward

(C) 1.2 N, downward

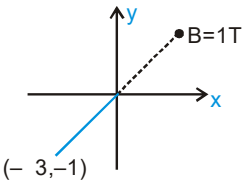
(D) $\frac{1.2}{\sqrt{2}}$ N, downward

45. There exists a uniform magnetic and electric field of magnitude 1 T and 1 V/m respectively along positive y–axis. A charged particle of mass 1 kg and of charge 1 C is having velocity 1 m/s along x–axis and is at origin at t = 0. Then the co–ordinates of particle at time π seconds will be–

(A) (0, 1, 2) **(B)** $(0, -\pi^2/2, -2)$

(C) $(2, \pi^2/2, 2)$ **(D)** $(0, \pi^2/2, 2)$

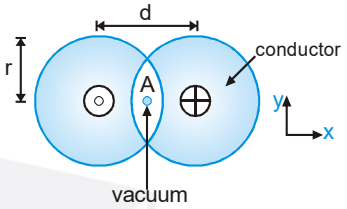
46. A uniform magnetic field of magnitude 1 T exists in region $y \geq 0$ is along $\hat{k}$ direction as shown. A particle of charge 1 C is projected from point $(-\sqrt{3}, -1)$ towards origin with speed 1 m/s. If mass of particle is 1 kg, then co–ordinates of centre of circle in which particle moves are



(A) $(1, \sqrt{3})$ **(B)** $(1, -\sqrt{3})$

(C) $\left(\frac{1}{2}, -\frac{\sqrt{3}}{2}\right)$ **(D)** $\left(\frac{\sqrt{3}}{2}, -\frac{1}{2}\right)$

47. Two long conductors are arranged as shown above to form overlapping cylinders, each of radius r, whose centers are separated by a distance d. Current of density J flows into the plane of the page along the shaded part of one conductor and an equal current flows out of the plane of the page along the shaded portion of the other, as shown. What are the magnitude and direction of the magnetic field at point A?



(A) $\left(\frac{\mu_0}{2\pi}\right)\pi dJ$, in the +y–direction

(B) $\left(\frac{\mu_0}{2\pi}\right)\frac{d^2}{r}$, in the +y direction

(C) $\left(\frac{\mu_0}{2\pi}\right)\frac{4d^2J}{r}$, in the –y direction

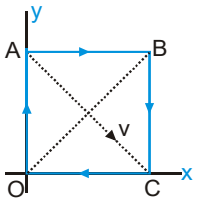
(D) $\left(\frac{\mu_0}{2\pi}\right)\frac{Jr^2}{d}$, in the –y direction

48. A particle of specific charge (charge/mass) α starts moving from the origin under the action of an electric field $\vec{E} = E_0\hat{i}$ and magnetic field $\vec{B} = B_0\hat{k}$. Its velocity at $(x_0, y_0, 0)$ is $\left(4\hat{i} - 3\hat{j}\right)$. The value of x_0 is

(A) $\frac{13\alpha E_0}{2B_0}$ **(B)** $\frac{16\alpha B_0}{E_0}$

(C) $\frac{25}{2\alpha E_0}$ **(D)** $\frac{5\alpha}{2B_0}$

49. OABC is a current carrying square loop. An electron is projected from the centre of loop along its diagonal AC as shown. Unit vector in the direction of initial acceleration will be



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(A) $\hat{k}$ (B) $-\left(\frac{\hat{i}+\hat{j}}{\sqrt{2}}\right)$

(C) $-\hat{k}$ (D) $\frac{\hat{i}+\hat{j}}{\sqrt{2}}$

50. Two particles of charges +Q and –Q are projected from the same point with a velocity v in a region of uniform magnetic field B such that the velocity vector makes an angle θ with the magnetic field. Their masses are M and 2M, respectively. Then, they will meet again for the first time at a point whose distance from the point of projection is

(A) $\frac{2\pi Mv\cos\theta}{QB}$ (B) $\frac{8\pi Mv\cos\theta}{QB}$

(C) $\frac{\pi Mv\cos\theta}{QB}$ (D) $\frac{4\pi Mv\cos\theta}{QB}$

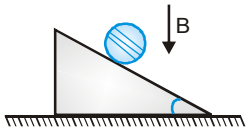
51. An electron moving with a velocity $\vec{v}_1 = 2\hat{i}$ m/s at a point in a magnetic field experiences a force $\vec{F}_1 = -2\hat{j}N$. If the electron is moving with a velocity $\vec{v}_2 = 2\hat{j}$ m/s at the same point, it experiences a force $\vec{F}_2 = +2\hat{i}N$. The force the electron would experience if it were moving with a velocity $\vec{v}_3 = 2\hat{k}$ m/s at the same point is

(A) zero (B) $2\hat{k}N$

(C) $-2\hat{k}N$

(D) Information is insufficient

52. In the figure shown a coil of single turn is wound on a sphere of radius R and mass m. The plane of the coil is parallel to the plane and lies in the equatorial plane of the sphere. Current in the coil is i. The value of B if the sphere is in equilibrium is



(A) $\frac{mg\cos\theta}{\pi iR}$ (B) $\frac{mg}{\pi iR}$

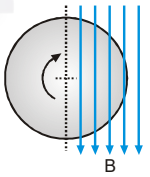
(C) $\frac{mg\tan\theta}{\pi iR}$ (D) $\frac{mg\sin\theta}{\pi iR}$

53. A conductor of length ℓ and mass m is placed along the east–west line on a table. Suddenly a certain amount of charge is passed through it and it is found to jump to a height h. The earth's magnetic induction is B. The charge passed through the conductor is

(A) $\frac{1}{Bmgh}$ (B) $\frac{\sqrt{2gh}}{B\ell m}$

(C) $\frac{gh}{B\ell m}$ (D) $\frac{m\sqrt{2gh}}{B\ell}$

54. A thin non conducting disc of radius R is rotating clockwise (see figure) with an angular velocity ω about its central axis, which is perpendicular to its plane. Both its surfaces carry +ve charges of uniform surface density. Half the disc is in a region of a uniform, unidirectional magnetic field B parallel to the plane of the disc, as shown. Then,



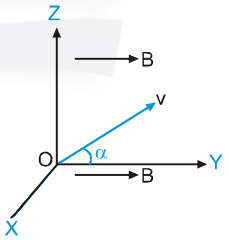
(A) The net torque on the disc is zero

(B) The net torque vector on the disc is directed leftwards

(C) The net torque vector on the disc is directed rightwards

(D) The net torque vector on the disc is parallel to B

55. In a region of space, a uniform magnetic field B exists in the y–direction. A proton is fired from the origin, with its initial velocity v making a small angle α with the y–direction in the yz plane. In the subsequent motion of the proton



(A) its x–coordinate can never be positive

(B) its x– and z–coordinates cannot both be zero at the same time

(C) its z–coordinate can never be negative

(D) its y–coordinate will be proportional to the square of its time of flight

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56. A charged particle of specific charge α is released from origin at time t = 0 with velocity $\vec{v} = v_0(\hat{i} + \hat{j})$ in uniform magnetic field $\vec{B} = B_0\hat{i}$. Coordinates of the particle at time $t = \frac{\pi}{B_0\alpha}$ are

(A) $\left(\frac{v_0}{2B_0\alpha}, \frac{\sqrt{2}v_0}{\alpha B_0}, \frac{-v_0}{B_0\alpha}\right)$ **(B)** $\left(\frac{-v_0}{2B_0\alpha}, 0, 0\right)$

(C) $\left(0, \frac{2v_0}{B_0\alpha}, \frac{v_0\pi}{2B_0\alpha}\right)$ **(D)** $\left(\frac{v_0\pi}{B_0\alpha}, 0, \frac{-2v_0}{B_0\alpha}\right)$

57. A particle of charge per unit mass α is released from origin with velocity $\vec{v} = v_0\hat{i}$ in a magnetic field $\vec{B} = -B_0\hat{k}$ for $x \le \frac{\sqrt{3}}{2}\frac{v_0}{B_0\alpha}$ and $\vec{B} = 0$ for $x > \frac{\sqrt{3}}{2}\frac{v_0}{B_0\alpha}$. The x–coordinates of the particle at time $t\left(> \frac{\pi}{3B_0\alpha}\right)$ would be

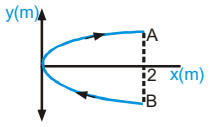
(A) $\frac{\sqrt{3}}{2}\frac{v_0}{B_0\alpha} + \frac{\sqrt{3}}{2}v_0\left(t - \frac{\pi}{B_0\alpha}\right)$

(B) $\frac{\sqrt{3}}{2}\frac{v_0}{B_0\alpha} + v_0\left(t - \frac{\pi}{3B_0\alpha}\right)$

(C) $\frac{\sqrt{3}}{2}\frac{v_0}{B_0\alpha} + \frac{v_0}{2}\left(t - \frac{\pi}{3B_0\alpha}\right)$

(D) $\frac{\sqrt{3}}{2}\frac{v_0}{B_0\alpha} + \frac{v_0 t}{2}$

58. A conducting wire bent in the form of a parabola $y^2 = 2x$ carries a current i=2A as shown in figure. This wire is placed in a uniform magnetic field $\vec{B} = -4\hat{k}$ Tesla. The magnetic force on the wire is (in newton)



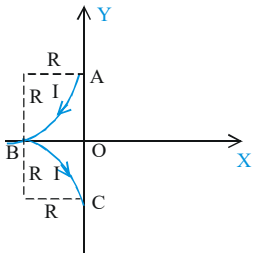
(A) $-16\hat{i}$

(B) $32\hat{i}$

(C) $-32\hat{i}$

(D) $16\hat{i}$

59. Conductor ABC consist of two quarter circular path of radius R lies in X–Y plane and carries current I as shown. A uniform magnetic field $\vec{B}$ is switched on in the region that exert force $\vec{F} = \sqrt{2}IRB_0\hat{k}$ on conductor ABC. $\vec{B}$ can be



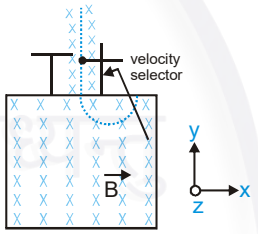
(A) $\frac{B_0}{\sqrt{2}}(-\hat{i})$

(B) $\frac{B_0}{\sqrt{2}}\hat{i}$

(C) $\frac{B_0}{\sqrt{2}}(\hat{i} + \hat{j})$

(D) Both (B) and (C)

60. Two charged particle A and B each of charge +e and masses 12 amu and 13 amu respectively follow a circular trajectory in chamber X after the velocity selector as shown in the figure. Both particles enter the velocity selector with speed 1.5×10^6 ms^{-1}. A uniform magnetic field of strength 1.0 T is maintained within the chamber X and in the velocity selector.



(A) Electric field across the conducting plate of the velocity selector is – 10^6 NC$^{-1}\hat{i}$

(B) Electric field across the conducting plate of the velocity selector is 10^6 NC$^{-1}\hat{i}$

(C) The ratio $\frac{r_A}{r_B}$ of the radii of the circular paths for the two particles is 12/13

(D) The ratio $\frac{r_A}{r_B}$ of the radii of the circular paths for the two particles is 13/12

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61. A particle of charge q and velocity v passes undeflected through a space with non–zero electric field E and magnetic field B. The undeflecting conditions will hold if

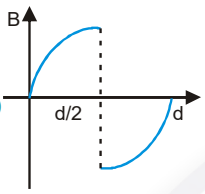
(A) signs of both q and E are reversed

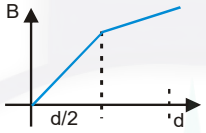
(B) signs of both q and B are reversed

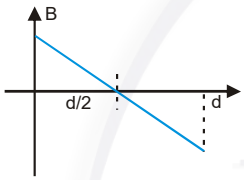
(C) both B and E are changed in magnitude, but keeping the product of $|B|$ and $|E|$ fixed.

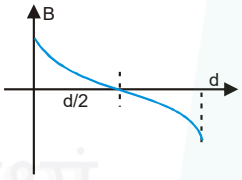
(D) both B and E are doubled in magnitude

62. A uniform beam of positively charged particles is moving with a constant velocity parallel to another beam of negatively charged particles moving with the same velocity in opposite direction separated by a distance d. The variation of magnetic field B along a perpendicular line draw between the two beams is best represented by

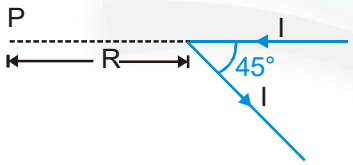
(A)


(B)


(C)


(D)


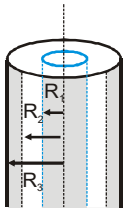
63. A long straight wire, carrying current I, is bent at its midpoint to form an angle of 45°. Magnetic field at point P, distance R from point of bending is equal to

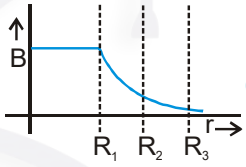


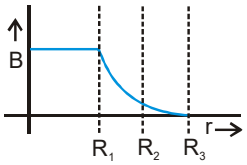
(A) $\frac{(\sqrt{2}-1)\mu_0 I}{4\pi R}$ **(B)** $\frac{(\sqrt{2}+1)\mu_0 I}{4\pi R}$

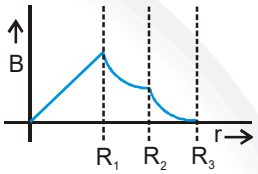
(C) $\frac{(\sqrt{2}+1)\mu_0 I}{4\sqrt{2}\pi R}$ **(D)** $\frac{(\sqrt{2}-1)\mu_0 I}{4\sqrt{2}\pi R}$

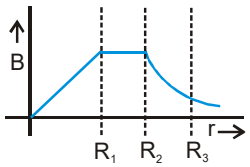
64. A coaxial cable is made up of two conductors. The inner conductor is solid and is of radius R_1 and the outer conductor is hollow of inner radius R_2 and outer radius R_3. The space between the conductors is filled with air. The inner and outer conductors are carrying currents of equal magnitudes and in opposite directions. Then the variation of magnetic field with distance from the axis is best plotted as



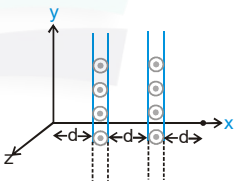
(A)


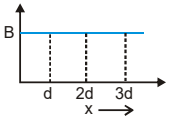
(B)


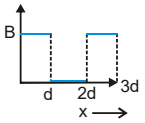
(C)


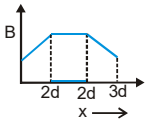
(D)


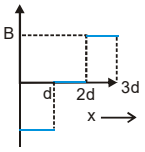
65. Two large conducting current planes perpendicular to x–axis are placed at (d, 0) and (2d, 0) as shown in figure. Current per unit width in both the planes is same and current is flowing in the outward direction. The variation of magnetic induction as function of 'x' ($0 \le x \le 3d$) is best represented by –



(A)


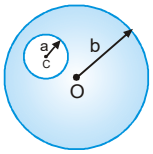
(B)


(C)


(D)


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66. A long straight metal rod has a very long hole of radius 'a' drilled parallel to the rod axis as shown in the figure. If the rod carries a current 'i' find the value of magnetic induction on the axis of the hole, where OC = c



(A) $\frac{\mu_0 ic}{\pi\left(b^2-a^2\right)}$ **(B)** $\frac{\mu_0 ic}{2\pi\left(b^2-a^2\right)}$

(C) $\frac{\mu_0 i\left(b^2-a^2\right)}{2\pi c}$ **(D)** $\frac{\mu_0 ic}{2\pi a^2 b^2}$

67. A magnetic needle lying parallel to a magnetic field requires W unit of work to turn it through 60°. The torque needed to maintain the needle in this position will be–

(A) $\sqrt{3}$ W **(B)** W

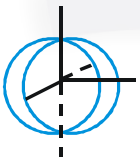
(C) ($\sqrt{3}$ /2)W **(D)** 2W

68. The magnetic moment of a short magnet is 8 Am^2 . The magnetic induction at a point 20cm away from its mid point on (i) axial point (ii) equatorial point respectively, will be :–

(A) 2×10^{-4} and 10^{-4} T **(B)** 3×10^{-4} and 2×10^{-4} T

(C) 4×10^{-4} and 3×10^{-4} T **(D)** None of these

69. Two insulated rings, one of slightly smaller diameter than the other, are suspended along their common diameter as shown. Initially the planes of the rings are mutually perpendicular. When a steady current is set up in each of them.



(A) The two rings rotate into a common plane

(B) The inner ring oscillates about its initial position

(C) The outer ring stays stationary while the inner one moves into the plane of the outer ring

(D) The inner ring stays stationary while the outer one moves into the plane of the inner ring.

70. A short bar magnet placed with its axis at 30° with a uniform external magnetic field of 0.16T experiences a torque of magnitude 0.032 J. The magnetic moment of the bar moment will be

(A) 0.23 J/T **(B)** 0.40 J/T

(C) 0.80J/T **(D)** Zero

71. A electron experiences a force $\left(4.0\hat{i}+3.0\hat{j}\right)\times10^{-13}$ N in a uniform magnetic field when its velocity is $2.5\hat{k}\times10^{7}$ ms^{-1}. When the velocity is redirected and becomes $\left(1.5\hat{i}-2.0j\right)\times10^{7}$ ms^{-1}, the magnetic force of the electron is zero. The magnetic field vector $\vec{B}$ is

(A) $-0.075\hat{i}+0.1\hat{j}$ **(B)** $0.1\hat{i}+0.075\hat{j}$

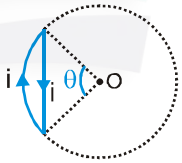
(C) $0.075\hat{i}-0.1\hat{j}+\hat{k}$ **(D)** $0.075\hat{i}-0.1\hat{j}$

72. A particle of charge q and mass m starts moving from the origin under the action of an electric field $\vec{E}=E_0\hat{i}$ and $\vec{B}=B_0\hat{i}$ with velocity $\vec{v}=v_0\hat{j}$. The speed of the particle will become $2v_0$ after a time

(A) $t=\frac{2mv_0}{qE}$ **(B)** $t=\frac{2Bq}{mv_0}$

(C) $t=\frac{\sqrt{3}Bq}{mv_0}$ **(D)** $t=\frac{\sqrt{3}mv_0}{qE}$

73. Net magnetic field at the centre of the circle O due to a current carrying loop as shown in figure is $(\theta<180°)$



(A) zero

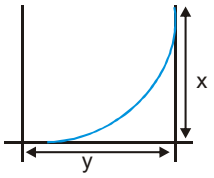
(B) perpendicular to paper inwards

(C) perpendicular to paper outwards

(D) is perpendicular to paper inwards if $\theta\le90°$ and perpendicular to paper outwards if $90°\le\theta<180°$

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74. A particle having charge q enters a region of uniform magnetic field $\vec{B}$ (directed inwards) and is deflected a distance x after travelling a distance y. The magnitude of the momentum of the particle is



(A) $\frac{qBy}{2}$ **(B)** $\frac{qBy}{x}$

(C) $\frac{qB}{2}\left(\frac{y^2}{x}+x\right)$ **(D)** $\frac{qBy^2}{2x}$

75. A particle of specified charge (q/m) is projected from the origin of coordinates with initial velocity $\left[u\hat{i}-v\hat{j}\right]$. Uniform electric magnetic fields exists in the region along the +y direction, of magnitude E and B. The particle will definitely return to the origin once if

(A) $\left[\frac{vB}{2\pi E}\right]$ is an integer

(B) $\left(u^2+v^2\right)^{1/2}\left[\frac{B}{\pi E}\right]$ is an integer

(C) $\left[\frac{vB}{\pi E}\right]$ in an integer

(D) $\left[\frac{uB}{\pi E}\right]$ is an integer

76. A charged particle enters a uniform magnetic field perpendicular to its initial direction travelling in air. The path of the particle is seen to follow the path in figure. Which of statements 1–3 is /are correct?

(1) The magnetic field strength may have been increased while the particle was travelling in air

(2) The particle lost energy by ionising the air

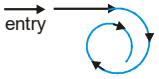
(3) The particle lost charge by ionising the air

(A) 1, 2, 3 are correct

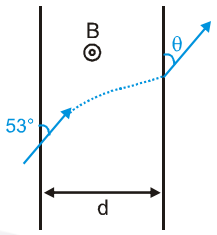
(B) 1, 2 only are correct

(C) 2, 3 only are correct

(D) 1 only



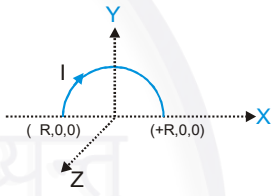
77. A particle moving with velocity v having specific charge (q/m) enters a region of magnetic field B having width $d=\frac{3mv}{5qB}$ at angle 53° to the boundary of magnetic field. Find the angle θ in the diagram.



(A) 37^0 **(B)** 60°

(C) 90° **(D)** None

78. A semi circular current carrying wire having radius R is placed in x–y plane with its centre at origin 'O'. There is non–uniform magnetic field $\vec{B}=\frac{B_0x}{2R}\hat{k}$ (here B_0 is +ve constant) is existing in the region. The magnetic force acting on semi circular wire will be along



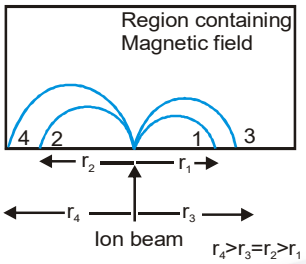
(A) –x axis **(B)** +y–axis

(C) –y axis **(D)** +x–axis

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Exercise # 3 PART - 1 MATRIX MATCH COLUMN

1. A beam consisting of four types of ions A, B, C and D enters a region that contains a uniform magnetic field as shown. The field is perpendicular to the plane of the paper, but its precise direction is not given.



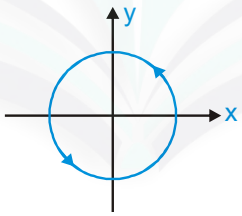
All ions in the beam travel with the same speed. The table below gives the masses and charges of the ions. The ions fall at different positions 1, 2, 3 and 4, as shown. Correctly match the ions with respective falling positions.

Table–I	Table–II
(A) A	(P) 1
(B) B	(Q) 2
(C) C	(R) 3
(D) D	(S) 4

2. A charged particle is moving in a circular path in uniform magnetic field. Match the following :

Table–I	Table–II
(A) Equivalent current due to motion of charge particle	(P) is proportional to v
(B) Magnetic moment	(Q) is proportional to v^2
(C) Magnetic field at centre of circle due to motion of charged particle	(R) is proportional to v^0
	(S) None

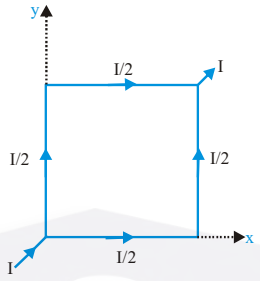
3. A circular current carrying loop is placed in x–y plane as shown in figure. A uniform magnetic field $\vec{B}=B_0\hat{k}$ is present in the region. Match the following :



Table–I	Table–II
(A) Magnetic moment of the loop	(P) zero
(B) Torque on the loop	(Q) maximum
(C) Potential energy of the loop	(R) along positive z–axis
(D) Equilibrium of the loop	(S) stable
	(T) None

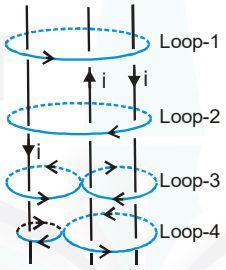
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4. A square loop of uniform conducting wire is as shown in figure. A current I (in amperes) enters the loop from one end and exits the loop from opposite end as shown in figure. The length of one side of square loop is ℓ metre. The wire has uniform cross section area and uniform linear mass density. In four situation of column I, the loop is subjected to four different magnetic field. Under the conditions of column I, match the column I with corresponding results of column II. $\vec{B}$ in column–I is a positive non–zero constant)



Column I	Column II
(A) $\vec{B}=B_0\hat{i}$ in tesla	(P) Magnitude of net force on loop is $\sqrt{2}\ B_0 I\ell$ newton
(B) $\vec{B}=B_0\hat{j}$ in tesla	(Q) Magnitude of net force on loop is zero
(C) $\vec{B}=B_0(\hat{i}+\hat{j})$ in tesla	(R) Magnitude of net torque on loop about its centre is zero
(D) $\vec{B}=B_0\hat{k}$ in tesla	(S) Magnitude of net force on loop is $B_0 I\ell$ newton

5. Three wires are carrying same constant current i in different directions. Four loops enclosing the wires in different manners are shown. The direction of $d\vec{\ell}$ is shown in figure.



Column I	Column II
(A) Along closed loop–1	(P) $\oint \vec{B}.d\vec{\ell} = \mu_0 i$
(B) Along closed loop–2	(Q) $\oint \vec{B}.d\vec{\ell} = -\mu_0 i$
(C) Along closed loop–3	(R) $\oint \vec{B}.d\vec{\ell} = 0$
(D) Along closed loop–4	(S) Net work done by the magnetic force to move a unit charge along the loop is zero

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6. **Column I** (Magnetic moment of) **Column II**

(A)	a uniformly charged ring rotating uniformly about its axis	**(P)**	$\frac{q\omega r^2}{5}$
(B)	a charged particle rotating uniformly about a point	**(Q)**	$\frac{q\omega r^2}{4}$
(C)	a uniformly charged disk rotating uniformly about its axis	**(R)**	$\frac{q\omega r^2}{3}$
(D)	a uniformly charged spherical shell rotating uniformly about one of its diameter	**(S)**	$\frac{q\omega r^2}{2}$
(E)	a uniformly charged sphere rotating uniformly about one of its diameter	**(T)**	$q\omega r^2$

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Exercise # 3 PART - 2 ASSERTION & REASONING

These questions contains, Statement I (assertion) and Statement II (reason).

(A) If both assertion and reason are true and the reason is the correct explanation of the assertion.

(B) If both assertion and reason are true but reason is not the correct explanation of the assertion.

(C) If assertion is true but reason is false.

(D) If assertion is false but reason is true.

(E) If the assertion and reason both are false.

1. **Assertion :** A direct uniformly distributed current flows through a solid long metallic cylinder along its length. It produces magnetic field only outside the cylinder .
Reason : A thin long cylindrical tube carrying uniformly distributed current along its length does not produce a magnetic field inside it. Moreover, a solid cylinder can be supposed to be made up of many thin cylindrical tubes.

2. **Assertion :** A charged particle undergoes non-rectilinear motion in a constant magnetic field. The only force acting on the particle is the magnetic force. Then kinetic energy of this particle remains constantbut momentum of the particle does not remains constant:
Reason : A force that always acts on the particle in direction perpendicular to its velocity does no work on the particle. But whenever resultant force acts on the particle, linear momentum of the particle does not remains constant:

3. **Assertion :** A parallel beam of negatively charged particles passes undeflected through crossed electric and magnetic fields (neglect the electromagnetic interaction between the negatively charged particles). When the electric field is switched off, the beam splits up in several beams. This splitting is due to the particles in the beam having different velocities.
Reason : For charged particles undergoing uniform circular motion in uniform magnetic field, radius of their path is directly proportional to speed. Hence charged particles with different speed may move in circular paths of different radii in a uniform magnetic field.

4. **Assertion :** Two charged particles are released from rest in gravity free space. After some time, one particle will exert a non-zero magnetic force on the other particle in addition to electrostatic force.
Reason : A moving charge produces magnetic field. Also a magnetic force may act on a charged particle moving in an external magnetic field.

5. **Assertion :** Cyclotron does not accelerate electron.
Reason : Mass of the electron is very small.

6. **Assertion :** Cyclotron is a device which is used to accelerate the positive ion.
Reason : Cyclotron frequency depends upon the velocity.

7. **Assertion :** Magnetic field interacts with a moving charge and not with a stationary charge.
Reason : A moving charge produces a magnetic field.

8. **Assertion :** If an electron is not deflected while passing through a certain region of space, then only possibility is that there is no magnetic region.
Reason : Force is directly proportional to the magnetic field applied.

9. **Assertion :** Free electron always keep on moving in a conductor even then no magnetic force act on them in magnetic field unless a current is passed through it.
Reason : The average velocity of free electron is zero.

10. **Assertion :** The ion cannot move with a speed beyond a certain limit in a cyclotron.
Reason : As velocity increases time taken by ion increases.

11. **Assertion :** The coil is bound over the metallic frame in moving coil galvanometer.
Reason : The metallic frame help in making steady deflection without any oscillation.

12. **Assertion :** A circular loop carrying current lies in XY plane with its center at origin having a magnetic flux in negative Z-axis.
Reason : Magnetic flux direction is independent of the direction of current in the conductor.

13. **Assertion :** The energy of charged particle moving in a uniform magnetic field does not change.
Reason : Work done by magnetic field on the charge is zero.

14. **Assertion :** If an electron, while coming vertically from outerspace, enter the earth's magnetic field, it is deflected towards west.
Reason : Electron has negative charge.

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Exercise # 4 PART - 1 PREVIOUS YEAR (NEET/AIPMT)

MAGNETIC EFFECT OF CURRENT

1. Two wires are held perpendicular to the plane of paper and are 5 m apart. They carry currents of 2.5 A and 5 A in same direction. Then, the magnetic field strength (B) at a point midway between the wires will be

(A) $\frac{\mu_0}{4\pi}$ T **(B)** $\frac{\mu_0}{2\pi}$ T

(C) $\frac{3\mu_0}{2\pi}$ T **(D)** $\frac{3\mu_0}{4\pi}$ T

2. Current is flowing in a coil of area A and number of turns N, then magnetic moment of the coil, M is equal to

(A) NiA **(B)** $\frac{Ni}{A}$

(C) $\frac{Ni}{\sqrt{A}}$ **(D)** N^2Ai

3. A charged particle of charge q and mass m enters perpendicularly in a magnetic field B Kinetic energy of the particle is E, then frequency of rotation is

(A) $\frac{qB}{m\pi}$ **(B)** $\frac{qB}{2\pi m}$

(C) $\frac{qBE}{2\pi m}$ **(D)** $\frac{qB}{2\pi E}$

4. The magnetic field of a given length of wire carrying a current for a single turn circular coil at centre is B, then its value for two turns for the same wire when same current passing through it is

(A) $\frac{B}{4}$ **(B)** $\frac{B}{2}$

(C) 2 B **(D)** 4 B

5. A charge q moves in a region where electric field E and magnetic field B both exist, then the force on it is

(A) q (v × B) **(B)** q E + q (v × B)

(C) q B + q (B × v) **(D)** q B + q (E × v)

6. A charged particle moves through a magnetic field in a direction perpendicular to it. Then, the

(A) acceleration remains unchanged

(B) velocity remains unchanged

(C) speed of the particle remains unchanged

(D) direction of the particle remains unchanged

7. A long solenoid carrying a current produces a magnetic field B along its axis. If the current is doubled and the number of turns per cm is halved, the new value of the magnetic field is

(A) 2B **(B)** 4 B

(C) $\frac{B}{2}$ **(D)** B

8. A coil in the shape of an equilateral triangle of side *l* is suspended between the pole pieces of a permanent magnet such that B is in plane of the coil. If due to a current i in the triangle a torque τ acts on it, the side *l* of the triangle is

(A) $\frac{2}{\sqrt{3}}\left(\frac{\tau}{Bi}\right)^{1/2}$ **(B)** $\frac{2}{\sqrt{3}}\left(\frac{\tau}{Bi}\right)$

(C) $2\left(\frac{\tau}{\sqrt{3}Bi}\right)^{1/2}$ **(D)** $\frac{1}{\sqrt{3}}\frac{\tau}{Bi}$

9. An electron moves in a circular orbit with a uniform speed v. It produces a magnetic field B at the centre of the circle. The radius of the circle is proportional to

(A) $\frac{B}{v}$ **(B)** $\frac{v}{B}$

(C) $\sqrt{\frac{v}{B}}$ **(D)** $\sqrt{\frac{B}{v}}$

10. When a charged particle moving with velocity v is subjected to a magnetic field of induction B, the force on it is non-zero. This implies that

(A) angle between v and B is necessarily 90°

(B) angle between v and B can have any value other than 90°

(C) angle between v and B can have any value other than zero and 180°

(D) angle between v and B is either zero or 180°

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11. Two circular coils 1 and 2 are made from the same wire but the radius of the 1st coil is toice that of the 2nd coil. What is the ratio of potential difference applied across them so that the magnetic field at their centres is the same?

(A) 3 **(B)** 4

(C) 6 **(D)** 2

12. Under the influence of a uniform magnetic field a charged particle is moving in a circle of radius R with constant speed v. The time period of the motion

(A) depends on v and not on R

(B) depends on both R and v

(C) is independent of both R and v

(D) depends on R and not on v

13. A charged particle (charge q) is moving in a circle of radius R with uniform speed v. The associated magnetic moment μ is given by

(A) $\frac{qvR}{2}$ **(B)** qvR^2

(C) $\frac{qvR^2}{2}$ **(D)** qvR

14. A beam of electrons passes undeflected through mutually perpendicular electric and magnetic fields. If the electric field is switched OFF and the same magnetic field is maintained, the electrons move

(A) in an elliptical orbit

(B) in a circular orbit

(C) along a parabolic path

(D) along a straight line

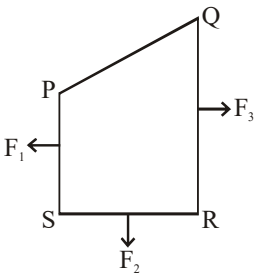
15. A closed loop PQRS carrying a current is placed in a uniform magnetic field. If the magnetic forces on segments PS, Sr and RQ are F_1, F_2 and F_3 respectively and are in the plane of the paper and along the directions shown in figure, the force on the segment QP is

(A) $F_3 - F_1 - F_2$

(B) $\sqrt{(F_3 - F_1)^2 + F_2^2}$

(C) $\sqrt{(F_3 - F_1)^2 - F_2^2}$

(D) $F_3 - F_1 + F_2$



16. A particle of mass m, charge q and kinetic energy T enters a transverse uniform magnetic field of induction B. After 3 s, the kinetic energy of the particle will be

(A) 3T **(B)** 2 T

(C) T **(D)** 4T

17. The magnetic force acting on a charged particle of charge – 2 μC in a magnetic field particle velocity is $(2\hat{i} + 3\hat{j}) \times 10^6 \, ms^{-1}$ is

(A) 8 N in z-direction **(B)** 4 N in z-direction

(C) 8 N in y-direction **(D)** 8 N in z-direction

18. A square current carrying loop is suspended in a uniform magnetic field acting in the plane of the loop. If the force on one arm of the loop is F, the net force on the remaining three arms of the loop is

(A) 3 F **(B)** – F

(C) – 3 F **(D)** F

19. A beam of cathode rays is subjected to crossed electric (E) and magnetic fields (B). The fields are adjusted such that the beam is not deflected. The specific charge of the cathode rays is given by

(A) $\frac{B^2}{2VE^2}$ **(B)** $\frac{2VB^2}{E^2}$

(C) $\frac{2VE^2}{B^2}$ **(D)** $\frac{E^2}{2VB^2}$

20. A uniform electric field and a uniform magnetic field are acting along the same direction in a certain region. If an electron is projected in the region such that its velocity is pointed along the direction of fields, then the electron

(A) speed will decrease

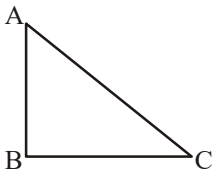
(B) speed will increase

(C) will turn towards left of direction of motion

(D) will turn towards right of direction of motion

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21. A current carrying closed loop in the form of a right angled isosceles ΔABC is placed in a uniform magnetic field acting along AB. If the magnetic force on the arm BC is F, the force on the arm AC is



(A) $-F$ **(B)** F

(C) $\sqrt{2}F$ **(D)** $-\sqrt{2}F$

22. An alternating electric field of frequency v, is applied across the dees (radius = R) of a cyclotron that is being used to accelerate protons (mass = m). The operating magnetic field (B) used in the cyclotron and the kinetic energy (K) of the proton beam, produced by it, are given by

(A) $B = \frac{mv}{e}$ and $K = 2m\pi^2v^2R^2$

(B) $B = \frac{2\pi mv}{e}$ and $K = m^2\pi vR^2$

(C) $B = \frac{2\pi mv}{e}$ and $K = 2m\pi^2v^2R^2$

(D) $B = \frac{mv}{e}$ and $K = m^2\pi vR^2$

23. Two similar coils of radius R are lying concentrically with their planes at right angles to each other. The currents flowing in them are I and and 2I, respectively. The resultant magnetic field induction at the centre will be

(A) $\frac{\sqrt{5}\mu_0 I}{2R}$ **(B)** $\frac{3\mu_0 I}{2R}$

(C) $\frac{\mu_0 I}{2R}$ **(D)** $\frac{\mu_0 I}{R}$

24. A current loop in a magnetic field

(A) experiences a torque whether the field is uniform or non-uniform in all orientations

(B) can be in equilibrium in one orientation

(C) can be in equilibrium in two orientations, both the equilibrium states are unstable

(D) can be in equilibrium in two orientations, one stable while other is unstable

25. When a proton is released from rest in a room, it starts with an initial acceleration a_0 towards West. When it is projected towards North with a speed v_0 it moves with an initial acceleration 3 a_0 towards West. The electric and magnetic fields in the room are

(A) $\frac{ma_0}{e}$ West, $\frac{2ma_0}{ev_0}$ up

(B) $\frac{ma_0}{e}$ West, $\frac{2ma_0}{ev_0}$ down

(C) $\frac{ma_0}{e}$ East, $\frac{3ma_0}{ev_0}$ up

(D) $\frac{ma_0}{e}$ East, $\frac{3ma_0}{ev_0}$ down

26. Two identical long conducting wires AOB and COD are placed at right angle to each other, such that one is above the other and O is their common point. The wires carry I_1 and I_2 currents, respectively. Point P is lying at distance d from O along a direction perpendicu lar to the plane containing the wires. The magnetic field at the point P will be

(A) $\frac{\mu_0}{2\pi d}\left(\frac{l_1}{l_2}\right)$

(B) $\frac{\mu_0}{2\pi d}(l_1 + l_2)$

(C) $\frac{\mu_0}{2\pi d}(l_1^2 - l_2^2)$

(D) $\frac{\mu_0}{2\pi d}(l_1^2 + l_2^2)^{1/2}$

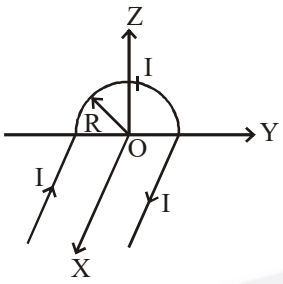
27. An electron moving in a circular orbit of radius r makes n rotations per second. The magnetic field produced at the centre has magnitude

(A) $\frac{\mu_0 ne}{2\pi r}$ **(B)** zero

(C) $\frac{\mu_0 n^2 e}{r}$ **(D)** $\frac{\mu_0 ne}{2r}$

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28. A wire carrying current I has the shape as shown in adjoining figure. Linear parts of the wire are very long and parallel to X-axis while semicircular portion of radius R is lying in Y-Z plane. Magnetic field at point O is



(A) $B = \frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{i} + 2\hat{k})$ **(B)** $B = -\frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{i} - 2\hat{k})$

(C) $B = -\frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{i} + 2\hat{k})$ **(D)** $B = \frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{i} - 2\hat{k})$

29. An electron is moving in a circular path under the influence of a transverse magnetic field of 3.57×10^{-2} T. If the value of e/m is 1.76×10^{11} C/kg, the frequency of revolution of the electron is

(A) 1 GHz **(B)** 100 MHz

(C) 62.8 MHz **(D)** 6.28 MHz

30. A long wire carrying a steady current is bent into a circular loop of one turn. The magnetic field at the centre of the loop is B. It is then bent into a circular coil of n turns. The magnetic field at the centre of this coil of n turns will be

(A) nB **(B)** n^2B

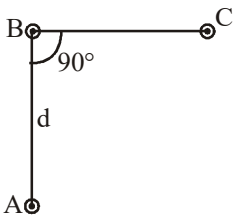
(C) 2nB **(D)** $2n^2B$

31. A long straight wire of radius a carries a steady current I. The current is uniformly distributed over its cross-section. The ratio of the magnetic fields B and B′ at radical distances $\frac{a}{2}$ and 2 a respectively, from the axis of the wire is

(A) $\frac{1}{2}$ **(B)** 1

(C) 4 **(D)** $\frac{1}{4}$

32. An arrangement of three parallel straight wires placed perpendicular to plane of paper carrying same current I along the same direction is shown in figure. Magnitude of force per unit length on the middle wire B is given by



(A) $\frac{\mu_0 i^2}{2\pi d}$ **(B)** $\frac{2\mu_0 i^2}{\pi d}$

(C) $\frac{\sqrt{2}\mu_0 i^2}{\pi d}$ **(D)** $\frac{\mu_0 i^2}{\sqrt{2}\pi d}$

33. A 250-turn rectangular coil of length 2.1 cm and width 1.25 cm carries a current of 85 μA and subjected to a magnetic field of strength 0.85 T. Work done for rotating the coil by 180° against the torque is

(A) 9.1 μJ **(B)** 4.55 μJ

(C) 2.3 μJ **(D)** 1.5 μJ

MAGNETISM

34. In which type of material the magnetic suscetibility does not depend on temperature?

(A) Diamagnetic **(B)** Paramagnetic

(C) Ferromagnetic **(D)** Ferrite

35. Two bar magnets having same geometry with magnetic moments M and 2 M, are firstly placed in such a way that their similar poles are on the same side, then its period of oscillation is T_1. Now, the polarity of one of the magnets is reversed the time period of oscillations becomes T_2. Then

(A) $T_1 < T_2$ **(B)** $T_1 > T_2$

(C) $T_1 = T_2$ **(D)** $T_2 = \infty$

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36. A diamagnetic material in a magnetic field moves

(A) perpendicular to the field
(B) from weaker to the stronger parts of the field
(C) from stronger to the weaker parts of the field
(D) None of the above

37. According to Curie's law, the magnetic susceptibility of a paramagnetic substance at an absolute temperature T is proportionsl to

(A) $\frac{1}{T^2}$ **(B)** T^2
(C) $\frac{1}{T}$ **(D)** T

38. If the magnetic dipole moment of an atom of diamagnetic material, paramagnetic material and ferromagnetic material are denoted by μ_d, μ_p and μ_f respectively,

(A) $\mu_d \neq 0$ and $\mu_f \neq 0$ **(B)** $\mu_p = 0$ and $\mu_f \neq 0$
(C) $\mu_d = 0$ and $\mu_p \neq 0$ **(D)** $\mu_d \neq 0$ and $\mu_p \neq 0$

39. Above Curie temperature

(A) a ferromagnetic substance becomes paramagnetic
(B) a paramagnetic substance becomes diamagnetic
(C) a diamagnetic substance becomes paramagnetic
(D) a paramagnetic substance becomes ferromagnetic

40. Nickel shows ferromagnetic property at room temperature. If the temperature is increased beyond Curie temperature, then it will show

(A) paramagnetism **(B)** anti-ferromagnetism
(C) no magnetic property **(D)** diamagnetis

41. If a diamagnetic substance is brough near the North or the South pole of a bar magnet, it is

(A) repelled by both the poles
(B) repelled by the North pole and attracted by the South pole
(C) attracted by the North pole and repelled by the Sourth pole
(D) attracted by both the poles

42. A bar magnetic having a magnetic moment of 2×10^4 J T^{-1} is free to rotate in horizontal plane. A horizontal magnetic field $B = 6 \times 10^{-4}$ T exists in the space. The work done in taking the maget slowly from a direction parallel to the field to a direction 60° from the field is

(A) 0.6 J **(B)** 12 J
(C) 6 J **(D)** 2 J

43. A vibration magnetometer placed in magnetic meridian has a small bar magnet. The magnet executes oscillations with a time period fo 2 s in the earth's horizontal magnetic field of 24 μT. When a horizontal field of 18 μT is produced opposite to the earth's field by placing a current carrying wire, the new time period of magnet will be

(A) 1 s **(B)** 2 s
(C) 3 s **(D)** 4 s

44. There are four light weight rod samples A, B, C and D separately suspended by thread. A bar magnet is slowly brough near each sample and the following observations are noted

(i) A is feebly repelled
(ii) B is feebly attracted
(iii) C is strongly attracted
(iv) D remains unaffected

Which one of the following is true?

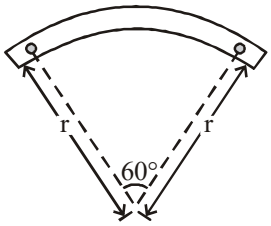
(A) C is of a diamagnetic material
(B) D is of a ferromagnetic material
(C) A is of non-magnetic material
(D) B is of a paramagnetic material

45. A compass needle which is allowed to move in a horizontal plane is taken to a geomagnetic pole. It

(A) will become rigid showing no movement
(B) will stay in any position
(C) will stay in North-South direction only
(D) will stay in East-West direction only

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46. A bar magnet of length l and magnetic dipole moment M is bent in the form of an arc as shown in figure. The new magnetic dipole moment will be

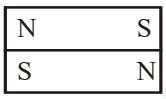


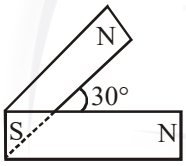
(A) M **(B)** $\frac{3}{\pi}$M

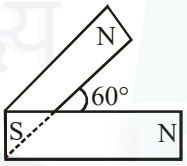
(C) $\frac{2}{\pi}$M **(D)** $\frac{M}{2}$

47. Following figures show the arrangement of bar magnets in different configurations. Each magnet has magnetic dipole moment M. which configuration has highest net magnetic dipole moment?

(i)


(ii)


(iii)


(iv)


(A) (i) **(B)** (ii)

(C) (iii) **(D)** (iv)

48. A bar magnetic is hung by a thin cotton thread in a uniform horizontal magnetic field and is in equilibrium state. the energy required to rotate it by 60° is W. Now the torque required to keep the magnet in this new position is

(A) $\frac{W}{\sqrt{3}}$ **(B)** $\sqrt{3}$ W

(B) $\frac{\sqrt{3}\,W}{2}$ **(D)** $\frac{2W}{\sqrt{3}}$

49. The magnetic susceptibility is negative for

(A) paramagnetic material only
(B) ferromagnetic material only
(C) paramagnetic and ferromagnetic materials
(D) diamagnetic material only

50. If θ_1 and θ_2 be the apparent angles of dip observed in two vertical planes at right angles to each other, then the true angle of dip θ is given by

(A) $\cot^2\theta = \cot^2\theta_1 + \cot^2\theta_2$
(B) $\tan^2\theta = \tan^2\theta_1 + \tan^2\theta_2$
(C) $\cot^2\theta = \cot^2\theta_1 - \cot^2\theta_2$
(D) $\tan^2\theta = \tan^2\theta_1 - \tan^2\theta_2$

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Exercise # 4 PART - 2 PREVIOUS YEAR (AIIMS)

MOVING CHARGES AND MAGNETISM

1. A moving coil galvanometer has a resistance of 900 Ω. In order to send only 10% of the main current through this galvanometer, the resistance of the required shunt is

(A) 0.9 Ω **(B)** 100 Ω

(C) 405 Ω **(D)** 90 Ω

2. What should be the amount of current through the ring of radius 5 cm so that field in the centre is with earth's magnetic field of 7×10^{-5} Wb/m^2 is

(A) 0.5 A **(B)** 0.28 A

(C) 2.8 A **(D)** 5.6 A

3. A wire of length *l* carries a steady current. It is bent first to form a circular plane loop of one turn. The magnetic field at the centre of the loop is B. The same length is now bent more sharply to give a double loop of smaller radius. The magnetic field at the centre caused by the same is

(A) B **(B)** B/4

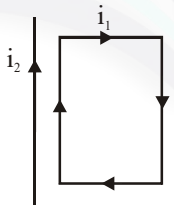
(C) 4B **(D)** B/2

4. The earth's magnetic field at a given point is 0.5×10^{-5} Wb/m^2. This field is to be annulled by magnetic induction at the center of a circular conducting loop of radius 5.0 cm. The current required to be flown in the loop is nearly

(A) 0.2 A **(B)** 0.4 A

(C) 4 A **(D)** 40 A

5. A rectangular loop carrying a current i_1, is situated near a long straight wire carrying a steady current i_2, The wire is parallel to one of the sides of the loop and is in the plane of the loop as shown in the figure. Then the current loop will



(A) move away from the wire

(B) move towards the wire

(C) remain stationary

(D) rotate about an axis parallel to the wire.

6. An electron is travelling along the x-direction. It encounters a magnetic field in the y-direction. Its subsequent motion will be

(A) straight line along the x-direction

(B) a circle in the xz plane

(C) a circle in the yz plane

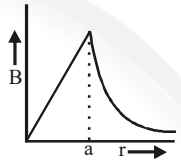
(D) a circle in the xy plane

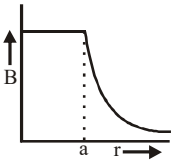
7. A circular coil of radius R carries an electric current. The magnetic field due to the coil at a point on the axis of the coil located at a distance r from the center of the coil, such that r > > R, varies as

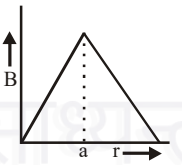
(A) 1/r **(B)** $1/r^{3/2}$

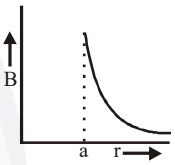
(C) $1/r^2$ **(D)** $1/r^3$

8. The magnetic field due to a straight conductor of uniform cross-section of radius a and carrying a steady current is represented by

(A)


(B)


(C)


(D)


9. The magnetic moment of a current (I) carrying circular coil of radius (r)

(A) $1/r^2$ **(B)** 1/r

(C) r **(D)** r^2

10. The cyclotron frequency of an electron gyrating in a magnetic field of 1 T is approximately

(A) 28 MHz **(B)** 280 MHz

(C) 2.8 MHz **(D)** 28 GHz

11. Circular loop of a wire and a long straight wire carry currents I_c and I_e respectively as shown in figure. Assuming that these are placed in the same plane, the magnetic fields will be aero at the centre of the loop when separation H is

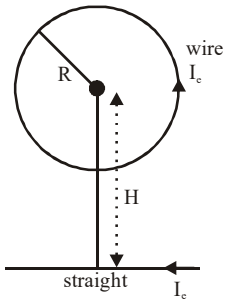
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(A) $\frac{I_e R}{I_c \pi}$

(B) $\frac{I_c R}{I_e \pi}$

(C) $\frac{\pi I_c}{I_e R}$

(D) $\frac{I_e \pi}{I_c R}$

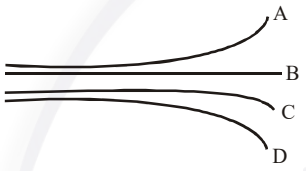


12. What is the magnetic field at a distance R from a coil of radius r carrying current I ?

(A) $\frac{\mu_0 I R^2}{2(R^2+r^2)^{\frac{3}{2}}}$ (B) $\frac{\mu_0 I r^2}{2(R^2+r^2)^{\frac{3}{2}}}$

(C) $\frac{\mu_0 I}{2r}$ (D) $\frac{\mu_0 I}{2R}$

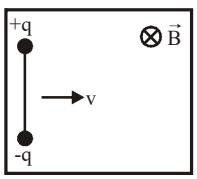
13. In the following diagram, which particle has highest e/m value ?



(A) A (B) B

(C) C (D) D

14. Two charges +q and –q are attached to the two ends of a light rod of length L, as shown in figure. The system is given a velocity v perpendicular to magnetic field $\vec{B}$. The magnetic force on the system of charges and magnitude of force on one charge by the rod, are respectively



(A) zero, zero (B) zero, qvB

(C) 2qvB, 0 (D) 2qvB, qvB

15. The ratio of magnetic fields on the axis of a circular current carrying coil of radius a to the magnetic field at its centre will be

(A) $\frac{1}{\left(1+\frac{x^2}{a^2}\right)^{3/2}}$ (B) $\frac{1}{\left(1+\frac{a^2}{x^2}\right)^{1/2}}$

(C) $\frac{1}{\left(1+\frac{a^2}{x^2}\right)^{2}}$ (D) $\frac{1}{\left(1+\frac{a^2}{x^2}\right)^{3}}$

16. A moving coil galvanometer has a resistance of 900 Ω. In order to send only 10% of the main current through this galvanometer, the resistance of the required shunt is

(A) 0.9 Ω (B) 100 Ω

(C) 405 Ω (D) 90 Ω

17. A current I_1 carrying wire AB is placed near another long wire CD carrying current I_2. If wire AB is free to move, it will have

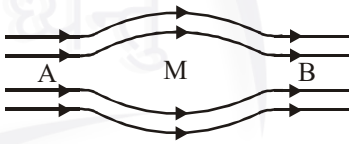
(A) rotational motion only

(B) translational motion only

(C) rotational as well as translational motion

(D) neither rotational nor translational motion

18. An uncharged particle is moving with a velocity of $\vec{v}$ in non-uniform magnetic field as shown



Velocity $\vec{v}$ would be

(A) Maximum at A & B

(B) Minimum at A & B

(C) Maximum at M

(D) Same at all points

19. A galvanometer has a current sensitivity of 1 mA per division. A variable shunt is connected across the galvanometer and the combination is put in series with a resistance 500 Ω and cell of internal resistance 1 Ω. It gives a deflection of 5 division for shunt of 5 ohm and 20 division for shunt of 25 ohm. The emf of cell is

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(A) 47.1 V (B) 57.1 V
(C) 67.1 V (D) 77.1 V

20. Magnetic energy per unit volume is represented by

(A) $\frac{B^2}{2\mu_0}$ (B) $\frac{B^2}{2\mu_0^2}$

(C) $\frac{2B^2}{\mu_0}$ (D) $\frac{B^2}{\mu_0}$

21. A proton travels few distance in an electric field, then it enters a crossed magnetic field of 1 T and radius 0.2 m, find the velocity of proton.

(A) 0.2×10^8 m s^{-1} (B) 0.2×10^7 m s^{-1}
(C) 0.2×10^6 m s^{-1} (D) 2×10^7 m s^{-1}

22. Magnetic field at a distance a from long current carrying wire is proportional to

(A) $\frac{1}{a}$ (B) $\frac{1}{a^2}$

(C) $\frac{1}{\sqrt{a}}$ (D) $\frac{1}{a^{3/2}}$

23. When a positively charged particle enters into a uniform magnetic field with uniform velocity, its trajectory can be

(i) a straight line (ii) a circle (iii) a helix

(A) (i) only
(B) (i) or (ii)
(C) (i) or (iii)
(D) any one of (i), (ii) and (iii)

24. A wire of mass 100 g, length 1 m and current 5 A is balanced in mid air by a magnetic field B, then find the value of B.

(A) 0.2 T (B) 0.1 T
(C) 0.5 T (D) 0.6 T

25. A toroid with mean radius r_0, diameter 2a have N turns carrying current I. What is the magnetic field B inside the toroid ?

(A) $\frac{NI}{2\pi r_0}$ (B) $\frac{NI}{2\pi(r_0 + a)}$

(C) $\frac{NI}{\pi(r_0 + a)}$ (D) 0

26. Two wires carrying

(A) Parallel current repel each other.
(B) Antiparallel current attract each other.
(C) Antiparallel current repel each other.
(D) Equal magnitudes of antiparallel current attract eachother.

27. Two parallel long wires A and B carry currents i_1 and i_2 ($< i_1$). When i_1 and i_2 are in the same direction, the magnetic field at a point mid way between the wires is 10 μT. If i_2 is reverse the field becomes 30 mT. The ratio i_1/i_2 is

(A) 1 (B) 2
(C) 3 (D) 4

28. A long straight wire carries 10 A d.c. current an electron travels perpendicular to the plane of this wire at a distance 0.1 m with velocity 5.0×10^6 m s^{-1}. Force acting on the electron due to current in wire is

(A) zero N (B) 0.6×10^{-17} N
(C) 2.4×10^{-17}N (D) 2.2×10^{-17} N

29. A particle of charge q and mass m starts moving from the origin under the action of an electric field $\vec{E} = E_0\hat{i}$ and $\vec{B} = B_0\hat{i}$ with a velocity $\vec{v} = v_0\hat{j}$. The speed of the particle will become $\frac{\sqrt{5}}{2}v_0$ after a time

(A) $\frac{mv_0}{qE_0}$ (B) $\frac{mv_0}{2qE_0}$

(C) $\frac{\sqrt{3mv_0}}{2qE_0}$ (D) $\frac{\sqrt{5mv_0}}{2qE_0}$

30. The force per unit length between two straight conductors separated by a distance of 0.02 m is 2×10^{-3} N m^{-1}. The current in one conductor is 10 A and that in the other conductor is

(A) 20 A (B) 5 A
(C) 2 A (D) 10 A

31. What is the magnetic field on the axis of a coil of radius r carrying current I at a distance R from the origin ?

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(A) $\frac{\mu_0 Ir^2}{2(r^2+R^2)^{3/2}}$ (B) $\frac{\mu_0 IR^2}{2(r^2+R^2)^{3/2}}$

(C) $\frac{\mu_0 I}{2(r+R)}$ (D) $\frac{\mu_0 IR}{2(r^2+R^2)^{1/2}}$

32. A voltmeter of resistance 20000 Ω reads 5 volt. To make it read 20 volt, the extra resistance required is

(A) 40000 Ω in parallel

(B) 60000 Ω in parallel

(C) 60000 Ω in series

(D) 40000 Ω in series

33. The magnetic field at the centre O of the arc shown in the figure is

(A) $2I(\sqrt{2}+\pi)\times\frac{10^{-7}}{r}$ (B) $2I(\sqrt{2}+\frac{\pi}{4})\times\frac{10^{-7}}{r}$

(C) $I(\sqrt{2}+\pi)\times\frac{10^{-7}}{r}$ (D) $I(\sqrt{2}+\frac{\pi}{4})\times\frac{10^{-7}}{r}$

ASSERTION AND REASON

34. **Assertion :** Cyclotron does not accelerate electrons.
Reason : Mass of electrons is very small.

35. **Assertion :** Voltmeter is connected in parallel with the circuit.
Reason : Resistance of a voltmeter is very large.

36. **Assertion :** A spark occur between the poles of a switch when the switch is opened.
Reason : Current flowing in the conductor produces magnetic field.

37. **Assertion :** When radius of circular lop carrying current is doubled, its magnetic moment becomes four times.
Reason : Magnetic moment depends on area of the loop.

38. **Assertion :** The energy of charged particle moving in a uniform magnetic field does not change.
Reason : Work done by magnetic field on the charge is zero.

39. **Assertion :** A charge, whether stationary or in motion produces a magnetic field around it.
Reason : Moving charges produce only electric field in the surrounding space.

40. **Assertion :** If a proton and an a-particle enter a uniform magnetic field perpendicularly with the same speed, the time period of revolution of α-particle is double that of proton.
Reason : In a magnetic field, the period of revolution of a charged particle is directly proportional to the mass of the particle and is inversely proportional to charge of particle.

41. **Assertion :** Magnetic force is always perpendicular to the magnetic field.
Reason : Electric force is along the direction of electric field.

42. **Assertion :** A planar circular loop of area A and carrying current I is equivalent to magnetic dipole of dipole moment M = IA.
Reason : At large distance, magnetic field of circular loop and magnetic dipole is same.

43. Assertion A charged particle can be accelerated in a cyclotron by the alternate distribution of the field.
Reason : Energy of charged particle is increased by the field applied.

44. **Assertion :** Magnetic lines form closed loops in nature.
Reason : Mono-magnetic pole does not exist in nature.

45. **Assertion :** Magnetic field is useful in producing parallel beam of charged particle.
Reason : Magnetic field inhibits the motion of charged particle moving across it.

46. **Assertion :** An emf e is induced in a closed loop when magnetic flux is varied. The induced electric field E is not a conservative field.
Reason : The line integral $\oint \vec{E}.\vec{dl}$ around the closed loop is non-zero.

47. **Assertion :** When a magnetic dipole is placed in a non uniform magnetic field, only a torque acts on the dipole.
Reason : Force would act on dipole if magnetic field is uniform.

48. **Assertion :** In water, value of magnetic field decreases.

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Reason : Water is a diamagnetic substance.

49. **Assertion :** Magnetic field is useful in producing parallel beam of charged particle.
Reason : Magnetic field inhibits the motion of charged particle moving across it.

MAGNETISM AND MATTER

50. Force between two identical bar magnets whose centres are r metre apart is 4.8 N when their axes are in the same line. If separation is increased to 2r, the force between them is reduced to
(A) 2.4 N (B) 0.6 N
(C) 1.2 N (D) 0.3 N

51. Which of the following statements is not correct about the magnetic field ?
(A) Magnetic lines of force don't cut each other.
(B) Inside the magnet the lines go from north to south pole of the magnet.
(C) The magnetic lines form a closed loop
(D) Tangents to the magnetic lines give the direction of the magnetic field.

52. The magnetic needle of a tangent galvanometer is deflected at an angle 30° due to a magnet. The horizontal component of earth's magnetic field 0.34×10^{-4} T is along the plane of the coil. The magnetic intensity is
(A) 1.96×10^{-4} T (B) 1.96×10^{4} T
(C) 1.96×10^{-5} T (D) 1.96×10^{5} T

53. A frog can be levitated in a magnetic field produced by a current in a vertical solenoid placed below the frog. This is possible because the body of the frog behaves as
(A) paramagnetic (B) diamagnetic
(C) ferromagnetic (D) antiferromagnetic.

54. Liquid oxygen remains suspended between two pole faces of a magnet because it is
(A) diamagnetic (B) paramagnetic
(C) ferromagnetic (D) antiferromagnetic

55. The magnetic susceptibility of an ideal diamagnetic substance is
(A) -1 (B) 0
(C) $+1$ (D) ∞

56. The intensity of magnetic field due to an isolated pole of strength m_p at a point distant r from it will be
(A) m_p/r^2 (B) $m_p r^2$
(C) r^2/m_p (D) m_p/r

57. Which of the following is true regarding dimagnetic substances (symbols have their usual meaning)
(C) $\mu_r < 1, x_m < 0$ (D) $\mu_r < 1, x_m > 0$

58. Which of the following substances magnetic susceptibility x_m is negative ?
(A) Diamagnetic (B) Paramagnetic
(C) Ferromagnetic (D) All of these

59. When orientation of dipoles parallel and antiparallel to magnetic field is distributed unequally, then the material is
(A) paramagnetic (B) ferromagnetic
(C) ferrimagnetic (D) antiferromagnetic

60. Relation between magnetic moment and angular velocity is
(A) $M \propto \omega$ (B) $M \propto \omega^2$
(C) $M \propto \sqrt{\omega}$ (D) None of these

61. The temperature of transition from ferromagnetic property to paramagnetic property is called
(A) Transition temperature
(B) Critical temperature
(C) Curie temperature
(D) Triplet temperature.

62. The angles of dip at the poles and the equator respectively are
(A) 30°, 60° (B) 0°, 90°
(C) 45°, 90° (D) 90°, 0°

63. The angle of dip at a certain place where the horizontal and vertical components of the earth's magnetic field are equal is
(A) 30° (B) 75°
(C) 60° (D) 45°

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ASSERTION AND REASON

64. **Assertion :** The true geographic north direction is found by using a compass needle.
Reason : The magnetic meridian of the earth is along the axis of rotation of the earth

65. **Assertion :** A disc-shaped magnet is leviated above a superconducting material that has been cooled by liquid nitrogen.
Reason : Superconductors repel a magnet.

66. **Assertion :** Diamagnetic material can exhibit magnetism.
Reason : diamagnetic materials have permanent magnetic dipole moment

67. **Assertion :** Ferromagnetic substances become paramagnetic above Curie temp.
Reason : Domains are destroyed at high temperature.

68. **Assertion :** We cannot think of magnetic field configuration with three poles.
Reason : A bar magnet does exert a torque on itself due to its own field.

69. **Assertion :** Magnetic susceptibility is a pure number.
Reason : The value of magnetic susceptibility for vacuum is one.

70. **Assertion :** the magnetic poles of earth do not coincide with the geographic poles.
Reason : The discrepancy between the orientation of a compass and true north-south direction is known as magnetic declination.

71. **Assertion :** magnetic field lines are continuous and closed.
Reason : Magnetic monopole does not exist.

72. **Assertion :** Magnetic force between tow short magnets, when they are co-axial follows inverse square law of distance.
Reason : The magnetic forces between two poles do not follow inverse square law of distance.

73. **Assertion :** A superconductor is a perfect diamagnetic substance.
Reason : A superconductor is a perfect conductor.

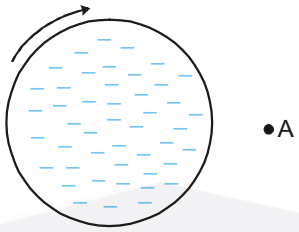
74. **Assertion :** Magnetic field lines are continuous and closed.
Reason : Magnetic monopole does not exist.

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MOCK TEST

STRAIGHT OBJECTIVE TYPE

1. The negatively and uniformly charged nonconducting disc as shown in the figure is rotated clockwise with great angular speed. The direction of the magnetic field at point A in the plane of the disc is



(A) into the page **(B)** out of the page **(C)** up the page **(D)** down the page

2. A particle is moving with velocity $\vec{v} = \hat{i} + 3\hat{j}$ and it produces an electric field at a point given by $\vec{E} = 2\hat{k}$. It will produce magnetic field at that point equal to (all quantities are in S.I. units)

(A) $\frac{6\hat{i} - 2\hat{j}}{c^2}$ **(B)** $\frac{6\hat{i} + 2\hat{j}}{c^2}$ **(C)** zero

(D) can not be determined from the given data

3. Two observers moving with different velocities see that a point charge produces same magnetic field at the same point A . Their relative velocity must be parallel to $\vec{r}$, where $\vec{r}$ is the position vector of point A with respect to point charge. This statement is :

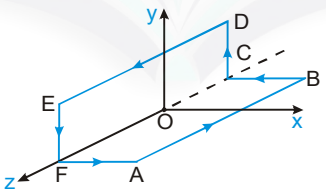
(A) true

(B) false

(C) nothing can be said

(D) true only if the charge is moving perpendicular to the $\vec{r}$

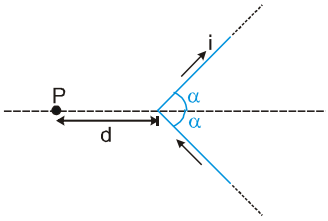
4. In the figure shown A B C D E F A was a square loop of side ℓ, but is folded in two equal parts so that half of it lies in x z plane and the other half lies in the y z plane. The origin 'O' is centre of the frame also. The loop carries current 'i'. The magnetic field at the centre is:



(A) $\frac{\mu_0 i}{2\sqrt{2}\,\pi\,\ell}\left(\hat{i} - \hat{j}\right)$ **(B)** $\frac{\mu_0 i}{4\,\pi\,\ell}\left(-\hat{i} + \hat{j}\right)$ **(C)** $\frac{\sqrt{2}\,\mu_0 i}{\pi\,\ell}\left(\hat{i} + \hat{j}\right)$ **(D)** $\frac{\mu_0 i}{\sqrt{2}\,\pi\,\ell}\left(\hat{i} + \hat{j}\right)$

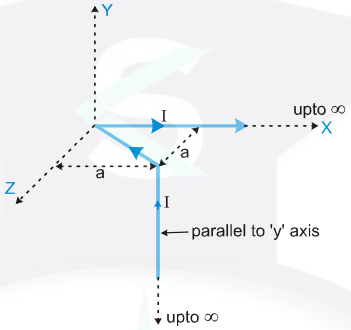
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5. If the magnetic field at 'P' in the given figure can be written as K tan $\left(\frac{\alpha}{2}\right)$ then K is :



(A) $\frac{\mu_0 I}{4\pi d}$ **(B)** $\frac{\mu_0 I}{2\pi d}$ **(C)** $\frac{\mu_0 I}{\pi d}$ **(D)** $\frac{2\mu_0 I}{\pi d}$

6. The magnetic field at the origin due to the current flowing in the wire as shown in figure below is

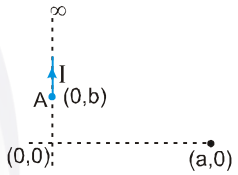


(A) $-\frac{\mu_0 I}{8\pi a}(\hat{i}+\hat{k})$ **(B)** $\frac{\mu_0 I}{2\pi a}(\hat{i}+\hat{k})$ **(C)** $\frac{\mu_0 I}{8\pi a}(-\hat{i}+\hat{k})$ **(D)** $\frac{\mu_0 I}{4\pi a\sqrt{2}}(\hat{i}-\hat{k})$

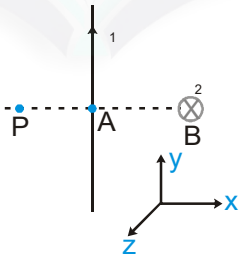
7. An infinitely long wire carrying current I is along Y axis such that its one end is at point A (0, b) while the wire extends upto + ∞. The magnitude of magnetic field strength at point (a, 0) is

(A) $\frac{\mu_0 I}{4\pi a}\left(1+\frac{b}{\sqrt{a^2+b^2}}\right)$ **(B)** $\frac{\mu_0 I}{4\pi a}\left(1-\frac{b}{\sqrt{a^2+b^2}}\right)$

(C) $\frac{\mu_0 I}{4\pi a}\left(\frac{b}{\sqrt{a^2+b^2}}\right)$ **(D)** None of these



8. Two infinitely long linear conductors are arranged perpendicular to each other and are in mutually perpendicular planes as shown in figure. If $I_1 = 2A$ along the y-axis and $I_2 = 3A$ along negative z-axis and AP = AB = 1 cm. The value of magnetic field strength $\vec{B}$ at P is -

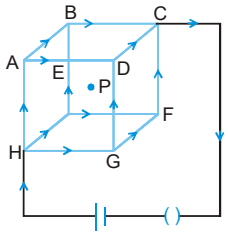


(A) $(3\times10^{-5}\,T)\,\hat{j}+(-4\times10^{-5}\,T)\,\hat{k}$ **(B)** $(3\times10^{-5}\,T)\,\hat{j}+(4\times10^{-5}\,T)\,\hat{k}$

(C) $(4\times10^{-5}\,T)\,\hat{j}+(3\times10^{-5}\,T)\,\hat{k}$ **(D)** $(-3\times10^{-5}\,T)\,\hat{j}+(4\times10^{-5}\,T)\,\hat{k}$

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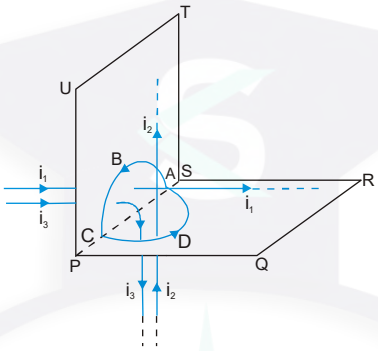
9. A steady current is set up in a cubic network composed of wires of equal resistance and length d as shown in figure. What is the magnetic field at the centre of cube P due to the cubic network ?



(A) $\frac{\mu_0}{4\pi}\frac{2I}{d}$ **(B)** $\frac{\mu_0}{4\pi}\frac{3I}{\sqrt{2}\,d}$

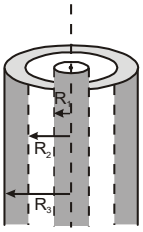
(C) 0 **(D)** $\frac{\mu_0}{4\pi}\frac{\theta\pi I}{d}$

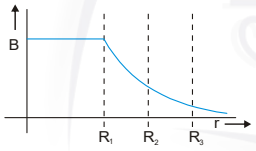
10. Figure shows an amperian path ABCDA. Part ABC is in vertical plane PSTU while part CDA is in horizontal plane PQRS. Direction of circulation along the path is shown by an arrow near point B and at D. $\oint \vec{B}.d\vec{\ell}$ for this path according to Ampere's law will be :

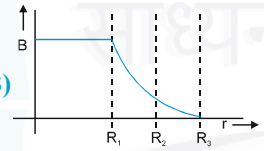


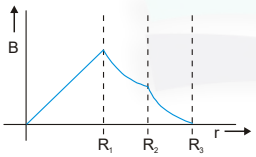
(A) $(i_1 - i_2 + i_3)\,\mu_0$ **(B)** $(-i_1 + i_2)\,\mu_0$ **(C)** $i_3\,\mu_0$ **(D)** $(i_1 + i_2)\,\mu_0$

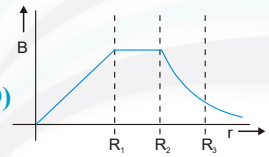
11. A coaxial cable is made up of two conductors. The inner conductor is solid and is of radius R_1 & the outer conductor is hollow of inner radius R_2 and outer radius R_3. The space between the conductors is filled with air. The inner and outer conductors are carrying currents of equal magnitudes and in opposite directions. Then the variation of magnetic field with distance from the axis isbest plotted as:



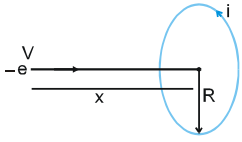
(A)


(B)


(C)


(D)


12. An electron moving with velocity V along the axis approaches a circular current carrying loop as shown in the figure. The magnitude of magnetic force on electron at this instant is

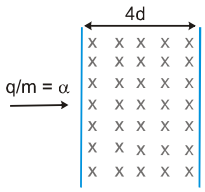


(A) $\frac{\mu_0}{2}\frac{e\,v\,i\,R^2\,x}{(x^2+R^2)^{3/2}}$ **(B)** $\mu_0\frac{e\,v\,i\,R^2\,x}{(x^2+R^2)^{3/2}}$

(C) $\frac{\mu_0}{4\pi}\frac{e\,v\,i\,R^2\,x}{(x^2+R^2)^{3/2}}$ **(D)** 0

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13. If a charged particle of charge to mass ratio $\frac{q}{m} = \alpha$ is entering in a uniform magnetic field of strength B which is extended up to 4d as shown in figure at a speed v = (2αd)(B), then which of the following is correct :



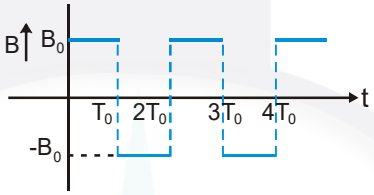
(A) angle subtended by charged particle at the centre of circular path is 2π.

(B) the charge will move on a circular path and will come out from magnetic field at a distance 4d from the point of insertion.

(C) the time for which particle will be in the magnetic field is $\frac{2\pi}{\alpha B}$.

(D) the charged particle will substend an angle of 90^0 at the centre of circular path

14. In a region magnetic field along x axis changes with time according to the given graph.



If time period, pitch and radius of helix path are T_0, P_0 and R respectively then which of the following is incorrect if the particle is projected at an angle θ_0 with the positive x-axis in x-y plane:

(A) At $t = \frac{T_0}{2}$, co-ordinates of charge are $\left(\frac{P_0}{2}, 0, -2R_0\right)$.

(B) At $t = \frac{3T_0}{2}$, co-ordinates of charge are $\left(\frac{3P_0}{2}, 0, 2R_0\right)$.

(C) Two extremes from x-axis are at a distance $2R_0$ from each other.

(D) Two extremes from x-axis are at a distance $4R_0$ from each other.

15. A Positive point charge is moving in clockwise direction in a circle with constant speed. Consider the magnetic field produced by the charge at a point P (not centre of the circle) on the axis of the circle.

(A) it is constant in magnitude only

(B) it is constant in direction only

(C) it is constant in direction and magnitude both

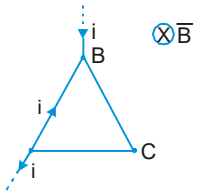
(D) it is not constant in magnitude and direction both.

16. An α particle is moving along a circle of radius R with a constant angular velocity ω. Point A lies in the same plane at a distance 2R from the centre. Point A records magnetic field produced by α particle. If the minimum time interval between two successive times at which A records zero magnetic field is 't', the angular speed ω, in terms of t is -

(A) $\frac{2\pi}{t}$ **(B)** $\frac{2\pi}{3t}$ **(C)** $\frac{\pi}{3t}$ **(D)** $\frac{\pi}{t}$

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17. Figure shows an equilateral triangle ABC of side ℓ carrying currents, placed in uniform magnetic field B. The magnitude of magnetic force on triangle is

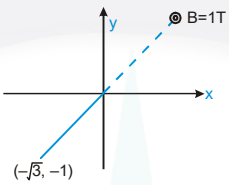


(A) $i\ell B$ **(B)** $2i\ell B$ **(C)** $3i\ell B$ **(D)** zero

18. There exists a uniform magnetic and electric field each of magnitude 1 T and 1 V/m respectively along positive y-axis. A charged particle of mass 1 kg and of charge 1 C is having velocity 1 m/sec along x-axis and is at origin at t = 0. Then the co-ordinates of particle at time π seconds will be:

(A) $(0, 1, 2)$ **(B)** $(0, -\pi^2/2, -2)$ **(C)** $(2, \pi^2/2, 2)$ **(D)** $(0, \pi^2/2, 2)$

19. A uniform magnetic field of magnitude 1 T exists in region $y \geq 0$ is along $\hat{k}$ direction as shown. A particle of charge 1 C is projected from point $(-\sqrt{3}, -1)$ towards origin with speed 1 m/sec. If mass of particle is 1 kg, then co-ordinates of centre of circle in which particle moves are:



(A) $(1, \sqrt{3})$ **(B)** $(1, -\sqrt{3})$ **(C)** $\left(\frac{1}{2}, -\frac{\sqrt{3}}{2}\right)$ **(D)** $\left(\frac{\sqrt{3}}{2}, -\frac{1}{2}\right)$

20. A uniform magnetic field exists in region which forms an equilateral triangle of side a. The magnetic field is perpendicular to the plane of the triangle. A charge q enters into this magnetic field perpendicularly with speed v along perpendicular bisector of one side and comes out along perpendicular bisector of other side. The magnetic induction in the triangle is

(A) $\frac{mv}{qa}$ **(B)** $\frac{2mv}{qa}$ **(C)** $\frac{mv}{2qa}$ **(D)** $\frac{mv}{4qa}$

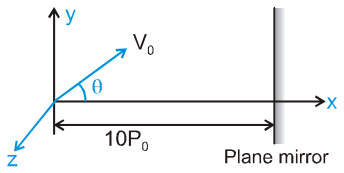
21. A positively charged particle having charge q and mass m enters with velocity $V\hat{j}$ at the origin in a magnetic field $B(-\hat{k})$ which is present in the space every where. The charge makes a perfectly inelastic collision with identical particle at rest but free to move at its maximum y-coordinate. After collision the combined charge will move on trajectory : (where $r = \frac{mV}{qB}$)

(A) $y = \frac{mv}{qB}(-\hat{i})$ **(B)** $(x + r)^2 + (y - r/2)^2 = r^2/4$

(C) $(x - r)^2 + (y - r)^2 = r^2$ **(D)** $(x - r)^2 + (y + r/2)^2 = r^2/4$

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22. In the plane mirror, the co-ordinates of image of charged particle (initially at origin as shown) after two and half time periods are (initial velocity V_0 is in the xy-plane and the plane mirror is perpendicular to the x-axis. A uniform magnetic field $B\hat{i}$ exists in the whole space. P_0 is pitch of helix, R_0 is radius of helix).



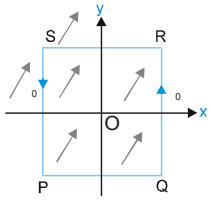
(A) $17P_0, 0, -2R_0$ **(B)** $3P_0, 0, -2R_0$

(C) $17.5\ P_0, 0, -2R_0$ **(D)** $3P_0, 0, 2R_0$

23. A uniform, constant magnetic field $\vec{B}$ is directed at an angle of 45° to the x-axis in the xy-plane, PQRS is a rigid square wire frame carrying a steady current I_0, with its centre at the origin O. At time t = 0, the frame is at rest in the position shown in the figure, with its sides parallel to the x and y axes. Each side of the frame is of mass M and length L.. The torque $\vec{\tau}$ about O acting on the frame due to the magnetic field will be

(A) $\vec{\tau} = \frac{BI_0L^2}{\sqrt{2}}\left(-\hat{i} + \hat{j}\right)$ **(B)** $\vec{\tau} = \frac{BI_0L^2}{\sqrt{2}}\left(\hat{i} - \hat{j}\right)$

(C) $\vec{\tau} = \frac{BI_0L^2}{\sqrt{2}}\left(\hat{i} + \hat{j}\right)$ **(D)** $\vec{\tau} = \frac{BI_0L^2}{\sqrt{2}}\left(-\hat{i} - \hat{j}\right)$

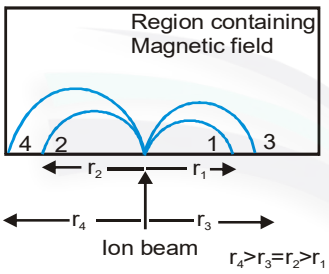


24. A ring of mass m, radius r having charge q uniformly distributed over it and free to rotate about its own axis is placed in a region having a magnetic field B parallel to its axis. If the magnetic field is suddenly switched off, the angular velocity acquired by the ring is

(A) $\frac{qB}{m}$ **(B)** $\frac{2qB}{m}$ **(C)** $\frac{qB}{2m}$ **(D)** None of these

MATRIX - MATCH TYPE

25. A beam consisting of four types of ions A, B, C and D enters a region that contains a uniform magnetic field as shown. The field is perpendicular to the plane of the paper, but its precise direction is not given. All ions in the beam travel with the same speed. The table below gives the masses and charges of the ions.



The ions fall at different positions 1, 2, 3 and 4, as shown. Correctly match the ions with respective falling positions.

(A) a **(P)** 1

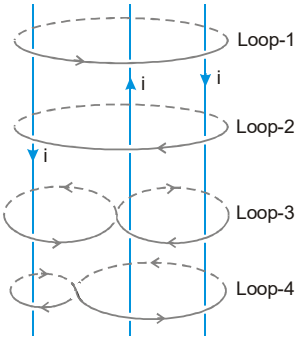
(B) b **(Q)** 2

(C) c **(R)** 3

(D) d **(S)** 4

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26. Three wires are carrying same constant current i in different directions. Four loops enclosing the wires in different mannersare shown. The direction of $d\vec{\ell}$ is shown in the figure :



(A) Along closed Loop-1

(B) Along closed Loop-2

(C) Along closed Loop-3

(D) Along closed Loop-4

(P) $\oint \vec{B}.d\vec{\ell} = \mu_0 i$

(Q) $\oint \vec{B}.d\vec{\ell} = -\mu_0 i$

(R) $\oint \vec{B}.d\vec{\ell} = 0$

(S) net work done by the magnetic force to move a unit charge along the loop is zero.

(T) $\oint \vec{B}.d\vec{\ell} = \mu_0 (2i)$

ASSERTION AND REASON TYPE

These questions contains, Statement 1 (assertion) and Statement II (reason).

(A) Statement-1 is True, Statement-2 is True; Statement-2 **is** a correct explanation for Statement-1

(B) Statement-1 is True, Statement-2 is True; Statement-2 **is NOT** a correct explanation for Statement-1

(C) Statement-1 is True, Statement-2 is False

(D) Statement-1 is False, Statement-2 is True.

27. **Assertion :** A charged particle undergoes uniform circular motion in a uniform magnetic field. The only force acting on the particle is that exerted by the uniform magnetic field. If now the speed of the same particle is somehow doubled keeping its charge and external magnetic field constant, then the centripetal force on the particle becomes four times.

Reason : The magnitude of centripetal force on a particle of mass m moving in a circle of radius R with uniform speed v is $\frac{mv^2}{R}$:

28. **Assertion :** A current carrying closed loop remains in equilibrium in a uniform and constant magnetic field parallel to its axis. Consider forces only due to this magnetic field .

Reason : Torque on a current carrying closed loop due to a magnetic field is maximum when the plane of the coil is parallel to the direction of the magnetic field.

29. **Assertion :** A solenoid tend to contract (along its length) when a current is passed through it.

Reason : If current in two coaxial circular rings of equal radii is in same sense(as seen by an observer on axis away from both the rings), the rings attract each other. Further the given current carrying rings attract each other because parallel current attract.

30. **Assertion :** A direct uniformly distributed current flows through a solid long metallic cylinder along its length. It produces magnetic field only outside the cylinder .

Reason : A thin long cylindrical tube carrying uniformly distributed current along its circumference does not produce a magnetic field inside it. Moreover, a solid cylinder can be supposed to be made up of many thin cylindrical tubes.

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ANSWER KEY

EXERCISE - 1

1. C **2.** B **3.** C **4.** B **5.** D **6.** C **7.** B **8.** D **9.** B **10.** D **11.** ABD **12.** D **13.** C
14. A **15.** B **16.** B **17.** C **18.** C **19.** C **20.** D **21.** B **22.** C **23.** B **24.** C **25.** B **26.** A
27. B **28.** B **29.** A **30.** A **31.** B **32.** D **33.** C **34.** D **35.** B **36.** D **37.** B **38.** C **39.** C
40. A **41.** B **42.** D **43.** B **44.** A **45.** C **46.** C **47.** D **48.** D **49.** B **50.** A **51.** D **52.** C
53. A **54.** B **55.** D **56.** D **57.** A **58.** C **59.** C **60.** B **61.** C **62.** A **63.** A **64.** D **65.** B
66. B **67.** D **68.** C **69.** D **70.** B

EXERCISE - 2

1. C **2.** D **3.** C **4.** D **5.** C **6.** C **7.** D **8.** C **9.** A **10.** C **11.** B **12.** B **13.** A
14. C **15.** B **16.** A **17.** B **18.** A **19.** C **20.** C **21.** C **22.** A **23.** A **24.** C **25.** A **26.** B
27. A **28.** A **29.** A **30.** C **31.** C **32.** D **33.** B **34.** C **35.** C **36.** A **37.** D **38.** A **39.** D
40. D **41.** D **42.** B **43.** B **44.** C **45.** D **46.** C **47.** A **48.** C **49.** B **50.** D **51.** A **52.** B
53. D **54.** B **55.** A **56.** D **57.** C **58.** B **59.** D **60.** C **61.** D **62.** D **63.** A **64.** C **65.** D
66. B **67.** A **68.** A **69.** A **70.** B **71.** A **72.** D **73.** C **74.** C **75.** C **76.** B **77.** C **78.** A

EXERCISE - 3 : PART # 1

1. A→ R ; B →S; C → Q ; D → P
2. A→ R; B → Q ;C → S
3. A → R ; B ; P → C → T ; D → S
4. A → R,S ; B → R,S; C → Q,R ; D →P,R
5. A → Q,S; B → P,S ;C → Q,S ;D → P,S
6. A → S; B → S;C Q ; D→ R; E→ P

PART # 2

1. D **2.** A **3.** D **4.** D **5.** A **6.** C **7.** A **8.** E **9.** A **10.** C **11.** A **12.** C **13.** A
14. B

EXERCISE - 4 : PART # 1

1. B **2.** A **3.** B **4.** D **5.** B **6.** C **7.** D **8.** C **9.** C **10.** C **11.** B **12.** C **13.** A
14. B **15.** B **16.** C **17.** A **18.** B **19.** D **20.** A **21.** A **22.** C **23.** A **24.** D **25.** B **26.** D
27. D **28.** A **29.** A **30.** B **31.** B **32.** D **33.** A **34.** A **35.** A **36.** C **37.** C **38.** C **39.** A
40. A **41.** A **42.** C **43.** B **44.** D **45.** C **46.** B **47.** C **48.** B **49.** D **50.** A

PART # 2

1. B **2.** D **3.** C **4.** B **5.** B **6.** B **7.** D **8.** A **9.** D **10.** D **11.** A **12.** B **13.** D
14. B **15.** A **16.** B **17.** C **18.** D **19.** A **20.** A **21.** A **22.** A **23.** D **24.** A **25.** D **26.** C
27. B **28.** A **29.** B **30.** A **31.** A **32.** C **33.** B **34.** D **35.** A **36.** B **37.** A **38.** D **39.** D
40. A **41.** B **42.** A **43.** A **44.** C **45.** A **46.** A **47.** D **48.** A **49.** A **50.** D **51.** B **52.** C
53. A **54.** B **55.** A **56.** A **57.** C **58.** A **59.** C **60.** A **61.** C **62.** D **63.** D **64.** D **65.** A
66. D **67.** A **68.** D **69.** C **70.** A **71.** A **72.** D **73.** B **74.** A

MOCK TEST

1. A **2.** A **3.** A **4.** C **5.** B **6.** C **7.** B **8.** B **9.** C **10.** D **11.** C **12.** D **13.** B
14. D **15.** A **16.** B **17.** A **18.** D **19.** C **20** B **21.** B **22.** C **23** A **24.** C
25. A→ S; B→ P; C →Q; D→ R
26. A → Q, S ; B → P, S ; C → Q, S ; D → P, S **27.** D **28.** B **29.** A **30.** D

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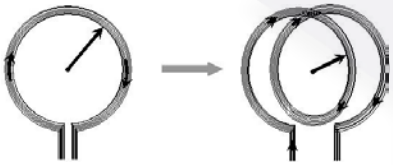
HINTS & SOLUTIONS

EXERCISE - 1
NEET LEVEL

1. **(C)** Magnetic field at the centre of current carrying coil is given by

$$B = \frac{\mu_0}{4\pi}\cdot\frac{2\pi Ni}{r} \Rightarrow B \propto \frac{N}{r} \Rightarrow \frac{B_1}{B_2} = \frac{N_1}{N_2}\times\frac{r_2}{r_1}.$$

The following figure shows that single turn coil changes to double turn coil.



$N_1 = 1$ $\quad$ $N_2 = 2$

$r_1 = r$ $\quad$ $r_2 = r/2$

$B_1 = B$ $\quad$ $B_2 = ?$

$$\Rightarrow \frac{B}{B_2} = \frac{1}{2}\times\frac{r/2}{r} = \frac{1}{4} \Rightarrow B_2 = 4B$$

Short trick : For such type of problems remember $B_2 = n^2 B_1$

2. **(B)** If distance is same field will be same $\left(\because B = \frac{\mu_0}{4\pi}\cdot\frac{2i}{r}\right)$

3. **(C)** Magnetic field lies inside as well as outside the solid current carrying conductor.

4. **(B)** Because for inside the pipe $i = 0$

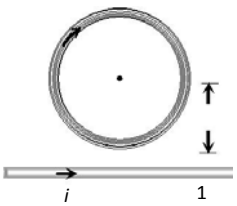
$$\therefore B = \frac{\mu_0 i}{2\pi r} = 0$$

5. **(D)** $dB = \frac{\mu_0}{4\pi}\cdot\frac{idl\sin\theta}{r^2} \Rightarrow d\vec{B} = \frac{\mu_0}{4\pi}\cdot\frac{i(d\vec{l}\times\vec{r})}{r^3}$

6. **(C)** The magnetic field at the centre of the circle

$$= \frac{\mu_o}{4\pi}\times\frac{2\pi i}{r} = 10^{-7}\times\frac{2\pi(nq)}{r} = \frac{2\pi nq}{r}\times 10^{-7} N/A\text{-}m$$

7. **(B)** The given shape is equivalent to the following diagram

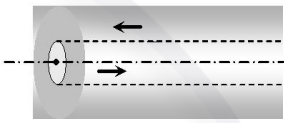


The field at O due to straight part of conductor is $B_1 = \frac{\mu_o}{4\pi}\cdot\frac{2i}{r}\odot$. The field at O due to circular coil is $B_2 = \frac{\mu_0}{4\pi}\cdot\frac{2\pi i}{r}\otimes$. Both fields will act in the opposite direction, hence the total field at O.

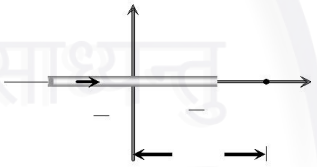
$$i.e.\ B = B_2 - B_1 = \left(\frac{\mu_o}{4\pi}\right)\times(\pi - 1)\frac{2i}{r} = \frac{\mu_o}{4\pi}\cdot\frac{2i}{r}(\pi - 1)$$

8. **(D)** $B = \frac{\mu_0}{4\pi}\frac{(2\pi-\theta)i}{R} = \frac{\mu_0}{4\pi}\frac{\left(2\pi - \frac{\pi}{2}\right)\times i}{R} = \frac{3\mu_0 i}{8R}$

9. **(B)** The respective figure is shown below Magnetic field at P due to inner and outer conductors are equal and opposite. Hence net magnetic field at P will be zero.



10. **(D)** Magnetic field at a point on the axis of a current carrying wire is always zero.

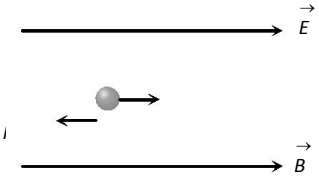


11. **(ABD)** Here the proton has no acceleration so $E = B = 0$.

When $E = 0$ but $B \neq 0$, but parallel to the motion of proton, there will be no force acting.

When $E \neq 0$ and $B \neq 0$ and E, B and motion of proton (v) are mutually perpendicular, there may be no net force. Forces due to E and B cancel each other.

12. **(D)** Since electron is moving is parallel to the magnetic field, hence magnetic force on it $F_m = 0$.



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The only force acting on the electron is electric force which reduces it's speed.

13. (C) $r = \frac{\sqrt{2mk}}{qB} = \frac{1}{B}\sqrt{\frac{2mV}{q}} \Rightarrow r \propto \sqrt{m}$

$\Rightarrow \frac{m_1}{m_2} = \left(\frac{R_1}{R_2}\right)^2$

14. (A) $r = \frac{mv}{Bq} = \frac{v}{(q/m)B} = \frac{2\times10^5}{5\times10^7\times4\times10^{-2}} = 0.1m$

15. (B) $r = \frac{p}{qB} \Rightarrow r \propto p$

16. (B) $B = \frac{mv}{qr} = \frac{9\times10^{-31}\times10^6}{1.6\times10^{-19}\times0.1} = 5.6\times10^{-5}T$

17. (C) $r = \frac{\sqrt{2mK}}{qB}$ *i.e.* $r \propto \frac{\sqrt{m}}{q}$

Here kinetic energy K and B are same.

$\therefore \frac{r_p}{r_\alpha} = \frac{\sqrt{m_p}}{\sqrt{m_\alpha}}.\frac{q_\alpha}{q_p} = \frac{\sqrt{m_p}}{\sqrt{4m_p}}.\frac{2q_p}{q_p} = 1$

18. (C) $\vec{F} = q\vec{v}\times\vec{B}$

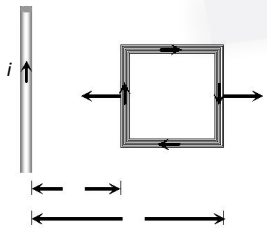
19. (C) **20. (D)**

21. (B) Two wires, if carries current in opposite direction, they repel each other.

22. (C) $\because r_1 < r_2$

So $F_1 > F_2$

$\Rightarrow F_{net} = (F_1 - F_2)$



towards the wire.

23. (B) $M = NiA = 20\times\frac{22}{7}(4\times10^{-2})^2 3 = 0.3\,A-m^2$

24. (C) Net force on a current carrying closed loop is always zero, if it is placed in an uniform magnetic field.

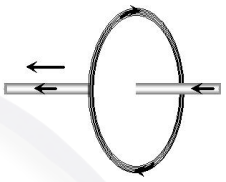
25. (B) Force per unit length $= \frac{\mu_0}{4\pi}.\frac{2i_1i_2}{r} = \frac{\mu_0}{2\pi}.\frac{i^2}{b}$

26. (A) $F = \frac{\mu_0}{4\pi}.\frac{2i_1i_2}{a}\times l$

$\Rightarrow F = 10^{-7}\times\frac{2\times10\times2}{(10\times10^{-2})}\times2 = 8\times10^{-5}N$

27. (B) For charge particles, if they are moving freely in space, electrostatic force is dominant over magnetic force between them. Hence due to electric force they repel each other.

28. (B) As shown in the following figure straight wire is placed parallel to the magnetic field produced by circular current. Hence force on wire $F = 0$



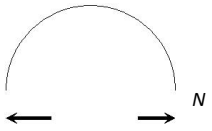
29. (A) Two straight conductors carry current in same direction, then attractive force acts between them.

30. (A) $F = \frac{\mu_0}{4\pi}\frac{2\times i_1i_2}{a} = \frac{10^{-7}\times2\times5\times5}{0.1} = 5\times10^{-5}N/m$

31. (B) On bending a rod it's pole strength remains unchanged where as its magnetic moment changes.

New magnetic moment $M' = m(2R) = m\left(\frac{2L}{\pi}\right) = \frac{2M}{\pi}$





32. (D)

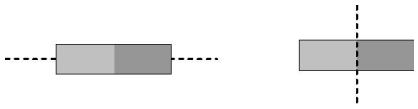
33. (C) $B_a = \frac{\mu_0}{4\pi}\frac{2M}{d^3} = \frac{\mu_0}{2\pi}\frac{M}{d^3}$

34. (D)

35. (B) If cut along the axis of magnet of length l, then new pole strength $m' = \frac{m}{2}$ and new length $l' = l$

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$\therefore$ New magnetic moment $M' = \frac{m}{2} \times l = \frac{ml}{2} = \frac{M}{2}$



If cut perpendicular to the axis of magnet, then new pole strength $m' = m$ and new length, $l' = l/2$

$\therefore$ New magnetic moment $M' = m \times \frac{l}{2} = \frac{ml}{2} = \frac{M}{2}$

36. (D) For a magnet $B = \frac{\mu_0}{4\pi} \cdot \frac{2M}{x^3}$ (Nearly)

$\Rightarrow \frac{B_1}{B_2} = \left(\frac{x_1}{x_2}\right)^3 = \left(\frac{x}{2x}\right)^3 = \frac{1}{8}$ (Approx.)

37. (B) For each part $m' = \frac{m}{2}$



38. (C) $\frac{B_1}{B_2} = \frac{d_1}{d_2}\left(\frac{d_2^2 - l^2}{d_1^2 - l^2}\right)^2 \Rightarrow \frac{12.5}{1} = \frac{10}{20}\left(\frac{400 - l^2}{100 - l^2}\right)^2$

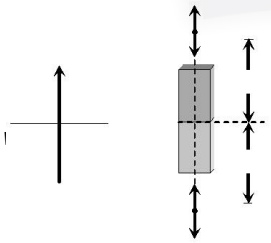
$\Rightarrow l = 5\ cm$

Hence length of magnet $= 2l = 10\ cm$

39. (C) $B_1 = \frac{2M}{d^3}, B_2 = \frac{M}{d^3}; \therefore \frac{B_1}{B_2} = 2:1$

40. (A)

41. (B)



At neutral point

$|B| = |B_H| \Rightarrow \frac{2M}{(20)^3} = 0.3 \Rightarrow M = 1.2 \times 10^3\ emu.$

42. (D) No magnetic lines of force passes through the steel box.

43. (B) At magnetic poles, the angle of dip is 90°. Hence the horizontal component $B_H = B\cos\theta = 0$.

44. (A) **45. (C)** **46. (C)**

47. (D) $B_H = \sqrt{3}\, B_V$, also $\tan\theta = \frac{B_V}{B_H} = \frac{1}{\sqrt{3}} \Rightarrow \theta = 30^o$

48. (D) At magnetic equator, the angle of dip is 0°. Hence the vertical component $V = I\sin\phi = 0$.

49. (B) **50. (A)** **51. (D)** **52. (C)** **53. (A)**

54. (B) In sum position : $T_S = 2\pi\sqrt{\frac{I_s}{(M_1 + M_2)B_H}}$

In difference position : $T_d = 2\pi\sqrt{\frac{I_d}{(M_1 - M_2)B_H}}$

It is clear that $T_d > T_s$

55. (D) $T = 2\pi\sqrt{\frac{I}{MB_H}}; \therefore \frac{T_1}{T_2} = \sqrt{\frac{(B_H)_2}{(B_H)_1}} \Rightarrow T_2 = T_1\sqrt{\frac{(B_H)_1}{(B_H)_2}}$

Here n_1=30 *oscillation /min* $= \frac{1}{2}$ *oscillation/sec*

$\therefore T_1 = \frac{1}{n_1} = 2\,\text{sec} \quad \therefore T_2 = 2\sqrt{\frac{B_H}{2B_H}} = 2 \times \frac{1}{\sqrt{2}} = \sqrt{2}\,\text{sec}$

56. (D)

57. (A) $T = 2\pi\sqrt{\frac{1}{MB_H}} \Rightarrow \frac{T_1}{T_2} = \sqrt{\frac{M_2}{M_1}}$

$\Rightarrow \frac{M_1}{M_2} = \frac{T_2^2}{T_1^2} = \frac{(60/15)^2}{(60/10)^2} = \frac{4}{9}$

58. (C) When magnet of length l is cut into four equal parts.

then $m' = \frac{m}{2}$ and $l' = \frac{l}{2}; \therefore M' = \frac{m}{2} \times \frac{l}{2} = \frac{ml}{4} = \frac{M}{4}$

New moment of inertia $I' = \frac{wl^2}{12} = \frac{\frac{w}{4} \cdot \left(\frac{1}{2}\right)^2}{12} = \frac{1}{16} \cdot \frac{wl^2}{12}$

Here w is the mass of magnet.

$\therefore I' = \frac{1}{16} I$; Time period of each part $T' = 2\pi\sqrt{\frac{I'}{M'B_H}}$

$= 2\pi\sqrt{\frac{I/16}{(M/4)B_H}} = 2\pi\sqrt{\frac{I}{4MB_H}} = \frac{T}{2}$

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59. (C) $T = 2\pi\sqrt{\dfrac{I_1 + I_2}{(M_1 - M_2)B_H}}$

Here $M_1 = M_2 = M,\ \therefore T = \infty$

60. (B) Time period in vibration magnetometer

$T = 2\pi\sqrt{\dfrac{I}{MB_H}}$, At poles

61. (C)

62. (A) Neon atom is diamagnetic, hence it's net magnetic moment is zero.

63. (A) Soft iron is highly ferromagnetic.

64. (D)

65. (B) On heating, different domains have net magnetisation in them which are randomly distributes. Thus the net magnetisastion of the substance due to various domains decreases to minimum.

66. (B) Repelled due to induction of similar poles.

67. (D) From the characteristic of *B-H* curve.

68. (C) **69. (D)** **70. (B)**

EXERCISE - 2
AIIMS LEVEL

1. (C) $B_1 = \dfrac{\mu_0}{2}\dfrac{I_1}{R} = 3\times10^{-5}\,T$

$B_2 = \dfrac{\mu_0}{2}\dfrac{I_2}{R} = 4\times10^{-5}\,T$

$B = \sqrt{B_1^2 + B_2^2} = 5\times10^{-5}\,T$

2. (D) $\vec{B}_O = \vec{B}_{arc} + \vec{B}_{st.wire} = \dfrac{\mu_0}{2}\dfrac{I}{R}(-\tilde{k}) + \dfrac{\mu_0}{2\pi}\dfrac{I}{R}(\tilde{k})$

3. (C) $B = \dfrac{\mu_0}{2}\dfrac{I}{R}\left(2\pi R = n2\pi r \Rightarrow r = \dfrac{R}{n}\right)$

$B' = \dfrac{\mu_0}{2}\dfrac{In}{(R/n)} = n^2B$

4. (D) $B_{axis} = \dfrac{1}{2}(B_{centre})$

$\Rightarrow \dfrac{\mu_0}{4\pi}\dfrac{2\pi R^2 I}{(R^2 + x^2)^{3/2}} = \left(\dfrac{\mu_0}{4\pi}\dfrac{2\pi I}{R}\right)\times\dfrac{1}{2}$

$\Rightarrow x = 0.766\,R$

5. (C) $\vec{B} = \vec{B}_{arc} + \vec{B}_{st.line} = 0 + \left(\dfrac{\mu_0}{4\pi}\dfrac{I}{R}\right)\times 2\tilde{k}$

6. (C) For radial component of magnetic field, the total force will be either in the upward or in the downward direction depending on the direction of current.

$\therefore$ Force $= ILB_{\perp} = I(2\pi a)B\sin\theta$

7. (D) $\vec{B}$ due to XY wire on wire PQ is into the plane.

$\therefore$ Force on wire PQ $= \int i\vec{d\ell}\times\vec{B}$

$= \int i\vec{d\ell}(-\tilde{i})\times B(-\tilde{k}) = \int i\vec{d\ell}B(-\tilde{j})$ (downward)

8. (C) B due to closed loop is zero in all cases. B due to straight lead wires is non–zero in case (c).

9. (A) Force $= I(L_{eff})B$

L_{eff} = length normal to $\vec{B} = \overrightarrow{RQ}$

$\therefore$ Force $= 5\times\dfrac{4}{100}\times 2 = 0.4\,N$

11. (B) For constant velocity a=0 $= g\sin\theta - \dfrac{i\ell B\cos\theta}{m}$

$\Rightarrow B = \dfrac{mg\tan\theta}{i\ell}$

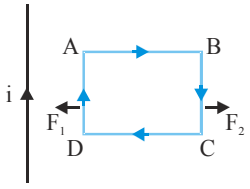
12. (B) $F = \dfrac{\mu_0}{2\pi}\dfrac{I_1I_2}{d} = \dfrac{2\times10^{-7}\times1\times1}{1} = 2\times10^{-7}\,N/m$

13. (A) $\vec{M} = NIA\tilde{n}$

$= 1\times10\times0.1\times0.1\left(\hat{i}\cos60° - \tilde{k}\cos30°\right)$

$= 0.05\left(\tilde{i} - \sqrt{3}\tilde{k}\right)A - m^2$

14. (C) $F_1 > F_2$ $\therefore F_{net} = F_1 - F_2$ (attractive)



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15. (B) Angle between $\vec{M}$ and $\vec{B}$ is $\left(\frac{\pi}{2}+\theta\right)$

16. (A) $B=\frac{\mu_0}{4\pi}\frac{(2e)}{r}\left(\frac{2\pi}{T}\right)=\frac{\mu_0\times1.6\times10^{-19}}{0.8\times2}$

$=\mu_0\times10^{-19}\,T$

17. (B) Force on electron, $\vec{F}=q\vec{v}\times\vec{B}$

$\Rightarrow F\left(\tilde{j}\right)=-ev\left(\tilde{i}\right)\times B\left(\tilde{B}\right)\Rightarrow\ \tilde{B}=\tilde{k}$

18. (A) $F_e=\frac{1}{4\pi\epsilon_0}\frac{e^2}{r^2}$

$F_m=\frac{\mu_0}{4\pi}\frac{e^2v^2}{r^2}$

$\Rightarrow\ \frac{F_e}{F_m}=\frac{1}{\epsilon_0\mu_0v^2}=\frac{c^2}{v^2}$

19. (C) Force on cosmic rays,

$\vec{F}=ev\left(-\tilde{k}\right)\times B\left(\tilde{j}\right)=evB\tilde{i}$ (towards East)

20. (C) Electrostatic force on electron, $\vec{F}_e=-eE\tilde{j}$

$\therefore$ Magnetic force on electron,

$\vec{F}_m=-ev\left(-\tilde{j}\right)\times B\tilde{k}=evB\tilde{i}$

The electron moves in circle with radius on x–axis.

21. (C) $R=\frac{mv}{qB}=\frac{\sqrt{2mK}}{qB}$

$\therefore\ \frac{R_1}{R_2}=\sqrt{\frac{m_1}{m_2}}$

$\Rightarrow\ \frac{m_1}{m_2}=\left(\frac{R_1}{R_2}\right)^2$

22. (A) Magnetic force acts normal to velocity and hence KE does not change but momentum changes.

25. (A) $R=\frac{\sqrt{2mK}}{qB}$; $R_\alpha=\frac{\sqrt{8mK}}{2qB}$;

$R_P=\frac{\sqrt{2mK}}{qB}$; $R_d=\frac{\sqrt{4mK}}{qB}$

26. (B) $B=\frac{\mu_0}{4\pi}\frac{I}{(a\cos30°)}(\sin30°+\sin30°)$

$\left[1-\frac{1}{2}+\frac{1}{3}-....\right]\ \Rightarrow\ \vec{B}=\frac{\mu_0}{4\pi}\frac{I\,\ell n4}{\sqrt{3}a}\tilde{k}$

27. (A) $\vec{B}=\left[\frac{\mu_0}{4\pi}\frac{I}{2r}\pi+\frac{\mu_0}{4\pi}\frac{I}{r}\pi\right]\otimes=\frac{3\mu_0I}{8r}\otimes$

28. (A) $\vec{F}=q\left(\vec{v}\times\vec{B}+\vec{E}\right)=0$

$\Rightarrow\ q\left(10\tilde{i}\times B\tilde{j}-10^4\tilde{k}\right)=0$

$\Rightarrow B=10^3\ Wb/m^2$

29. (A) $\vec{B}_{z\ wire}=0$; $\vec{B}_{y\ wire}=\left(-\tilde{i}\right)\left(\frac{\mu_0}{2\pi a}\right)$;

$\vec{B}_{x\ wire}=\left(\tilde{j}\right)\left(\frac{\mu_0 i}{2\pi a}\right)\ \therefore\vec{B}=\frac{\mu_0 i}{2\pi a}\left(\tilde{j}-\tilde{i}\right)$

30. (C) Magnetic field around a current carrying wire has circular symmetry. Hence zero $\vec{B}$ line lies in the same plane of wires. The locus of zero $\vec{B}$ is a straight line.

31. (C) $q\left[|\vec{E}|-|v\vec{B}|\right]=0\ \Rightarrow v=\frac{E}{B}$

$\therefore$ Radius, $R=\frac{mv}{qB}=\frac{mE}{qB^2}$

$=\frac{9.1\times10^{-31}\times3.2\times10^5}{1.6\times10^{-19}\times4\times10^{-6}}=0.455m$

32. (D) $qE=\frac{mv_0^2}{r_1}$ and $qvB=\frac{mv_0^2}{r_2}\Rightarrow\frac{r_1}{r_2}=\frac{v_0B}{E}$

33. (B) $R=\frac{mv}{qB}=d\ \Rightarrow v=\frac{qBd}{m}$

34. (C) $v=(g\sin\theta)t$

$N=mg\cos\theta-qvB=0\ \Rightarrow\ t=\frac{m\cot\theta}{qB}$

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35. (C) $R = \frac{mv}{qB} = \frac{\sqrt{2mqV}}{qB} = \frac{d}{2} \Rightarrow m = \frac{qB^2d^2}{8V}$

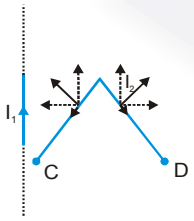
36. (A) $\vec{M} \times \vec{B} = I\vec{\alpha}$

$\Rightarrow NIA \times B \times \sin 90° = \frac{MR^2}{2}\alpha$

$\Rightarrow 1 \times 4 \times \pi R^2 \times 10 \times 1 = \frac{2}{2}R^2 \times \alpha$

$\Rightarrow \alpha = 40\pi \text{ rad/s}^2$

37. (D) Net force will have –x ad + y components



38. (A) $\left[\frac{E^2\mu_0 \in}{B^2}\right] = \left[\frac{v^2}{c^2}\right] = M^0L^0T^0$

39. (D) Effective resistance in each upper and lower arms are equal. Hence equal currents flows and produces zero M.F. in P and R configuration.

40. (D) $\frac{B_1}{B_2} = \frac{\mu_0 i_1}{2r} \times \frac{2(2r)}{\mu_0 i_2} = \frac{1}{3} \Rightarrow \frac{i_1}{i_2} = \frac{1}{6}$

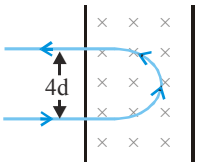
41. (D) $I_g = \frac{150}{10} \times 10^{-3} = 0.015 \text{ A}$

$V_g = \frac{150}{2} \times 10^{-3} = 0.075 \text{ V} \therefore G = \frac{V_g}{I_g} = 5\,\Omega$

If R = resistance to be added in series, I (G+R)=V

$\Rightarrow 0.015\,(5+R) = 150 \times 1 \Rightarrow R = 9995\,\Omega$

42. (B) $R = \frac{mv}{qB} = \frac{v}{\alpha B} = 2d$



Angle substended at the centre = π

Time to stay in magnetic field $= \frac{T}{2} = \frac{\pi}{\alpha B}$

43. (B) $\vec{B} = \frac{\mu_0}{2\pi}\frac{I_1}{(AP)}\hat{k} + \frac{\mu_0}{2\pi}\frac{I_2}{(PB)}\hat{j}$

$= \left[\frac{2 \times 10^{-7} \times 2}{10^{-2}}\right]\hat{k} + \left[\frac{2 \times 10^{-7} \times 3}{2 \times 10^{-2}}\right]\hat{j}$

$= (3 \times 10^{-5}\text{ T})\hat{j} + (4 \times 10^{-5}\text{ T})\hat{k}$

44. (C) Effective length, length normal to $\vec{B}$, remains same.

45. (D) $T = \frac{2\pi m}{qB} = 2\pi \Rightarrow R = \frac{mv}{qB} = \frac{|x|}{|x|} = 1\text{m}$

At $t = \pi$; charge will complete half circle.

$\therefore x = 0; y = \frac{1}{2}\left(\frac{qE}{m}\right)t^2 = \frac{1}{2}\left(\frac{1 \times 1}{1}\right)\pi^2 = \frac{\pi^2}{2}$

$z = 2R = 2\text{m}$

46. (C) $\vec{F} = q\vec{v} \times \vec{B} = 1\frac{1}{2}(\sqrt{3}\hat{i} + \hat{j}) \times 1\hat{k} = \left(\frac{\hat{i} - \sqrt{3}\hat{j}}{2}\right)$

$R = \frac{mv}{qB} = \frac{1 \times 1}{1 \times 1} = 1 \Rightarrow \vec{R} = \vec{r}_2 - \vec{r}_1 = \left(\frac{\hat{i} - \sqrt{3}\hat{j}}{2}\right)$

$\Rightarrow \vec{r}_2 = \text{centre's coordinates} = \left(\frac{\hat{i} - \sqrt{3}\hat{j}}{2}\right) + (-\sqrt{3}\hat{i} - \hat{j})$

47. (A) Ampere's Law $\Rightarrow B2\pi\frac{d}{2} = \mu_0 J\left(\frac{\pi d^2}{4}\right)$

$B = \left(\frac{\mu_0}{4\pi}.\pi dJ\right)\tilde{j} \qquad \therefore B_{net} = 2B = \left(\frac{\mu_0}{2\pi}\right)\pi dJ\tilde{j}$

48. (C) From work energy theorem

$W = \Delta KE \Rightarrow qE_0x_0 = \frac{1}{2}mv^2$

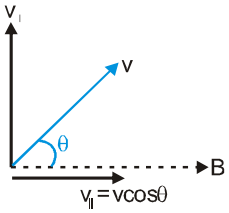
$\Rightarrow \alpha E_0x_0 = \frac{1}{2}(4^2 + 3^2) \Rightarrow x_0 = \frac{25}{2\alpha E_0}$

49. (B) $\vec{F} = -qv\left(\frac{\hat{i} - \hat{j}}{\sqrt{2}}\right) \times B(-\hat{k}) = qvB\left(\frac{-\hat{i} - \hat{j}}{\sqrt{2}}\right)$

$\therefore \hat{F} = -\left(\frac{\hat{i} + \hat{j}}{\sqrt{2}}\right)$

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50. (D) $T_1 = \dfrac{2\pi M}{QB} = T_0$



$T_2 = \dfrac{2\pi(2M)}{QB} = 2T_0$

They will meet at time $2T_0$.

$\therefore$ Distance from origin $= v\cos\theta \times 2T_0 = \dfrac{4\pi Mv\cos\theta}{QB}$

51. (A) $\vec{F} = -e\vec{v} \times \vec{B}$

$\Rightarrow -2\hat{j} = -e\left[2\hat{i} \times (B_1\hat{i} + B_2\hat{j} + B_3\hat{k})\right] \Rightarrow B_2 = 0$

$\Rightarrow 2\hat{i} = -e\left[2\hat{j} \times (B_1\hat{i} + B_2\hat{j} + B_3\hat{k})\right] \Rightarrow B_1 = 0$

Then $\vec{F} = -e\left[2\hat{k} \times (B_3\hat{k})\right] = 0$

52. (B) $\Sigma F = 0 \Rightarrow mg\sin\theta - f = 0,\ f = mg\sin\theta$ ...(i)

$\Sigma T = 0 \Rightarrow MB\sin\theta - fR = 0$

$\Rightarrow i\pi R^2 B\sin\theta = mg\sin\theta R \Rightarrow B = \dfrac{mg}{\pi iR}$

53. (D) Impulse = change in momentum

$\Rightarrow (i\ell B\Delta t) = m(\sqrt{2gh} - 0) \Rightarrow (i\Delta t) = \Delta q = \dfrac{m\sqrt{2gh}}{\ell B}$

54. (B) $\vec{\tau} = \vec{M} \times \vec{B} = \dfrac{IA}{2}(-\hat{k}) \times B(-\hat{j}) = \dfrac{IAB}{2}(-\hat{i})$ (Leftward)

55. (A) $\vec{F} = q(v\cos\alpha\hat{j} + v\sin\alpha\hat{k}) \times B\hat{j} = qvB\sin\alpha(-\hat{i})$

Hence the x-coordinate of proton can never be +ve.

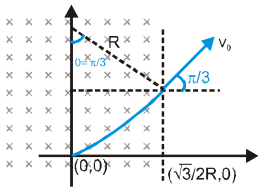
56. (D) $\vec{F} = q\vec{v} \times \vec{B} = qv_0(\hat{i} + \hat{j}) \times \vec{B} = (-)qv_0B\hat{k}$

$T = \dfrac{2\pi m}{qB} \quad \therefore \omega t = \dfrac{2\pi}{T}t = \dfrac{2\pi qB}{2\pi m} \times \dfrac{\pi}{qB} = \pi$

$\therefore\ X = v_0 t = \dfrac{v_0\pi}{B_0\alpha};\ Y = 0$

$Z = -2R = \dfrac{-2Mv_0}{2B_0} = -\dfrac{2v_0}{\alpha B_0}$

57. (C) $R\sin\theta = \dfrac{\sqrt{3}}{2}\dfrac{mv_0}{qB_0} = \dfrac{\sqrt{3}}{2}\dfrac{v_0}{\alpha B_0} = \dfrac{\sqrt{3}}{2}R\ ;\ \theta = \pi/3$



$\therefore$ x-coordinate $= \dfrac{\sqrt{3}}{2}R + v_0\cos\theta\left(t - \dfrac{\theta}{\omega}\right)$

$= \dfrac{\sqrt{3}v_0}{2B_0\alpha} + \dfrac{v_0}{2}\left(t - \dfrac{\pi}{3B_0\alpha}\right)$

58. (B) $L_{effective} = AB = 4\hat{j}$

$\therefore\ |\vec{F}| = |I\vec{L} \times \vec{B}| = IL_{eff}B = 2.4\hat{j} \times 4(-\hat{k}) = -32\hat{i}$ N

59. (D) $\vec{F} = I\vec{L} \times \vec{B} \Rightarrow I\left(R(-\hat{j}) \times B\hat{B}\right) = \sqrt{2}IRB_0\hat{k}$

Possible values of $\therefore\ \vec{B} = \dfrac{B_0}{\sqrt{2}}\hat{i}$ and $\vec{B} = \dfrac{B_0}{\sqrt{2}}(\hat{i} + \hat{j})$

60. (C) $\vec{F} = q[\vec{E} + \vec{v} \times \vec{B}] = 0 \Rightarrow |\vec{E}| = |\vec{v} \times \vec{B}| = vB$

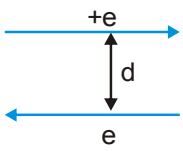
$\therefore E = |1.5\times10^{-6}(-\hat{j}) \times 1(-\hat{k})| = |1.5 \times 10^{-6}(-\hat{i})|$ N/C

$\dfrac{R_A}{R_B} = \dfrac{(mv/qB)_A}{(mv/qB)_B} = \dfrac{m_A}{m_B} = \dfrac{12}{13}$

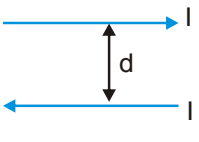
61. (D) $\vec{F} = q[\vec{E} + \vec{v} \times \vec{B}] = 0 \Rightarrow |\vec{E}| = |-\vec{v} \times \vec{B}| = |-vB| = vb$

$v = \dfrac{E}{B} = \dfrac{2E}{2B}$ (direction remaining same)

62. (D)



$\vec{B}$ at mid point = 0



Equivalent form

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63. (A) $\vec{B}_P = \frac{\mu_0}{4\pi}\frac{I}{R/\sqrt{2}}(\sin 90° - 45°)$

$= \frac{(\sqrt{2}-1)\mu_0 I}{4\pi R}(-\tilde{k})$

64. (C) For inner cylinder $B = \frac{\mu_0}{2\pi}\frac{ir}{R_1^2}$

For air space $B = \frac{\mu_0}{2\pi}\frac{i}{r}$

For outer cylinder $B = \frac{\mu_0}{2\pi}\frac{i}{r} - \frac{\mu_0 i}{2\pi r}\left(\frac{r^2 - R_2^2}{R_3^2 - R_2^2}\right)$

65. (D) $\vec{B}$ add up is the left and the right zone. But in the middle zone $\vec{B}$ becomes zero.

66. (B) $B_C = B_{I_1} + B_{I_2} = \frac{\mu_0 ic}{2\pi(b^2 - a^2)} + 0$

67. (A) $W = MB(1-\cos 60°) = \frac{MB}{2}$

$|\vec{T}| = MB\sin 60° = \sqrt{3}\,\frac{MB}{2} = \sqrt{3}\ W$

68. (A) $B_{\text{axial point}} = 2\left(\frac{\mu_0}{4\pi}\right)\frac{M}{r^3}$

$= \frac{2\times 10^{-7}\times 8}{(0.2)^3} = 2\times 10^{-4}\ T$

$B_{\text{eq. point}} = \left(\frac{\mu_0}{4\pi}\right)\frac{M}{r^3} = 10^{-4}\ T$

69. (A) Both rings experience torque due to other's magnetic field .

70. (B) $MB\sin\theta = T \Rightarrow M\times 0.16\times\frac{1}{2} = 0.032 \Rightarrow M = 0.4\ J/T$

71. (A) $\vec{F} = q\vec{v}\times\vec{B} \Rightarrow (4\tilde{i}+3\tilde{j})\times 10^{-13} = -1.6\times 10^{-19}$

$\left[(2.5\times 10^7)\tilde{k}\times(B_1\tilde{i}+B_2\tilde{j}+B_3\tilde{k})\right]$

$\Rightarrow B_1 = -0.075, B_2 = +0.1$

Again : $\vec{F} = q\vec{v}\times\vec{B}$; $q = -1.6\times 10^{-19}$

$\left[(1.5\tilde{i}-2\tilde{j})10^7\right]\times(0.075\tilde{i}+0.1\tilde{j}+B_3\tilde{k})$

$\Rightarrow B_3 = 0 \quad \therefore \vec{B} = -0.075\tilde{i} + 0.1\tilde{j}$

72. (D) $v_y = v_0$

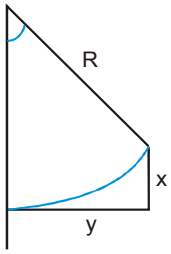
$v_x = \left(\frac{qE_0}{m}\right)t$; $v = \sqrt{v_0^2 + \left(\frac{qE_0}{m}t\right)^2} = 2v_0 \Rightarrow t = \frac{\sqrt{3}mv_0}{qE}$

73. (C) $\vec{B}_0 = \frac{\mu_0}{4\pi}\frac{I}{R}\theta(-\tilde{k}) + \frac{\mu_0}{4\pi}\frac{I}{R\cos\frac{\theta}{2}}\left(\sin\frac{\theta}{2}+\sin\frac{\theta}{2}\right)\tilde{k}$

$\Rightarrow \vec{B}_0 = \frac{\mu_0}{4\pi}\frac{I}{R}\left(2\tan\frac{\theta}{2}-\theta\right)\tilde{k} > 0$

$\therefore \vec{B}_0$ is directed outwards.

74. (C) Radius, $R = \frac{mv}{qB} \Rightarrow mv = qBR$



where $R\sin\theta = y$; $R(1-\cos\theta) = x$

$\Rightarrow R = \frac{1}{2}\left(\frac{y^2}{x}+x\right)$

$\therefore mv = \frac{qB}{2}\left(\frac{y^2}{x}+x\right)$

75. (C) $T = \frac{2\pi m}{qB}$ (Time period of rotation)

For motion in E.F.

$s = ut + \frac{1}{2}at^2 \Rightarrow 0 = vt - \frac{1}{2}\left(\frac{qE}{m}\right)t^2$

$\Rightarrow t = \frac{2mv}{qE} = nT \Rightarrow n = \frac{vB}{\pi E} = \text{An integer}$

76. (B) $R = \frac{mv}{qB}$

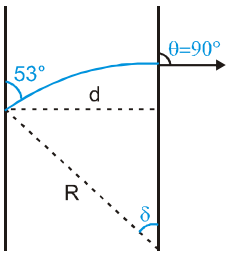
The radius may be decease if v decreases or B increases.

77. (C) $R\sin\delta = d$

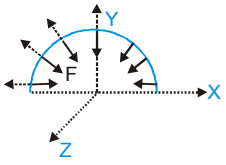
$\frac{mv}{qB}\sin\delta = \frac{3mv}{5qB}$

$\delta = 37°$

$\therefore \theta = 53° + \delta = 90°$



78. (A) Since $\vec{B}$ depends on x-coordinate the net force acts along -x axis.



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EXERCISE - 3

P-1 (Matrix Match)

1. $R = \frac{mv}{qB} = R_0$

	Position
$R_A = 2R_0$	$\rightarrow 4$
$R_B = -4R_0$	$\rightarrow 1$
$R_C = -2R_0$	$\rightarrow 2$
$R_D = +R_0$	$\rightarrow 3$

2. **(A)** $I = \frac{q}{T}\left(T = \frac{2\pi m}{qB}\right) \Rightarrow I \propto v^0$

(B) $M = IA = \frac{q}{T}\pi R^2 = \frac{q}{T}\pi\left(\frac{Mv}{qB}\right)^2 \Rightarrow M \propto v^2$

(C) $B = \frac{\mu_0}{4\pi}\frac{qv}{r^2}$ $B \propto v^2$

3. **(A)** Magnetic moment $= NIA\,\hat{k}$

(B) Torque $= M\hat{k} \times B\hat{k} = 0$

(C) P.E. $= -M\hat{k}.B\hat{k} = -MB$

(D) P.E. is minimum, equilibrium is stable

4. Since magnetic moment = 0 hence torque = 0

(A) $\vec{B} = B_0\hat{i} \Rightarrow |\vec{F}| = \left(\frac{i}{2}\ell B\right) \times 2 = i\ell B$

(B) $\vec{B} = B_0\hat{j} \Rightarrow |\vec{F}| = \left(\frac{i}{2}\ell B\right) \times 2 = i\ell B$

(C) $\vec{B} = B_0(\hat{i} + \hat{j}) \Rightarrow |\vec{F}| = \frac{i}{2} \times \ell_{eff} \times B = 0\ (L_{eff} = 0)$

(D) $\vec{B} = B_0\hat{k} \Rightarrow \vec{F} = \sqrt{\left(\frac{i\ell B}{2} \times 2\right)^2 + \left(\frac{i\ell B}{2} \times 2\right)^2} = \sqrt{2}\, i\ell B$

5. **(A)** $\oint_{\text{loop-1}} \vec{B}.d\vec{\ell} = \mu_0(i - i - i) = -\mu_0 i$

(B) $\oint_{\text{loop-2}} \vec{B}.d\vec{\ell} = \mu_0(i + i - i) = \mu_0 i$

(C) $\oint_{\text{loop-3}} \vec{B}.d\vec{\ell} = \mu_0(i - i - i) = -\mu_0 i$

(D) $\oint_{\text{loop-4}} \vec{B}.d\vec{\ell} = \mu_0(i - i + i) = \mu_0 i$

6. **(A)** $M = \frac{q\omega}{2\pi} \times \pi r^2 = \frac{q\omega r^2}{2}$

(B) $M = \frac{q\omega}{2\pi} \times \pi r^2 = \frac{q\omega r^2}{2}$

(C) $M = \int_0^R \frac{q(2\pi r dr)}{\pi R^2} \times \frac{\omega}{2\pi} \times \pi r^2 = \frac{q\omega r^2}{4}$

(D) $M = \int_{-\pi/2}^{+\pi/2} \frac{q}{4\pi R^2}(2\pi R\cos\theta)(R d\theta) \times \frac{\omega}{2\pi} \times \pi(R\cos\theta)^2$

$= \frac{q\omega r^2}{3}$

(E) $M = \int_{-R}^{+R} \frac{q}{\left(\frac{4}{3}\pi R^3\right)}\pi(R^2 - y^2)dy \times \frac{\omega}{2\pi} \times \pi(R^2 - y^2) = \frac{q\omega r^2}{5}$

EXERCISE - 3

P-2 (Assertion & Reason)

1. D **2.** A **3.** D **4.** D **5.** A **6.** C
7. A **8.** E **9.** A **10.** C **11.** A **12.** C
13. A **14.** B

EXERCISE - 4

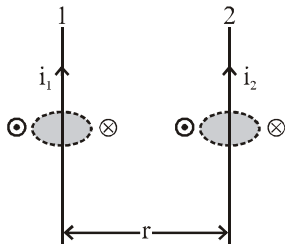
P-1 (NEET/AIPMT)

1. **(B)** According to Maxwells right handed screw rule, the magnetic field at righ and of wire 1 is perpendicular to the current carrying wire in plane of paper going inwards shown by ⊗. Similarly, the magnetic field at left hand of wire 2 is perpendicular to current carrying wire in plane of paper opposite to first wire shown by ⊙. Thus, the two fields are opposite to each other

Therefore, net magnetic field

$$B = B_1 - B_2 = \frac{\mu_0 i_1}{2\pi r_1} - \frac{\mu_0 i_2}{2\pi r_2}$$

At mid-point, $r_1 = r_2 = \frac{r}{2} = \frac{5}{2} = 2.5$ cm



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Hence, $B = \frac{\mu_0}{2\pi}\left(\frac{i_1}{r/2} - \frac{i_2}{r/2}\right)$

$= \frac{\mu_0}{2\pi}\left(\frac{5}{2.5} - \frac{2.5}{2.5}\right)$

$= \frac{\mu_0}{2\pi}(2-1) = \frac{\mu_0}{2\pi}T$

2. **(A)** If there are N turns is a coil, i is the current flowing and A is the area of the coil, then magnetic dipole moment or simiply magnetic moment of the coil is

$M = NiA$

As we know when velocity of charged particle entering to magnetic field region is perpendicular to B, then it follows circular path.

3. **(B)** Magnetic force = centripetal force

i.e. $qvB = \frac{mv^2}{r}$

or $qvB = mr\omega^2 \qquad (v = r\omega)$

or $\omega^2 = \frac{qvB}{mr} = \frac{q(r\omega)B}{mr}$

Angular frequency, $\omega = \frac{qB}{m}$

If v is the frequency of rotation, then

$w = 2\pi v \Rightarrow v = \frac{\omega}{2\pi}$

$\therefore \quad v = \frac{qB}{2\pi m}$

Note : In the resultant expression $\frac{q}{m}$ is known as specific charge. It is sometimes denoted by α. So, in terms of α, the above formula can be written as

$\omega = B\alpha$ and $v = \frac{B\alpha}{2\pi}$

4. **(D)** Magnetic field at the centre of circular coil carrying current i with N number of turns is given by

$B = \frac{\mu_0 Ni}{2r}$

Case I $N = 1, L = 2\pi r$

$\Rightarrow \quad r = \frac{L}{2\pi}$

$\therefore \quad B = \frac{\mu_0 \times 1 \times i}{2r} = \frac{\mu_0 i}{2r}$

Case II $N = 2, L = 2 \times 2\pi r'$

$\Rightarrow \quad r' = \frac{L}{4\pi} = \frac{r}{2} \qquad \therefore \; B' = \frac{\mu_0 \times 2 \times i}{2r'}$

Putting the value of r′

$B' = \frac{\mu_0 \times 2i}{2 \times (r/2)} = \frac{4\mu_0 i}{2r} = 4B$

Note : Magnetic field at the centre of circular coil is maximum and decreases as we move away from the centre (on the axis of coil).

5. **(B)** If E is the electric field strength and B is the magnetic field strength and q is the charge on a particle, then electric force on the charge

$F_e = qE$

and magnetic force on the charge

$F_m = q(v \times B)$

the net force on the charge

$F = F_e + F_m = qE + q(v \times B)$

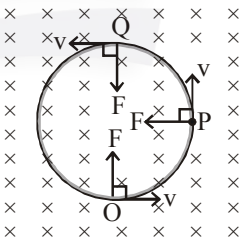
Alternative

According to Lorentz force if a charged particle is in both electric field **(E)** and magnetic field **(B)**, force is given by

$F = q[E + (v \times B)]$

6. **(C)** When a charged particle moves through a perpendicular magnetic field, then a magnetic force acts on it which changes the direction of particle but does not alter the magnitude of its velocity (i.e., speed).

So, speed of charged particle remains unchanged i.e., of velocity magnitude remains constant.



Note

If a charged particle moves at 45° to magnetic field, then path of the particle will be a helix whose circular part has radius according to relation, $r = \frac{mv\sin\theta}{qB}$.

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7. **(D)** For a solenoid magnetic field is given by $B = \mu_0 ni$

where, n = number of turns per unit length and

i = courrent through the coil

or so for two different cases $B \propto ni$

$$\therefore \quad \frac{B_1}{B_2} = \frac{n_1 i_1}{n_2 i_2}$$

Here, $n_1 = n, \; n_2 = \frac{n}{2},$

$i_1 = i, i_2 = 2i, B_1 = B$

Hence, $\frac{B}{B_2} = \frac{n}{n/2} \times \frac{i}{2i} = 1$ or $B_2 = B$

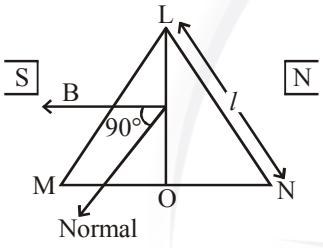
8. **(C)** Torque acting on equilateral triangle ina magnetic field B is

$\tau = M \times B, \tau = iAB \sin\theta \qquad [iA = M]$

Area of ΔLMN

$A = \frac{\sqrt{3}}{4} l^2$ and $\theta = 90°$ [l = sides of trangle]

Substituting the given values in the expression for torque, we have



$$t = i \times \frac{\sqrt{3}}{4} l^2 B \sin 90° = \frac{\sqrt{3}}{4} i l^2 B \qquad (\because \sin 90° = 1)$$

Hence, $l = 2\left(\frac{t}{\sqrt{3}\, Bi}\right)^{1/2}$

9. **(C)** The time period of electron moving in a circular orbit,

$$T = \frac{\text{Circumference of circular path}}{\text{Speed}} = \frac{2\pi r}{v}$$

Now, equivalent current due to flow of electron is given by

$$i = \frac{q}{T} = \frac{e}{(2\pi r / v)} = \frac{ev}{2\pi r} \qquad [q = e]$$

Magnetic field at centre of circle

$$B = \frac{\mu_0 i}{2r} = \frac{\mu_0 ev}{4\pi r^2} \qquad \left(i = \frac{eV}{2\pi r}\right)$$

$$\Rightarrow \quad r \propto \sqrt{\frac{v}{B}}$$

10. **(C)** When a charged particle q is moving in a uniform magnetic field B with velocity v such that angle between v and B is θ, then the charge q experience a force which is given by

$F = q(v \times B) = qvB \sin\theta$

If $\theta = 0°$ or $180°$, then $\sin\theta = 0$

$\therefore \quad F = qvB \sin\theta = 0$

Since, force on charged particle is non-zero, so angle between v and B can have any value other than 0° and 180°.

Note : Force experienced by the charged particle is the Lorentz force.

11. **(B)** Magnetic field at the centre of a circular coil is

$$B = \frac{\mu_0}{2\pi} \times \frac{i}{r}$$

where, i is current flowing in the coil and r is radius of coil.

At the centre of coil-1,

$$B_1 = \frac{\mu_0}{2\pi} \times \frac{i_1}{r_1} \qquad ...(i)$$

At the centre of coil-2

$$B_2 = \frac{\mu_0}{2\pi} \times \frac{i_2}{r_2} \qquad ...(ii)$$

but $B_1 = B_2$

$$\therefore \quad \frac{\mu_0}{2\pi} \frac{i_1}{r_1} = \frac{\mu_0}{2\pi} \frac{i_2}{r_2}$$

or $\frac{i_1}{r_1} = \frac{i_2}{r_2}$

As given $r_1 = 2 r_2$

$$\therefore \quad \frac{i_1}{2r_2} = \frac{i_2}{r_2} \text{ or } i_1 = 2 i_2 \qquad ...(ii)$$

Now, ratio of potential differences

$$\frac{V_2}{V_1} = \frac{i_2 \times R_2}{i_1 \times R_1} = \frac{i_2 \times R_2}{2i_2 \times 2R_2} = \frac{1}{4} \qquad [R \propto r]$$

$$\therefore \quad \frac{V_1}{V_2} = \frac{4}{1}$$

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Note : If wires are made of same material, then resistance of coil is proportional to the radius of coil

i.e., $R \propto I$ So, $R \propto 2\pi r$

12. (C) When magnetic field is perpendicular to motion of charged particle, then particle performs circular motion.

So, centripetial force = magnetic force

i.e. $\frac{mv^2}{R} = Bqv$ or $R = \frac{mv}{Bq}$

Further, time period of the motion

$$T = \frac{2\pi r}{v} = \frac{2\pi\left(\frac{mv}{Bq}\right)}{v} \quad \text{or} \quad T = \frac{2\pi m}{Bq}$$

13. (A) As revolving charge is equivalent to a current, so

$$= qf = q \times \frac{\omega}{2\pi}$$

But, $\omega = \frac{v}{R}$

where, R is radius of circle and v is uniform speed of charged particle.

Therefore, $i = \frac{qv}{2\pi R}$

Now, magnetic moment associated with charged particle is given by

$$\mu = iA = i \times \pi R^2 \text{ or } \mu = \frac{qv}{2\pi R} \times \pi R^2 = \frac{1}{2}qvR$$

Alternative

Current produced due to circular motion of charge q is given by

$i = \frac{q}{T}$ [T = Time period of revolution]

Now $T = \frac{2\pi R}{v}$

So, $i = \frac{q}{2\pi R} \times v$

Now, magnetic moment (μ) is given by

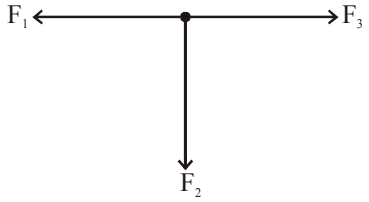
$\mu = iA$

So, $\mu = \frac{qv}{2\pi R} \times \pi R^2 \Rightarrow \mu = \frac{qvR}{2}$

14. (B) If both electric and magnetic fields are present and are perpendicular to each other and the particle is moving perpendicular to both of them with $F_e = F_m$. In this situation $E \neq 0$ and $B \neq 0$ and $F_e + F_m = 0$.

But if electric field becomes zero, then only force due to magnetic field exists. And E is perpendicular to the B so the charge moves along a circle.

15. (B) As the net force on closed loop is euqal to zero. So, force on QP will be equal and opposite to sum of forces on other 3 sides.



So, from vector laws, $F_{QP} = \sqrt{(F_3 - F_1)^2 + F_2^2}$

16. (C) Magnetic field can never increase the energy of a charged particle so, its kinetic energy will remain same.

17. (A) Magnetic Lorentz force, $F = q(v \times B)$

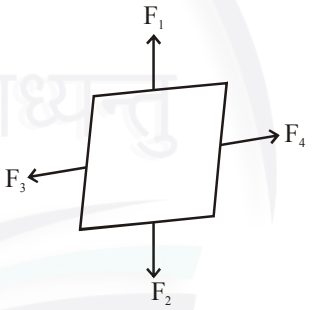
$$= -2 \times 10^{-6}\{(2\hat{i} + 3\hat{j}) \times 10^6 \times 2\hat{j}\}$$

$$= -2 \times 10^{-6}[2 \times 2 \times 10^6 \hat{k}]$$

= 8 N along negative Z-axis

18. (B) When a current carrying loop is placed in a magnetic field, the coil experiences a torque given by τ = NB i Asinθ. Torque is maximum when $\theta = 90°$, i.e., the plane of the coil is parallel to the field.

$\tau_{max} = NBiA$



Forces F_1 and F_2 acting on the coil are equal in magnitude and opposite in direction. As the forces F_1 and F_2 have the same line of action, their resultant effect on the coil is zero.

The two forces F_3 and F_4 are equal in magnitude and opposite in direction. As the two forces have different lines of action, they constitute a torque. thus, if the force on one arc of the loop is F, the net force on the remaining three arms of the loop is –F.

19. (D) As the electron beam is not deflected,

then $F_m = F_e$ or $Bev = Ee$

or $v = \frac{E}{B}$ ...(i)

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As the electron moves from cathode to anode, its potential energy at the cathode appears as its kinetic energy at the anode. If V is the potential difference between the anode and cathode, then potential energy of the electron at cathode = eV.

Also, kinetic energy of the electron at

anode $= \frac{1}{2}mv^2$. According to law of conservation of energy,

$$\frac{1}{2}mv^2 = eV \text{ or } v = \sqrt{\frac{2eV}{m}} \quad ...(ii)$$

From Eqs. (i) and (ii), we have

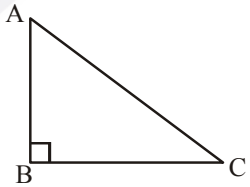
$$\sqrt{\frac{2eV}{m}} = \frac{E}{B} \text{ or } \frac{e}{m} = \frac{E^2}{2VB^2}$$

20. (A) Magnetic field **(B)** will not apply any force. Only electric field E will apply a force opposite to velocity of the electron hence, speed decreases.

21. (A) Force on AB is given by

$$F_{AB} = 0$$

According to the question,



$$F_{AB} = 0$$
$$F_{AB} + F_{BC} + F_{CA} = 0$$
$$F_{BC} + F_{CA} = 0$$
$$F_{CA} = -F_{BC} = -F$$

22. (C) Frequency, $v = \frac{eB}{2\pi m}$

$KE = \frac{1}{2}mv^2$ and radius $R = \frac{mv}{eB}$

Here, velocity, $v = \frac{\pi R}{T/2} = \frac{2\pi R}{T} = 2\pi Rv$

$\therefore$ Radius, $R = \frac{m(2\pi Rv)}{eB}$

Magnetic field, $B = \frac{2\pi mv}{e}$

Kinetic energy, $K = \frac{1}{2}m(2\pi Rv)^2$

$= 2\,m\pi^2 v^2 R^2$

23. (A) The magnetic field **(B)** at the centre of circular current carrying coil of radius R and current I is

$$B = \frac{\mu_0 I}{2R}$$

Similarly, if current is 2I, then

Magnetic field $= \frac{\mu_0 2I}{2R} = 2B$

So, resultant magnetic field $= \sqrt{B^2 + (2B)^2} = \sqrt{5B^2}$

$$= \sqrt{5}B = \frac{\mu_0 I\sqrt{5}}{2R}$$

24. (D) For paralle, M is stable and for antiparallel, it is unstable.

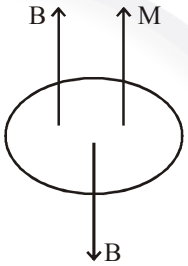
25. (B) Initial acceleration is given by

$$a_0 = \frac{eE}{m} \quad (F = eE)$$

$$\Rightarrow E = \frac{a_0 m}{e} \quad ...(i)$$

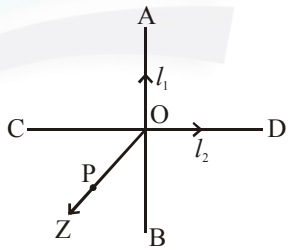
$$\therefore \frac{ev_0B + eE}{m} = 3a_0m$$

or $ev_0B + eE = 3a_0m$



$$\therefore ev_0B = 3ma_0 - eE$$
$$\Rightarrow = 3\,ma_0 - ma_0 \quad \text{[from Eq. (i)]}$$
$$\therefore B = \frac{2ma_0}{ev_0}, \text{ in vertically downward direction}$$

26. (D) As from question



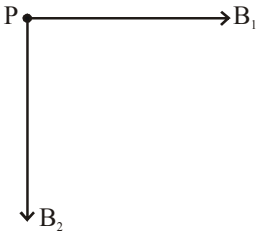
The point P is lying at a distance d along the Z-axis.

As magnetic field B_1 is given by $= \frac{\mu_0}{2\pi}\frac{I_1}{d}$

and magnetic field B_2 is given by $= \frac{\mu_0}{2\pi}\frac{I_2}{d}$

B1 and B2 are $\perp$ to each other

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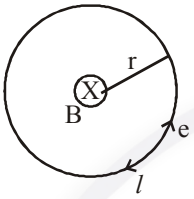


So, B_{net} is given by

$$B_{net} = \sqrt{B_1^2 + B_2^2},$$

$$B_{net} = \frac{\mu_0}{2\pi d}\frac{1}{d}(I_1^2 + I_2^2)^{1/2}$$

27. (D) As $I = \frac{q}{t}$. So, for an electron revolving in a circular orbit of radius r



$q = e$ and $t = T$

$$\Rightarrow \quad I = \frac{e}{T} = \frac{e}{2\pi/\omega} = \frac{\omega e}{2\pi} = \frac{2\pi ne}{2\pi} = ne$$

The magnetic field produced at the centre is

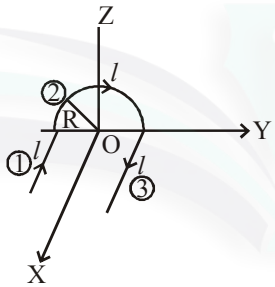
$$B = \frac{\mu_0 I}{2R} = \frac{\mu_0 ne}{2r}$$

28. (A) The magnetic field in the different regions is given by

$$B_1 = \frac{\mu_0}{4\pi} \times \frac{I}{R}(-\hat{k})$$

$$B_3 = \frac{\mu_0 I}{4\pi R}(-\hat{k})$$

$$B_2 = \frac{\mu_0 I}{4\pi R}(-\hat{i})$$



The net magnetic field at the centre O is

$$B = B_1 + B_2 + B_3$$

$$= \frac{\mu_0 I}{4\pi R}(-2\hat{k}) + \frac{\mu_0 I}{4R}(-\hat{i})$$

$$= -\frac{\mu_0 I}{4\pi R}(2\hat{k} + \pi\hat{i})$$

29. (A) As we know tha, radius of charged particle in a magnetic field B is given by

$$r = \frac{mv}{qB} \qquad ...(i)$$

where, r = change on the particle

v = speed of the particle

$\therefore$ The time taken to complete the circle,

$$T = \frac{2\pi r}{v} \Rightarrow \frac{T}{2\pi} = \frac{m}{qB} \qquad \text{[from Eq. (i)]}$$

$$\therefore \quad \omega = \frac{2\pi}{T} = \frac{qB}{m}$$

$$\because \quad q = e \text{ and } \frac{e}{m} = 1.76 \times 10^{11} \text{ C/kg}$$

$$B = 3.57 \times 10^{-2} \text{ T}$$

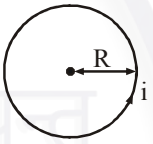
$$\Rightarrow \quad \frac{2\pi}{T} = \frac{eB}{m} \quad f = \frac{1}{2\pi}\frac{e}{m}B \qquad \left(\because \frac{1}{T} = f\right)$$

$$= \frac{1}{2\pi} \times 1.76 \times 10^{11} \times 3.57 \times 10^{-2}$$

$$= 1.0 \times 10^9 \text{ Hz} = 1 \text{ GHz}$$

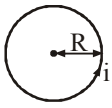
30. (B) Key Idea $B_{centre} = \frac{n \cdot \mu_0 i}{2R}$ (For a circular coil)

where, n : Number of turns in circular coil



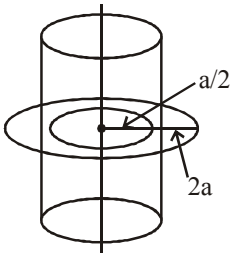
$$B = \frac{\mu_0 i}{2R} = \frac{\mu_0(2\pi)}{2(l)} = \frac{\mu_0 \pi i}{l}$$

$$= \frac{\mu_0 ni}{2\left(\frac{l}{2n\pi}\right)} = \frac{n^2 \mu_0 \pi i}{l} = n^2 B$$



31. (B) Consider two cmperian loops of radius $\frac{a}{2}$ and 2a as shown in the diagram.

Applying Ampere's circuital law for these loops we get,



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$$\oint B.dL = \mu_0 I_{enclosed}$$

For the smaller loop

$$\Rightarrow \quad B \times 2\pi\frac{a}{2} = \mu_0 \times \frac{I}{\pi a^2} \times \pi\left(\frac{a}{2}\right)^2$$

$$= \mu_0 I \times \frac{1}{4} = \frac{\mu_0 I}{4}$$

$\Rightarrow B_1 = \frac{\mu_0 I}{4\pi a}$, at distance $\frac{a}{2}$ from the axis of the wire.

Similarly, for bigger amperian loop.

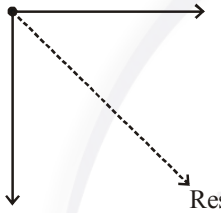
$B' \times 2\pi(2a) = \mu_0 I$ [total current enclosed by Amperian loop is 2]

$$\Rightarrow \quad B' = \frac{\mu_0 I}{4\pi a}$$

at distance 2a from the axis of the wire.

So, ratio of, $\frac{B}{B'} = \frac{\mu_0 I}{4\pi a} \times \frac{4\pi a}{\mu_0 I} = 1$

32. (D) As force on wire B due to A and C are attractive, so we have following condition



$$F = \frac{\mu_0 I^2}{2\pi d}$$

Resultant force on B

$$= \sqrt{F_1^2 + F_2^2} = \sqrt{2}\, F = \sqrt{2} \times \frac{\mu_0 I^2}{2\pi d} = \frac{\mu_0 I^2}{\sqrt{2}\pi d}$$

33. (A) Work done for rotating the coil

$$W = MB(\cos\theta_1 - \cos\theta_2)$$

where, M = magnetic moment

B = magnetic field

Given, $\theta_1 = 0°, \theta_2 = 180°$

$$\Rightarrow \quad W = MB(\cos 0° - \cos 180°)$$

$$= 2MB = 2 \times NIA \times B$$

$$= 2 \times 250 \times 85 \times 10^{-6} \times (2.1 \times 1.25 \times 10^{-4}) \times 0.85$$

$$= 9.48 \times 10^{-6}\ J$$

$$\approx 9.5 \times 10^{-6}\ J = 9.5\ \mu J$$

The closest option is **(A)**.

34. (A) The magnetic susceptibility of a material is a measure of the ease with which a specimen of that material can be magnetised in a magnetising field. For a diamagnetic substance, magnetic susceptibility (χ_m) is independent of temperature.

35. (A) The time period of bar magnet is

$$T = 2\pi\sqrt{\frac{I}{MH}}$$

where, M = magnetic moment of magnet

I = moment of inertia

and H = horizontal component of magnetic field

When same poles of magnets are placed on same side, then net magnetic moment

$$M_1 = M + 2M = 3M$$

$$\therefore \quad T_1 = 2\pi\sqrt{\frac{I}{M_1 H}}$$

$$= 2\pi\sqrt{\frac{I}{3MH}} \qquad ...(i)$$

When opposite poles of magnets are placed on same side, then net magnetic moment

$$M_2 = 2M - M = M$$

$$\therefore \quad T_2 = 2\pi\sqrt{\frac{I}{M_2 H}} = 2\pi\sqrt{\frac{I}{MH}} \qquad ...(ii)$$

From Eqs. (i) and (ii), we observe that

$$T_1 < T_2$$

36. (C) When a diamagnetic material is placed in an external magnetic field, the spin motion of electrons is so modified that the electrons which produced the magnetic moments in the direction of external field slow down while the electrons which produce magnetic moments in opposite direction get accelerated.

Thus, a net magnetic moment is induced in the opposite direction of applied magnetic field.

Hence, the substance is magnetised opposite to the external fiedl. Thus, it moves from stronger to weaker parts of the magnetic field.

Diamagnetism is present in all the substances.

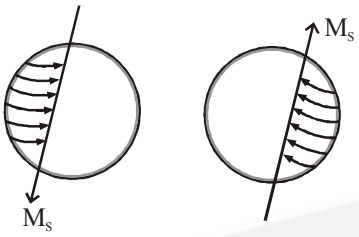
However, its effect is so weak in most cases that it gets shifted by other effects like paramagnetism, ferromagnetis etc.

37. (C) According to Curie's law, magnetic susceptibility (χ_m) of a paramagnetic substance is inversely proportional to absolute temperature (T) i.e.

$$\chi_m \propto \frac{1}{T}$$

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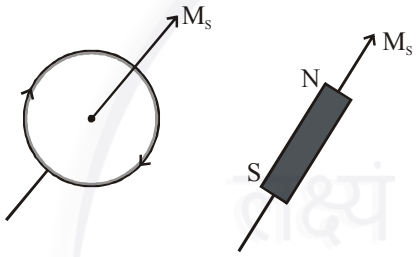
38. (C) In diamagnetic substances, in each pair of electrons the spin of both the electrons are in opposite directions. Hence, the electrons of each pair completely cancel the magnetic moment of each other. Thus, the net magnetic moment of each atom of such substances is zero, i.e. $\mu_d = 0$.



The property of paramagnetism is found in those substances whose atoms or molecules have an excess of electrons spinning in same direction.

Hence, atoms of paramagnetic substances have permanent magnetic moment i.e. $\mu_p \neq 0$.

The property of ferromagnetism is found in substances which acquire very strong magnetism when placed in an external magnetic field. Like the paramagnetic substances each atom of ferromagnetic substances also has a permanent magnetic moment i.e. $\mu_f \neq 0$.



39. (A) Ferromagnetism decreases with rise in temperature. If we heat a ferromagnetic substance, then at a definite temperature, the ferromagnetic property of the substance suddenly disappears and the substance becomes paramagnetic. the temperature above which a ferromagnetic substance becomes paramagnetic. The temperature above which a ferromagnetic substance becomes paramagnetic is called the Curie temperature of the substance.

40. (A) Nickel exhibits ferromagnetism because of a quantum physical effect called exchange coupling in which the electron spins of one atom interact with those of neighbouring atoms. the result is alignment of the magnetic dipole moments of the atoms, in spite of the randomising tendency of atomic collisions. This persistent alignment is what gives ferromagnetic materials their permanent magnetism.

41. (A) Diamagnetic substances are weakly magnetised in a direction opposite to that of applied magnetic field.These are repelled in an external magnetic field i.e. have a tendency to move from high to low field region, i.e. it is repelled by both North and South poles of a bar magnet.

42. (C) When magnetic dipole is rotated from initial position θ_1 to final position θ_2,

then work done = $MB(\cos\theta_1 - \cos\theta_2)$

Given, $\theta_1 = 0°$, $\theta_2 = 60°$

Magnetic moment, $M = 2 \times 10^4$ J/T

Magnetic field, $B = 6 \times 10^{-4}$ T

So, $$W = MB\left(1 - \frac{1}{2}\right) \qquad \left[\because \cos 0° = 1 \text{ and } \cos 60° = 1/2\right]$$

$$= \frac{2 \times 10^4 \times 6 \times 10^{-4}}{2} = 6 \text{ J}$$

43. (B) **Problem Solving Strategy** Find out the relation of time period with the earth's horizontal magnetic field and then compare it for the two given cases.

Time period in vibration magnetometer is given by

$$T = 2\pi\sqrt{\frac{I}{M \times B_H}}$$

$$\Rightarrow \quad T \propto \frac{1}{\sqrt{B_H}}$$

So, for two different cases

$$\Rightarrow \quad \frac{T_1}{T_2} = \sqrt{\frac{(B_H)_2}{(B_H)_1}}$$

$$\therefore \quad T = 2.3 \text{ s} \approx 2 \text{ s}$$

44. (D) Paramagnetic material will be feebly attracted, diamagnetic material will be feebly repelled and ferromagnetic material will be strongly attracted.

45. (C) It will stay in any position at geomagnetic North and South poles.

46. (B) The magnetic moment, $M = ml$

$$\begin{pmatrix} m = \text{pole strength} \\ l = \text{length of magnet} \end{pmatrix}$$

According to question,

$$l = \frac{\pi}{3} \times r$$

So, $$r = \frac{3l}{\pi}$$

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New magnetic moment, $M' = m \times r$

$$= m \times \frac{3l}{\pi} = \frac{3}{\pi} \cdot ml = \frac{3M}{\pi}$$

47. (C) Magnetic moment is from S to N

So, $M_{net} = \sqrt{M^2 + M^2 + 2M^2 \cos\theta}$

M_{net} will be maximum if cos θ is maximum cos θ will be maximum when θ will be minimum.

So, at $\theta = 30°$, M_{net} will be maximum.

48. (B) ∵ Work done in rotating the magnet

$W = MB (\cos\theta_0 - \cos\theta)$

Where, M = magnetic moment of the magnet

B = magnetic field

$W = MB (\cos 0° - \cos 60°)$

$$= MB\left(1 - \frac{1}{2}\right) = \frac{MB}{2}$$

$\therefore \quad MB = 2W \qquad ...(i)$

Torque on a magnetic in this position is given by.

$\tau = M \times B$

$= MB \cdot \sin\theta = 2W \cdot \sin 60°$ [from Eq. (i)]

$$= 2W\frac{\sqrt{3}}{2} = W\sqrt{3}$$

49. (D) As we know the relation between the magnetic permeability and susceptibility of material, i.e.

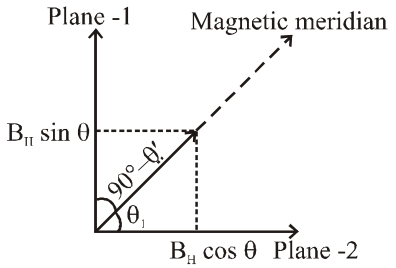
$\mu_r = 1 + \chi_m \qquad ...(i)$

∵ For diamagnetic substances, $\mu_r < 1$

So, according to equation (i), the magnetic susceptibility (χ_m) of diamagnetic substance will be negative.

While in the case of para and ferromagnetic substances, diamagnetic susceptibility is positive.

50. (A) Let the B_H and B_V be the horizontal and vertical component of earth's magnetic field B.



$$\tan\theta = \frac{B_V}{B_H} \Rightarrow \cot\theta = \frac{B_H}{B_V} \qquad ...(i)$$

Let, plane 1 and 2 are mutually perpendicular planes making angle θ and (90° – θ) with magnetic meridian. The vertical component of earth of earth's magnetic field remain same in two plane but effective horizontal components in the two planes is given by

$B_1 = B_H \cos\theta'$

and $B_2 = B_H \sin\theta'$

Then, $\tan\theta_1 = \frac{B_V}{B_1} = \frac{B_V}{B_H \cos\theta'}$

$$\cot\theta_1 = \frac{B_H \cos\theta'}{B_V} \qquad ...(ii)$$

Similarly,

$$\Rightarrow \tan\theta_2 = \frac{B_V}{B_2} = \frac{B_V}{B_H \sin\theta'}$$

$$\Rightarrow \cot\theta_2 = \frac{B_H \sin\theta'}{B_V} \qquad ...(v)$$

From Eq. (iv) and Eq. (v)

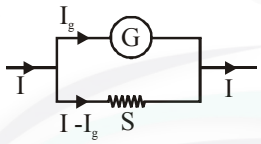
$$\Rightarrow \cot^2\theta_1 + \cot^2\theta_2 = \frac{B_H^2 \cos^2\theta'}{B_V^2} + \frac{B_H^2 \sin^2\theta'}{B_V^2}$$

$$\Rightarrow \cot^2\theta_1 + \cot^2\theta_2 = \frac{B_H^2}{B_V^2}(\cos^2\theta' + \sin^2\theta')$$

$\Rightarrow \cot^2\theta_1 + \cot^2\theta_2 = \cot^2\theta$

EXERCISE - 4
P-2 (AIIMS)

1. (B)



Here, $I_g = \frac{I}{10}$,

$$\Rightarrow IgG = (I - I_g)S \Rightarrow S = \frac{I_g G}{I - I_g} \qquad [\because G = 900\,\Omega]$$

Hence $S = 100\,\Omega$

2. (D) Given that the field at the centre of the ring B = 7×10^{-5} Wb/m²

We know that $B = \frac{\mu_0 I}{2r}$

$$\Rightarrow I = \frac{2Br}{\mu_0} = \frac{2 \times 7 \times 10^{-5} \times 0.05}{4\pi \times 10^{-7}} = 5.57 \text{ A}$$

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3. **(C)** The wire of length l is bent to form a circular loop, so $2\pi r = l$

$\Rightarrow r = \frac{l}{2\pi}$. The magnetic field at the centre of the loop is $B = \frac{\mu_0 I}{2r} = \frac{\mu_0 I \times 2\pi}{2l}$

Now the same length of the wire is bent to from a double loop

$\therefore \quad 2 \times 2\pi r' = l \quad \Rightarrow r' = \frac{l}{4\pi}$

And the magnetic field at the centre

$$B' = \frac{\mu I \times 2}{2 \times r'} = \frac{2\mu_0 I}{2 \times \frac{l}{4\pi}} = \frac{2 \times 4\pi\mu_0 I}{2l}$$

$$\therefore \quad \frac{B'}{B} = 4 \Rightarrow B' = 4B$$

4. **(B)** The magnetic field at the centre of a circular loop carrying current I is given by $B = \frac{\mu_0 I}{2r}$ where r is the radius of the circular loop.

Given that $r = 5.0\ cm = 0.05\ m$.

Earth's magnetic field $B_E = 0.5 \times 10^{-5}\ Wb/m^2$

B_E is annulled by B

$$\therefore \quad \frac{\mu_0 I}{2r} = B_E = 0.5 \times 10^{-5}$$

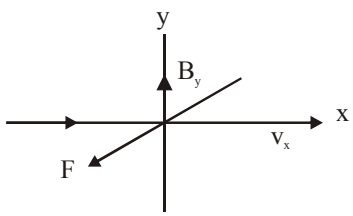
$$\Rightarrow \quad I = \frac{0.5 \times 10^{-5} \times 2 \times 0.05}{\mu_0} = \frac{0.5 \times 10^{-5} \times 0.1}{4\pi \times 10^{-7}}$$

$I = 0.3978 \approx 0.4\ A.$

5. **(B)** As two like currents attract and unlike currents repel each other, the wire will attract the side of the loop near the wire and parallel to it and the far side of the loop again parallel to the wire will be repelled. But the force of attraction will be more as that side of the loop is closer to the wire and so effectively the current loop will move towards the wire.

6. **(B)** The force on a charged particle e due to a magnetic field is given by

$\vec{F} = e(\vec{v} \times \vec{B})$



Here $\vec{v} = v_x \hat{i}$ and $\vec{B} = B_y \hat{j}$

$\therefore \quad \vec{F} = ev_x B_y (\hat{i} \times \hat{j}) = ev_x B_y \hat{k}$

Therefore the subsequent motion of the charged particle will be a circle in the xz plane.

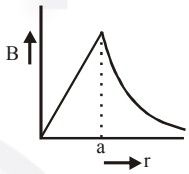
7. **(D)** Magnetic field at a point on the axis of a loop is given by

$$B = \frac{\mu_0}{4\pi} \frac{2\pi I R^2}{(R^2 + r^2)^{3/2}}.$$

when $r >> R$, $B = \frac{\mu_0}{4\pi} \frac{2\pi R^2 I}{r^3} = \frac{\mu_0}{2\pi} \frac{AI}{r^3}$.

Thus, $B \propto (1/r^3)$.

8. **(A)** Magnetic field at a point outside the straight conductor is



$B = \frac{\mu_0 I}{2\pi r}$ i.e. $B \propto (1/r)$ $(r > a)$

Magnetic field at a point lying inside the conductor is $B \propto r\ (r < a)$.

9 **(D)** The magnetic moment of a current carrying conductor is $i \cdot n\pi r^2 = niA$.

i.e. Magnetic moment $\propto r^2$.

10. **(D)** Cyclotron frequency $\upsilon = \frac{qB}{2\pi m}$

$$= \frac{1.6 \times 10^{-19} \times 1}{2 \times 3.14 \times 9.1 \times 10^{-31}} = 28 \times 10^9\ Hz = 28\ GHz.$$

11. **(A)** Magnetic field due to a circular loop at the centre of the loop is $B_1 = \frac{\mu_0}{4\pi} \frac{2\pi I}{R}$.

Magnetic field due to a straight line at the centre of the loop is $B_2 = \frac{\mu_0 2I_e}{4\pi H}$

Both these fields act in opposite direction hence total magnetic field at the centre of the loop is

$$B = B_1 - B_2 = \frac{\mu_0 2\pi I_c}{4\pi R} - \frac{\mu_0 2I_e}{4\pi H}$$

$B = 0$ (given).

$$\therefore \quad \frac{\mu_0 2\pi I_c}{4\pi R} = \frac{\mu_0 2I_e}{4\pi H} \quad \text{or,} \quad H = \frac{I_e R}{\pi I_c}$$

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12. (B) A coil of radius r carrying current I, magnetic field at a point at a distance R from the centre of the coil is given by

$$B = \frac{\mu_0 I r^2}{2[R^2 + r^2]^{3/2}}$$

At the centre of a coil, R = 0

$$\therefore \quad B = \frac{\mu_0 I r^2}{2r^3} = \frac{\mu_0 I}{2r}$$

13. (D) $evB = \frac{mv^2}{r}$

$\frac{e}{m} \propto \frac{1}{r}$, if B and v are the same. The radius of curvature of D is minimum. Therefore $\frac{e}{m}$ is maximum.

14. (B) Net charge of system = 0

$\therefore$ Net force on system = 0

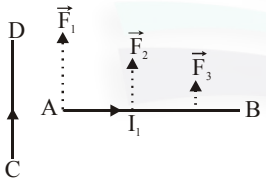
Now consider one charge : F = qvB.

15. (A)

16. (B) $I_g = 0.1I$, $I_s = 0.9I$; $S = I_g G/I_s$

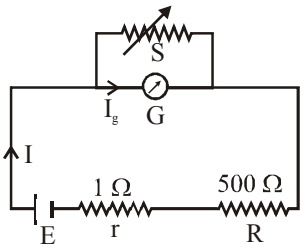
$= 0.1 \times 900/0.9 = 100\ \Omega$

17. (C) Since the magnetic field, due to current through wire CD at various location on wire AB is not uniform, therefore, the wire AB, carrying current I_1 is subjected to variable magnetic field due to which, neither the force nor the torque on the wire AB will be zero. As a result of which the wire AB will have both translational and rotational motions.



18. (D)

19. (A)



Here, $I = \frac{E}{R + r + \frac{GS}{G+S}}$ and $I_g = \frac{IS}{G+S}$

$$I_g = \frac{E}{(R+r) + \frac{GS}{(G+S)}} \times \frac{S}{(G+S)}$$

$$\therefore \quad I_g = \frac{ES}{(R+r)(G+S) + GS}$$

For S = 5 ohm, $I_g = 5 \times 10^{-3}$ A

and for S = 25 ohm, $I_g = 20 \times 10^{-3}$ A

Hence, $5 \times 10^{-3} = \frac{E \times 5}{501(G+5) + 5G}$ ....(i)

and $20 \times 10^{-3} = \frac{E \times 25}{501(G+25) + 25G}$ ...(ii)

Dividing and solving, G = 88.2 Ω

From (i), we get

$E = 10^{-3}[501\,(88.2+5) + 5 \times 88.2] = 47.1$ volt

20. (A)

21. (A) Given, B = 1 T, r = 0.2 m

$$r = \frac{mv}{qB}$$

i.e., $v = \frac{0.2 \times 1.6 \times 10^{-19} \times 1}{1.6 \times 10^{-27}} = 0.2 \times 10^8\ m\ s^{-1}$

22. (A) The expression for magnetic field is case of a long current carrying wire is $B = \frac{\mu_0 I}{2\pi a}$

i.e., $B \propto \frac{1}{a}$

23. (D)

24. (A) Here, m = 100 g = 10^{-1} kg, l = 1 m, I = 5 A

For a wire balanced midway air by a magnetic field is $mg = IlB$.

or $B = \frac{mg}{Il} = \frac{10^{-1} \times 10}{5 \times 1}$

B = 0.2 T.

25. (D) The magnetic field at any point inside the toroid is zero.

26. (C) Two parallel current carrying wires in the same direction attract each other whereas two parallel current carrying wires in the opposite direction repel each other.

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27. (B) $\frac{\mu_0}{4\pi}\frac{2i_1}{r}-\frac{\mu_0}{4\pi}\frac{2i_2}{r}=10\mu T$

$\frac{\mu_0}{4\pi}\frac{2i_1}{r}+\frac{\mu_0}{4\pi}\frac{2i_2}{r}=30\mu T$

On solving $i_1 = 20$ A and $i_2 = 10$ A. $\therefore i_1/i_2 = 2$

28. **(A)** Force on the electron $\vec{F}=-e(\vec{v}\times\vec{B})$. As electron is travelling in a plane perpendicular to the plane of wire, so angle θ between $\vec{v}$ and $\vec{B}$ is either 0° or 180° and sin 0° or sin 180° = 0.

29. **(B)** Here, $\vec{E}$ and $\vec{B}$ are acting along x-axis and $\vec{v}$ is along y-axis i.e. perpendicular to both $\vec{E}$ and $\vec{B}$. Therefore, the path of charged particle is a helix with increasing speed. Speed of particle at time t is

$v=\sqrt{v_x^2+v_y^2}$ ...(i)

Here, $v_y = v_0$; $v_x = \frac{qE_0}{m}t$ and $v=\frac{\sqrt{5}}{2}v_0$

Putting values in (i), we get $t=\frac{mv_0}{2qE_0}$

30. **(A)** Force per unit length between two parallel current carrying wire is given by

$F=\frac{\mu_0}{2\pi}\frac{I_1I_2}{r}$

Here, $\frac{\mu_0}{4\pi}10^{-7}$ N m A^{-2}, r = 0.02 m

F = 2 × 10^{-3} N m^{-1}, I_1 = 10 A, I_2 = ?

So, $2\times10^{-3}=2\times10^{-7}\times\frac{10\times I_1}{0.02}$

$0.02\times10^4=10\,I_1$ $\therefore$ $I_1 = 20$ A

31. **(A)**

32. **(C)** For a voltmeter, in which current I_g passes,

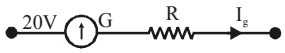
when range is lower, $5 = G\times I_g$ ...(i)

when range is higher, $20 = (G+R)\,I_g$ ...(ii)

where G = resistance of voltmeter = 20000 Ω

$\therefore$ From (i) and (ii)



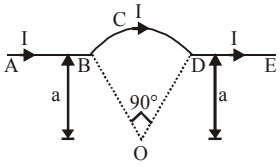


$\frac{5}{20}=\frac{G}{G+R}$ or $\frac{1}{4}=\frac{G}{G+R}$

or R = 3G = 3 × 20000 = 60000

or extra resistance = 60000 W in series.

33. **(B)**



here, $a=\frac{r}{\sqrt{2}}$

Magnetic field at point O due to AB is

$B_1=\frac{\mu_0}{4\pi}\frac{I}{a}=\frac{\mu_0 I}{4\pi(r/\sqrt{2}}$

Magnetic field at point O due to BCD is

$B_2=\frac{\mu_0 I}{4\pi r}\left(\frac{\pi}{2}\right)$

Magnetic field at point O due to DE is

$B_3=\frac{\mu_0 I}{4\pi a}=\frac{\mu_0 I}{4\pi(r/\sqrt{2})}$

Resultant magnetic field at point O is

$B = B_1 + B_2 + B_3$

$=\frac{\mu_0 I}{r\pi(r/\sqrt{2})}+\frac{\mu_0 I}{4\pi r}\left(\frac{\pi}{2}\right)+\frac{\mu_0 I}{4\pi(r/\sqrt{2})}$

$=\frac{\mu_0 I}{4\pi r}\left(\sqrt{2}\frac{\pi}{2}+\sqrt{2}\right)=\frac{\mu_0 I}{4\pi r}\left(2\sqrt{2}+\frac{\pi}{2}\right)$

$=\frac{\mu_0 2I}{4\pi r}\left(\sqrt{2}+\frac{\pi}{4}\right)$

$=\frac{10^{-7}\times 2I}{r}\left(\sqrt{2}+\frac{\pi}{4}\right)$ $\left[\because \frac{\mu_0}{4\pi}=10^{-7}\right]$

34. **(D)** Any charged particle can be accelerated with the help of a cyclotron but in the case of an electron, being very light, the process of accelerating the electron with a cyclotron is relativistically unfavourable. Very easily it will attain a velocity at which it will show relativistic effects.

35. **(A)** A voltmeter is always connected in parallel. This has of course a large resistance. The assertion and reason are correct and it is the correct explanation.

36. **(B)**

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37. **(A)** Magnetic moment, $m = nIA$

38. **(D)** The force on a charged particle moving in a uniform magnetic field always acts in direction perpendicular to the direction of motion of the charge. As work done by magnetic field on the charge is zero. [$W = FS\cos\theta$], so the energy of the charged particle does not change.

39. **(D)** A charge, whether stationary or in motion, produces an electric field around it. If it is in motion, then in addition to the electric field, it also produces a magnetic field, because moving charges produce magnetic field in the surrounding space.

40. **(A)** The period of a charged particle in a magnetic field is given by $T = \frac{2\pi m}{qB}$, i.e., $T \propto \frac{m}{q}$

We know that, $m_p = m$, $m_\alpha = 4m$, $q_p = e$, $q_\alpha = 2e$

$\therefore \quad \frac{T_p}{T_\alpha} = \frac{1}{2}$ or $T_\alpha = 2T_p$

41. **(B)**

42. **(A)** Magnetic field due to a circular loop carrying current 1 is given as

$$B = \frac{\mu_0}{4\pi}\frac{2\pi I r^2}{(r^2 + x^2)^{3/2}}$$

where, r = radius of loop

x = distance from centre of loop

for large distances, $(x >> r)$,

$$\therefore \quad B = \frac{\mu_0}{4\pi}\frac{2IA}{x^3} = \frac{\mu_0}{4\pi}\frac{2M}{x^3}$$

where M = IM = magnetic dipole moment of current loop which is equal to the magnetic field due to magnetic dipole.

thus, the current loop can be considered as a magnetic dipole.

43. **(A)** Cyclotron is used to accelerate charged particles to high energies. It uses both electric and magnetic fields together to increase the energy of the charged particle.

44. **(C)** The magnetic field lines form closed loops unlike electrostatic field lines which originate from the charge and end at charge. Mono-magnetic pole does not exist in nature.

45. **(A)**

46. **(A)** We know, $\varepsilon = \oint \vec{E}\cdot d\vec{l} = -\frac{d\phi_B}{dt}$

As $\oint \vec{E}\cdot d\vec{l} \neq 0$,

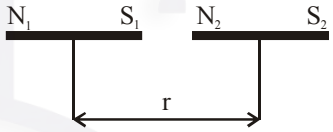
the induced electric field is non-conservative in nature.

47. **(D)** In a non-uniform magnetic field, a torque and a net force both act on the dipole. If magnetic field is uniform, net force on dipole would be zero.

48. **(A)** Water is a diamagnetic substance. The relative permeability of water is less than 1.

49. **(A)**

50. **(D)** Two magnets placed along same axis/line at distance r (between their centres) exert a force on each other.



$$\text{Force} = \frac{6M_1M_2}{r^4}$$

where M_1 and M_2 are magnetic moments

$$\therefore \quad \frac{F_2}{F_1} = \left(\frac{r_1}{r_2}\right)^4 = \left(\frac{1}{2}\right)^4 = \frac{1}{16}$$

or $F_2 = \frac{F_1}{16} = \frac{4.8}{16} = 0.3$ N.

51. **(B)** Inside the magnet the lines go from south pole to the north pole.

52. **(C)** Angle through which magnet is deflected (θ) = 30° Horizontal magnetic field (B_H) = 0.34×10^{-4} T. magnetic intensity = $B_H\tan\theta = 0.34 \times 10^{-4} \times \tan 30° = (0.34 \times 10^{-4}) \times 0.577 = 1.96 \times 10^{-5}$ T.

53. **(A)** In the presence of an external magnetic field, the atomic dipoles of paramagnetic substances are aligned along the field. The material gets magnetised and it produces an extra magnetic field in the material in the direction of the field. So for paramagnetic materials, the resultant field is greater than the applied field. As the body of a frog behaves like a paramagnetic substance, the smallest magnetic field on the body of the frog will be strong enough to lift it up.

54. **(B)** Molecular bonding of O_2 based on orbitals show that O_2 is paramagnetic, which is true experimentally.

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55. **(A) :** for dimagnetic substance, magnetic susceptibility is $-1 \le x < 0$

For ideal or perfect diamagnetic substances magnetic susceptibility is –1.

Type 1 - superconductors are perfect diamagnetic.

56. **(A)** the magnetic intensity due to an isolated pole of strength m_p at a distance $(r) = \frac{m_p}{r^2}$

57. **(C)** Relative magnetic permeability of diamagnetic substances is always less than unity. i.e. $\mu_r < 1$ $\mu_r = (1 + x_m)$ as $\mu_r < 1$, x_m is negative.

Hence, susceptibility of diamagnetic substances has a small negative value.

58. **(A)** Susceptibility x_m is small and negative for diamagnetic substances.

59. **(C)** The orientation of dipoles parallel and antiparallel to magnetic field is distributed unequally in ferrimagnetic materials.

60. **(A)** Magnetic moment,

$$M = IA = I(\pi r^2) = \frac{q}{T} \times \pi r^2 \qquad (\because q = It)$$

As $\omega = \frac{2\pi}{T}$

$\therefore \quad M = \frac{q\omega r^2}{2}$

or $M \propto \omega$

61. **(C)**

62. **(D)** Since angle of dip at a place is defined as the angle δ, which if the direction of total intensity of earth's magnetic field B makes with a horizontal line in magnetic meridian,

At poles $B = B_V$ and $B_V = B \sin\delta$

$\therefore \quad \sin\delta = 1 \Rightarrow d = 90°$

At equator $B = B_H$ and $B_H = B\cos\delta$

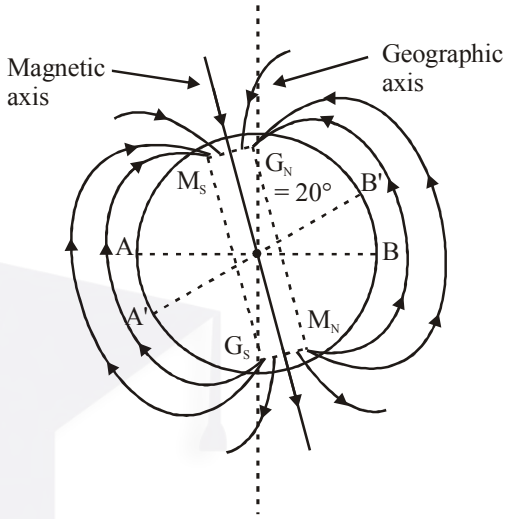
$\therefore \quad \cos\delta = 1 \Rightarrow d = 0°$.

63. **(D)** Since $B_H = B_V$ (Given)

$$\tan\delta = \frac{B_V}{B_H} = \frac{B_H}{B_H} = 1$$

$\therefore \quad \delta = 45°$

64. **(D)** From the compass we are able to know the direction of the magnetic poles. The north of compass points towards the magnetic south pole.



If we know the magnetic declination at that particular place (which is angle between geographic meridian and magnetic meridian) we can easily find out the true geographic north-south direction.

Imaginary lines drawn along the earth's surface in the direction of the horizontal component of the magnetic field of the earth at all points passing through the north and south magnetic poles. This is similar to the longitudes of the earth, which pass through the geographic north and south poles.

65. **(A)** Since superconductor exist only below a certain critical temperature and above that temperature they behave like normal materials. When magnet is placed above superconductor and cooled using liquid nitrogen. The induced magnetic field inside the superconductor is exactly equal and opposite in direction to the applied magnetic field, so that they cancel within the super conductor. These poles will repel each other and the force of repulsion is enough to float the magnet.

66. **(D)** diamagnetic materials have L = 0, S = 0, J = 0. They have no magnetic moment. Reason given is wrong.

67. **(A)** The assertion is true. From Curie Weiss law where the susceptibility $x = \frac{C}{(T - T_C)}$. If the temperature rises above the Curie temperature T_C, ferromagnetic materials become paramagnetic materials because the domains get destroyed as stated.

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68. (D) It is quit clear that magnetic poles always exists in pairs. Since, one can imagine magnetic field configuration with three poles. When north poles or south poles of two magnets are glued together. They provide a three pole field configuration. It is also know that a bar magnet does not exert a torque on itself due to its own field.

69. (C) Magnetic susceptibility (x_m) is defined as the ratio of the intensity (M) of magnetisation to the magnetic intensity (H) of the magnetising field, that is

$$x_m = \frac{M}{H}$$

It is a pure number, because I and H have the same unit. Its value for vacuum is zero as there can be no magnetisation in vacuum.

70. (A) **71. (A)**

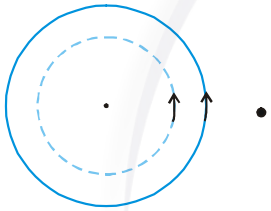
72. (D) It does not follow inverse square law of distance. The assertion is false. The reason is also false.

73. (B) : Superconductor is both a perfect diamagnetic substance as well as a perfect conductor.

74. (A)

MOCK TEST

1. (A)



Disc behaves like made up of coils arranged in a plane in which current is flowing in anti-clockwise direction. Hence, the field at A is directed into the page. Hence (A).

2. (A) $\vec{B} = \frac{\mu_0}{4\pi} q \frac{\vec{v}\times\vec{r}}{r^3}$ and $\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{q\vec{r}}{r^3}$

$\therefore \quad \vec{B} = \mu_0 \epsilon_0 (\vec{v}\times\vec{E}) = \frac{\vec{v}\times\vec{E}}{c^2}$

3. (A) Since

$\vec{B} = \frac{\mu_0}{4\pi} q \frac{\vec{v}\times\vec{r}}{r^3}$, $\vec{v}\times\vec{r}$ must be same

where $\vec{v}$ = velocity of charge with respect to observer
Let A and B are the observers

then $(\vec{v}_C - \vec{v}_A)\times\vec{r} = (\vec{v}_C - \vec{v}_B)\times\vec{r}$

or $(\vec{v}_A - \vec{v}_B)\times\vec{r} = 0$ or $(\vec{v}_A - \vec{v}_B) \| \vec{r}$

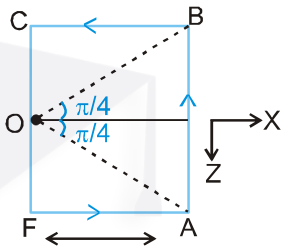
4. (C) Due to FABC the magnetic field at O is along y – axis and due to CDEF the magnetic field is along x–axis .

Hence the field will be of the form A $\left[\hat{i}+\hat{j}\right]$

Calculating field due to FABC :

due to AB :

$$\vec{B}_{AB} = \frac{\mu_0 i}{4\pi\left(\frac{\ell}{2}\right)}(\sin 45^\circ + \sin 45^\circ)\,\hat{j} = \sqrt{2}\frac{\mu_0 i}{2\pi\ell}\hat{j}$$



Due to BC :

$$\vec{B}_{BC} = \frac{\mu_0 i}{4\pi l\left(\frac{\ell}{2}\right)}(\sin 0^\circ + \sin 45^\circ)\hat{j} = \frac{\mu_0 i}{2\sqrt{2}\pi\ell}\hat{j}$$

Similarly due to FA :

$$\vec{B}_{FA} = \frac{\mu_0 i}{2\sqrt{2}\pi\ell}\hat{i}$$

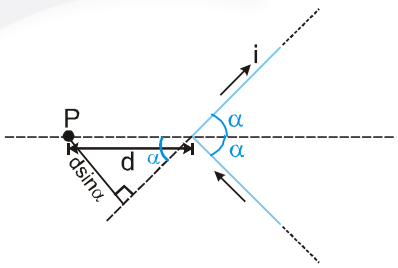
Hence $\vec{B}_{PABC} = \frac{\mu_0 i}{\pi\ell}\left[\frac{1}{2\sqrt{2}} + \frac{1}{2\sqrt{2}} + \frac{\sqrt{2}}{2}\right]\hat{i}$

$$\vec{B}_{FABC} = \frac{\sqrt{2}\mu_0 i}{\pi\ell}\left(\hat{j}\right)$$

Similarly due to CDEF:

$$\vec{B}_{CDEF} = \frac{\sqrt{2}\mu_0 i}{\pi\ell}\left(\hat{i}\right) \Rightarrow \vec{B}_{net} = \frac{\sqrt{2}\mu_0 i}{\pi\ell}\left(\hat{i}+\hat{j}\right)$$

5. Let us compute the magnetic field due to any one segment :



$$B = \frac{\mu_0 i}{4\pi(d\sin\alpha)}(\cos 0^0 + \cos(180-\alpha))$$

$$= \frac{\mu_0 i}{4\pi(d\sin\alpha)}(1-\cos\alpha) = \frac{\mu_0 i}{4\pi d}\tan\frac{\alpha}{2}$$

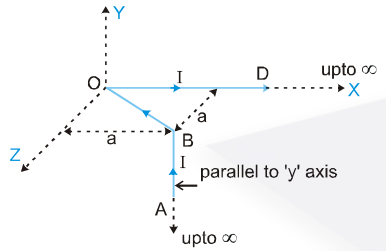
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Resultant field will be :

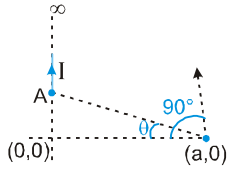
$$B_{net} = 2B = \frac{\mu_0 i}{2\pi d}\tan\frac{\alpha}{2} \Rightarrow k = \frac{\mu_0 i}{2\pi d}$$

6. **(C)** $B_{OD} = 0 \quad B_{OB} = 0$

$$B_{AB} = \frac{\mu_0 I}{4\pi a\sqrt{2}}[\cos 45°(-\hat{i}) + \cos 45°\hat{k}] = \frac{\mu_0 I}{8\pi a}(-\hat{i} + \hat{k})$$



7. **(B)**



$$B = \frac{\mu_0}{4\pi}\frac{i}{a}(\sin 90 + \sin(-\theta)) = \frac{\mu_0}{4\pi}\frac{i}{a}(1 - \sin\theta)$$

$$= \frac{\mu_0}{4\pi}\frac{i}{a}\left(1 - \frac{b}{\sqrt{a^2 + b^2}}\right)$$

8. **(B)** Magnetic field strength at P due to I_1

$$\vec{B}_1 = \frac{\mu_0 I_1}{2\pi(AP)}\hat{k} = \frac{4\pi\times10^{-7}\times2}{2\pi\times1\times10^{-2}}\hat{k} = (4\times10^{-5}\text{T})\,\hat{k}$$

Magnetic field strength at P due the I_2

$$\vec{B}_2 = \frac{\mu_0 I_2}{2\pi(BP)}\hat{j} = \frac{4\pi\times10^{-7}\times3}{2\pi\times2\times10^{-2}}\hat{j} = (3\times10^{-5}\text{T})\,\hat{j}$$

Hence, $\vec{B} = (3\times10^{-5}\text{ T})\,\hat{j} + (4\times10^{-5}\text{T})\,\hat{k}$

9. **(C)** By symmetry, the magnetic field at the centre P is zero.

10. **(D)** $\oint_{ABCDA}\vec{B}.\vec{d\ell} = \mu_0(i_1 + i_3 + i_2 - i_3) = \mu_0(i_1 + i_2)$ [since for the given direction of circumlation i_3 entering at PSTU is positive while i_3 at PQRS is negative]

Alternate solution

$$\oint_{ABCDA}\vec{B}.\vec{d\ell} = \oint_{ABCA}\vec{B}.\vec{d\ell} + \oint_{CDAC}\vec{B}.\vec{d\ell} = \mu_0 i_1 + \mu_0 i_2$$

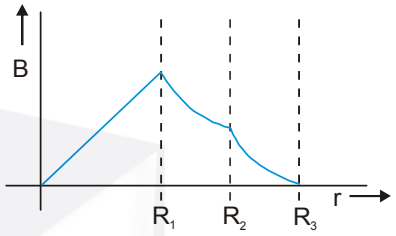
$$= \mu_0(i_1 + i_2)$$

11. **(C)** From ampere's law, the field at the axis is zero.

From x = zero to R_1, the field increases linearly as the current enclosed increases.

From x = R_1 to R_2 and from x = R_2 to R_3, the field decreases hyperbolicaly but with different slopes as the media are different.

Hence the required graph is

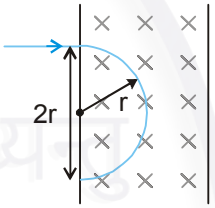


12. **(D)** $F = q[v(-\hat{i})] \times B(\hat{i})] = 0$

Because B as well as v is are along axis of circular loop.

13. **(B)** Electromagnetic force will provide the necessary centripetal force.

$$eBv = \frac{mv^2}{r}$$

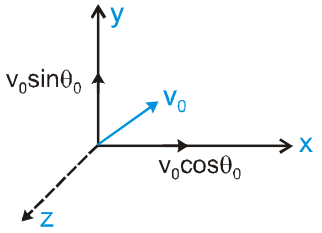


$$\Rightarrow r = \frac{mv}{eB} = \frac{v}{B\alpha} = \frac{(2\alpha d)(B)}{(B\alpha)} = 2d$$

i.e. the electron will move out after travelling on a semicircular path of radius r = 2d.

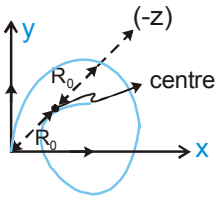
Hence (B)

14. **(D)** As the magnetic field is along the x-axis, the magnetic force will be along (–) z-axis from t = 0 to t = T_0 and along (+)ve z-axis from t = T_0 to t = $2T_0$.



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For $t = 0$ to $t = T_0$:– At $t = \frac{T_0}{2}$;



$$\text{x-coordinate} = \frac{(V_0 \cos\theta)\, T_0}{2}$$

$$= \frac{P_0}{2} \text{ (Since pitch} = P_0 = (V_0 \cos\theta) T_0)$$

y-coordinate $= 0$ (from figure)

and z-coordinate $= -2\,R_0$ (from figure)

Hence (A) is correct.

Similarly at $t = \frac{3T_0}{2}$;

coordinates are $\left(\frac{3P_0}{2}, 0, 2R_0\right)$

Hence (B) is correct.

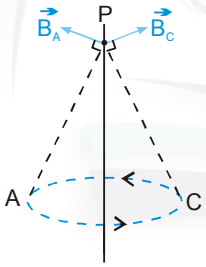
Note : z -coordinate will be $+ 2R_0$, because from $t = T_0$ to $t = 2T_0$, direction of $\vec{B}$ changes.

As the charge will perform circular motion about x-axis, the two extremes from x-axis are $2R_0$ from each other.

Hence (C) is also correct.

Hence only (D) is incorrect.

15. (A) The point charge moves in circle as shown in figure. The magnetic field vectors at a point P on axis of circle are $\vec{B}_A$ and $\vec{B}_C$ at the instants the point charge is at A and C respectively as shown in the figure.



Hence as the particles rotates in circle, only magnitude of magnetic field remains constant at the point on axis P but its direction changes.

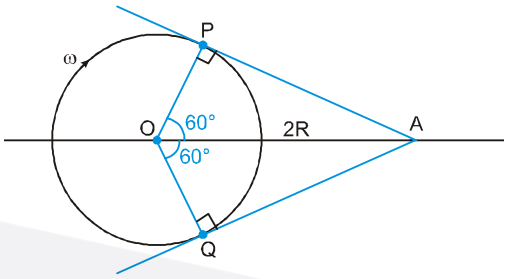
Alternate solution

The magnetic field at point on the axis due to charged particle moving along a circular path is given by

$$\frac{\mu_0}{4\pi} \frac{q\vec{v} \times \vec{r}}{r^3}$$

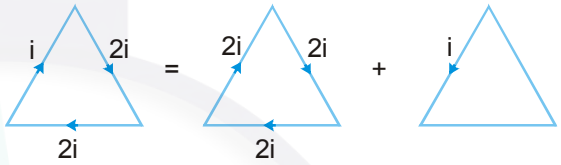
It can be seen that he magnitude of the magnetic field at an point on the axis remains constant. But the direction of the of the field keeps on changing.

16. (B) Point A shall record zero magnetic field (due to α-particle) when the α-particle is at position P and Q as shown in figure. The time taken by α-particle to go from P to Q is



$$t = \frac{1}{3}\,\frac{2\pi}{\omega} \quad \text{or} \quad \omega = \frac{2\pi}{3t}$$

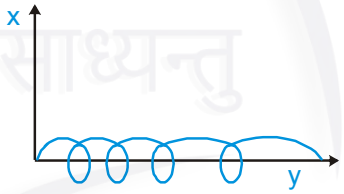
17. (A)



(A) (B)

force in figure (A) is zero, and force in figure (B) $= i\,\ell B$.

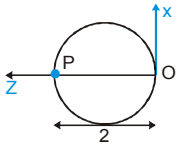
18. (D) The particle will move in a non-uniform helical path with increasing pitch as shown below:



Its time period will be :

$$T = \frac{2\pi m}{qB} = 2\pi \text{ seconds}$$

Changing the view, the particle is seemed to move in a circular path in (x – z) plane as below



After π-seconds the particle will be at point 'P', hence x coordinate will be 0

For linear motion along y-direction.

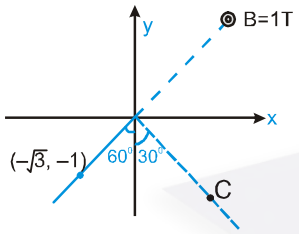
$$y(\pi) = 0(\pi) + \frac{1}{2}\frac{Eq}{m}(\pi)^2$$

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$y(\pi) = \frac{\pi^2}{2}$ and OP = 2

Hence the coordinate $\left(0, \frac{\pi^2}{2}, 2\right)$.

19. (C) The centre will be at 'C' as shown :



Coordinates of the centre are $(r\cos 60^0, -r\sin 60^0)$

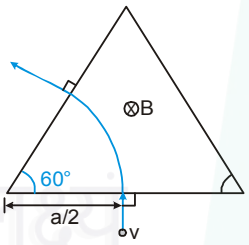
where r = radius of circle = $\frac{mv}{Bq} = \frac{1\times1}{1\times1} = 1$

i.e. $\left(\frac{1}{2}, -\frac{\sqrt{3}}{2}\right)$

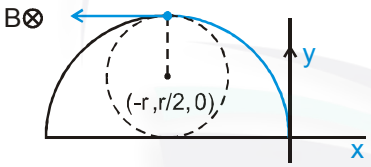
20. (B) The charged particle moves in a circle of radius $\frac{a}{2}$

$\therefore \quad qvB = \frac{mv^2}{a/2}$

or $B = \frac{2mv}{qa}$



21. (B)



Hence (B).

22. (C) After two and half time periods, it is at a distance $2R_0$ on the negative z-axis. y-coordinate will be zero And the x-coordinate = $2.5\ P_0$.
i.e. it is at a distance $7.5\ P_0$ from the mirror, hence its image will be at $2(7.5\ P_0) + 2.5\ P_0 = 17.5\ P_0$.
Hence (C).

23. (A) $\tau = \vec{m}\times\vec{B}S = I_0L^2\hat{k}\times\left(\frac{B}{\sqrt{2}}\hat{i} + \frac{B}{\sqrt{2}}\hat{j}\right)$

$= \frac{I_0L^2B}{\sqrt{2}}(\hat{j} - \hat{i})$

24. (C) $\int E.d\ell = \frac{-d\varphi}{dt} = -\pi r^2\frac{dB}{dt}$

$N = \int \lambda E d\ell = -R\lambda\pi r^2\frac{dB}{dt}$

$\int N dt = -R\lambda\pi r^2\int dB = R\lambda\pi r^2 B = I\omega$

$\Rightarrow \pi r^2 B\frac{q}{2\pi r} = mr^2\omega \Rightarrow \omega = \frac{qB}{2m}$

25. A→ S; B→ P; C →Q; D→ R

R = mv/qB

$R_B > R_A$

and $R_A = R_C$ (in opposite sense)

and R_D is smallest

26. A → Q, S ; B → P, S ; C → Q, S ; D → P, S

Work done by magnetic force on the charge = 0 in any part of its motion.

$\therefore$ 'S' is matching for all parts (i), (ii), (iii), (iv)

For loop 1 $\Sigma I_{in} = -i + i - i = -i \quad \therefore \oint \vec{B}.d\vec{\ell} = \mu_0(-i)$

For loop 2 $\Sigma I_{in} = i - i + i = i \quad \therefore \oint \vec{B}.d\vec{\ell} = \mu_0(i)$

For loop 3 $\Sigma I_{in} = -i - i + i = -i \quad \oint \vec{B}.d\vec{\ell} = \mu_0(-i)$

For loop 4 $\Sigma I_{in} = +i + i - i = +i \quad \oint \vec{B}.d\vec{\ell} = \mu_0(i)$

(Note : That current will be taken as positive which produces lines of magnetic field in the same sense in which $\vec{d\ell}$ is taken)

27. (D) The magnitude of magnetic force on charged particle undergoing uniform circular motion in uniform magnetic field is

$F = qvB$

$\therefore$ If v is doubled keeping q and B constant, the force F just doubles. Hence statement 1 is false.

28. (B) Both statements are correct, but statement 2 is not a correct explanation of statement 1.

29. (A) Solenoid tends to contract because the current in all the circular turns is in same direction. Hence all turns(can be assumed as a ring) attract each other.

30. (D) The current through solid metallic cylinder also produces magnetic field inside the cylinder. Hence statement-1 is false

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CHAPTER 05

ELECTROMAGNETIC INDUCTION

Induction may be defined, the operation of discovering and proving general propositions.

"JOHN STUART MILL"

INTRODUCTION

From previous chapters, we know that current produces magnetic field. Is reverse possible i.e. can magnetic field produce electric current ? The answer is 'yes'. It is found that currents were induced in closed coils when subjected to changing magnetic fields.

The phenomenon in which electric current is generated by changing magnetic fields is known as electromagnetic induction. The current so produced is known as induced current.

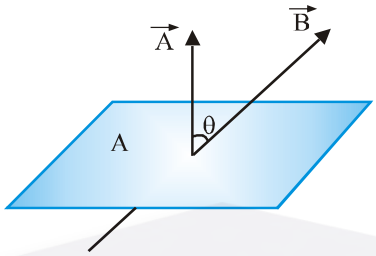
If current is produced in the circuit, this must be due to some emf produced in the circuit. This emf produced in the circuit. This emf produced as a result of change in magnetic field is known as induced emf.

The phenomenon of electromagnetic induction (EMI) is the basis of working of power generators, dynamos, transformers etc.

Magnetic Flux

Magnetic flux though any surface held in a magnetic field is measured as the total number of magnetic field lines crossing the surface. It is a scalar quantity.

Consider a plane area A placed in a magnetic field B as shown in figure. Area vector $\vec{A}$ makes an angle θ with the direction of magnetic field.



Now the magnetic flux passing through the area is defined as

$$\phi = \vec{B}.\vec{A} \qquad [\text{for uniform } \vec{B}]$$

or $$\phi = BA\cos\theta = (B\cos\theta)A = B_{\perp}A$$

where $B_{\perp} = B\cos\theta$ is the component of the magnetic field B perpendicular to the face of the area. Direction of area vector is normal to the face of the area.

Special Cases

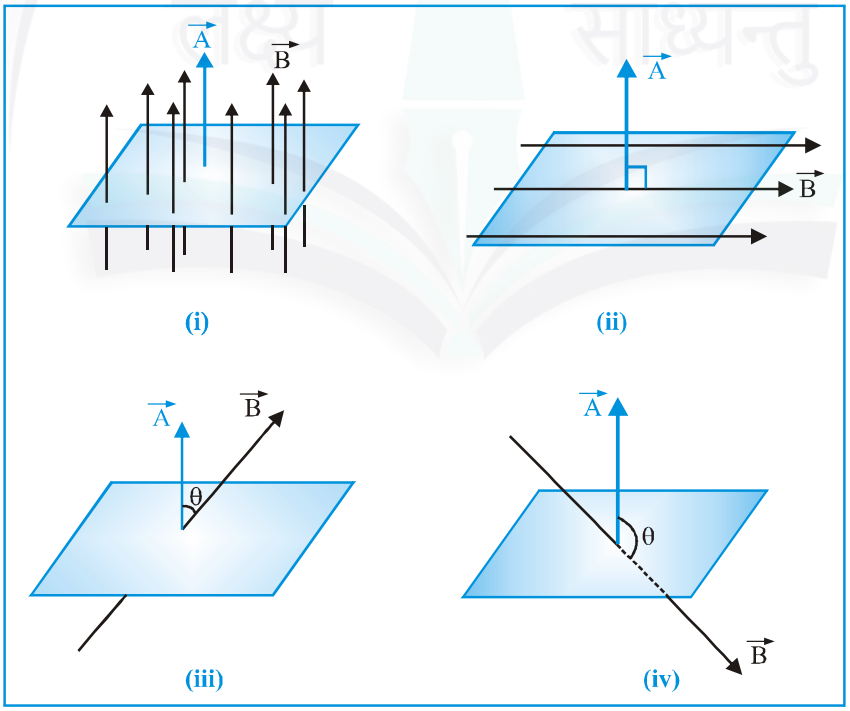
(i) if $\theta = 0°$, then $\phi = BA\cos 0° \Rightarrow \phi = BA$ (maximum flux)

(ii) if $\theta = 90°$, then $\phi = BA\cos 90° \Rightarrow \phi = 0$ (maximum flux)

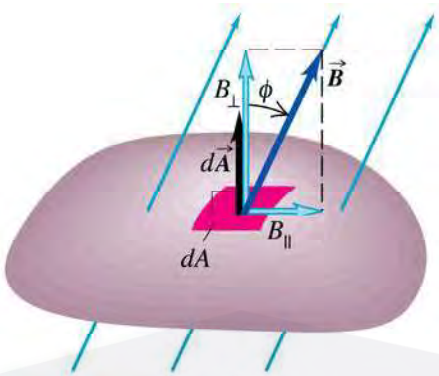
(iii) if $\theta < 90°$, then $\cos\theta > 0 \Rightarrow \phi > 0$ (positive flux)

(iv) if $\theta > 90°$, then $\cos\theta < 0 \Rightarrow \phi < 0$ (negative flux)

If the surface is not plane, we can divide any surface into elements of area dA (as shown in figure). For each element we determine $B_{\perp}$, the component of normal to the surface at the position of that element, as shown. from above figure, $B_{\perp} = B\cos\phi$, where ϕ is the angle between the direction of B and a line perpendicular to the surface. In general, this component varies from point to point on the surface.



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We define magnetic flux $d\Phi_B$ through the area element dA as

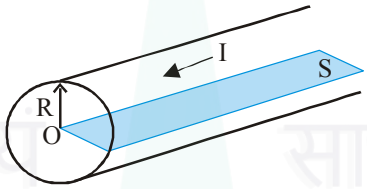
$$d\Phi = B_\perp dA$$

The total magnetic flux through the surface is the sum of the contributions from the individual area elements :

$$\phi = \int B_\perp dA = \int B\cos\phi dA = \int \vec{B}.\vec{dA} \quad \text{(magnetic flux through a surface)}$$

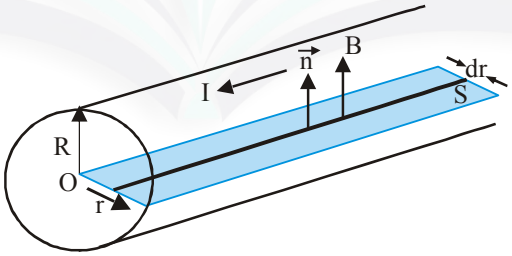
The unit of magnetic flux is tesla-metre^2 which is called weber (Wb) in honour of Wilhelm Weber. 1 Wb = 1 Tm^2. Clearly, B can be measured in Wb m^{-2} = 1 T. Sometimes it is referred to as flux density.

Ex. A long copper wire carries a current of I ampere. Calculate the magnetic flux per metre of wire for a plane surface S inside the wire as shown in figure.



Sol. Consider an element of width *dr* at a distance *r* from the axis of the wire. The field due to the current I in the wire at the position of element will be $B = \frac{\mu_0 I_r}{2\pi R^2}$

and as its direction is perpendicular to the plane surface, flux linked with the element is given by



$$d\phi = B\ ds\cos\theta = \frac{\mu_0}{2\pi}\frac{I}{R^2} r(1dr)\cos 0$$

So, the flux linked with the plane surface is given by

$$\phi = \frac{\mu_0}{2\pi}\frac{I}{R^2}\int_0^R r = \frac{\mu_0 I}{4\pi}$$

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Faraday's Law of Electromagnetic Induction

On the basis of several experimental observations, Michael Faraday came to the following conclusions.

1. Whenever there is a relative motion between a magnet (source of magnetic field) and a closed conducting loop, electric current appears in the loop. It happens because of the change in magnetic flux associated with the loop.
2. Since emf causes current in a circuit, when loop and magnet are brought in relative motion current flows in the loop. This implies that an emf is set up in the loop. This emf is known as induced emf and its magnitude is directly proportional to the rate of change of magnetic flux through the loop with time.

Now, we come to the Faraday's law of electromagnetic induction. In mathematical form induced emf can be given by the expression $\varepsilon = -\frac{d\varphi_B}{dt}$

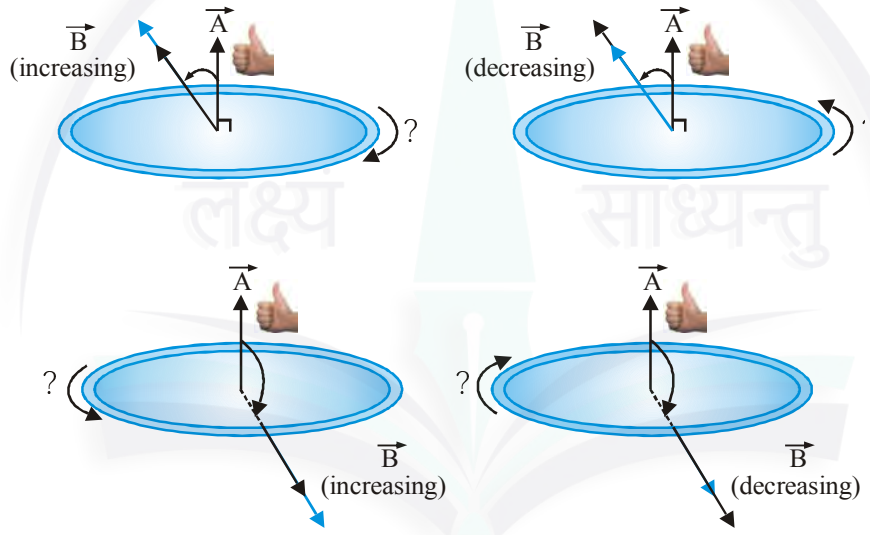
As such Faraday's law in itself is complete to tell the magnitude and polarity of induced emf but Lenz's rule is commonly used to determine the polarity of induced emf or direction of induced current.

Direction of Induced emf

We can find the direction of an induced emf or current $\varepsilon = -d\Phi_B / dt$ together with some simple sign rules. Here is the procedure :

(1) Define a positive direction for the area vector $\vec{A}$.

(2) From the directions of $\vec{A}$ and the magnetic field $\vec{B}$, determine the sign of the magnetic flux Φ_B and its rate of change $d\Phi_B / dt$. Figure shows several examples.



(i) $\vec{A}$ is upward to anticlockwise direction is positive.

(ii) ϕ =BAcosθ

$$\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(BA\cos\theta) \Rightarrow \varepsilon = -A\cos\theta\frac{dB}{dt} \quad \text{..... (i)}$$

Here θ is acute, so cos θ is positive. B is increasing, so dB/dt is positive. Then we find that ε is negative. So ε is clockwise as shown.

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For Fig. (b)

Here B is decreasing, so dB/dt is negative. Then from eq. **(i)**, ε is positive. So ε is anticlockwise as shown.

For Fig (c)

Here θ is obtuse, so cos θ is negative. B is increasing, so dB/dt is positive. Then from eq. **(i)** ε is positive, so ε is anticlockwise as shown.

For. Fig. (d)

Here θ is obtuse, so cos θ is negative. B is decreasing, so dB/dt is negative. Then from eq. **(i)** ε is negative, so ε is clockwise as shown.

Ex. 1. A coil is placed in a constant magnetic field .The magnetic field is parallel to the plane of the coil as shown in figure. Find the emf induced in the coil .



Sol. $\phi = 0$ (always) since area is perpendicular to magnetic field.

$\therefore$ emf = 0

Ex. 2. Find the emf induced in the coil shown in figure. The magnetic field is perpendicular to the plane of the coil and is constant.

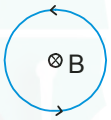


Sol. $\phi = BA$ (always)

= const.

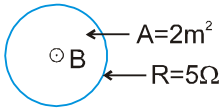
$\therefore$ emf = 0

Ex. 3. Find the direction of induced current in the coil shown in figure. Magnetic field is perpendicular to the plane of coil and it is increasing with time.



Sol. Inward flux is increasing with time. To opposite it outward magnetic field should be induced. Hence current will flow anticlockwise.

Ex. 4. Figure shows a coil placed in decreasing magnetic field applied perpendicular to the plane of coil .The magnetic field is decreasing at a rate of 10T/s. Find out current in magnitude and direction



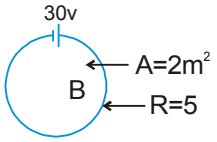
Sol. $\phi = B.A$

$$\text{emf} = A.\frac{dB}{dt} = 2 \times 10 = 20 \text{ v}$$

$\therefore$ $i = 20/5 = 4$ amp. From Lenz's law direction of current will be anticlockwise.

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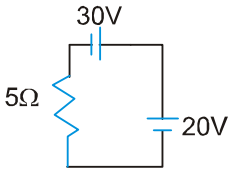
Ex. 5. Figure shows a coil placed in a magnetic field decreasing at a rate of 10T/s. There is also a source of emf 30 V in the coil. Find the magnitude and direction of the current in the coil.



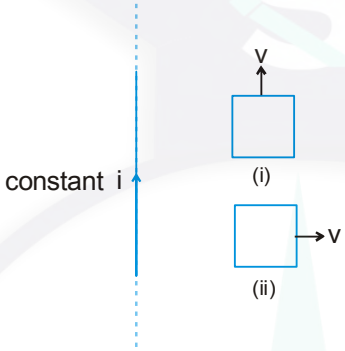
Sol. Induce emf = 20V

equivalent

i = 2A clockwise



Ex. 6. Figure shows a long current carrying wire and two rectangular loops moving with velocity v. Find the direction of current in each loop.



Sol. : In loop **(i)** no emf will be induced because there is no flux change.

In loop **(ii)** emf will be induced because the coil is moving in a region of decreasing magnetic field inward in direction. Therefore to oppose the flux decrease in inward direction, current will be induced such that its magnetic field will be inwards. For this direction of current should be clockwise.

Lenz's Law

Direction of the Induced Current in a Circuit

Lenz's law states that 'when the magnetic flux through a loop changes, a current is induced in the loop such that the magnetic field due to the induced current opposes the change in the magnetic flux through the loop.'

The above rule can be systematically applied as follows to determine the direction of the induced currents.

(i) Identify the loop in which the induced current is to be determined.

(ii) Determine the direction of the magnetic field in this loop (i.e in or out of the loop).

(iii) The direction of flux is the same as the direction of the magnetic field. Determine if the flux through the loop is increasing or decreasing (because of change in area or change in B).

Choose the appropriate current in the loop that will oppose the change in flux.

(i) If the flux is into the paper and increasing them the flux due to the induced current should be out of the paper.

(ii) If the flux is into the paper and decreasing, the flux due to the induced current should be into the paper.

(iii) If the flux is out of the paper and increasing, the flux due to the induced current should be into the paper.

(iv) If the flux is out of the paper and decreasing, the flux due to the induced current should be out of the paper.

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The above description is the physical interpretation of Lenz's law. We can determine the direction of the induced current mathematically by simply applying Lenz's law $\xi_{ind} = \frac{d\Phi_B}{dt}$ with the appropriate conventions.

The right hand sign convention used is as follows :

(i) For counterclockwise current, emf is positive.

(ii) For clockwise current, emf is negative.

(iii) Magnetic flux out of the paper is positive.

(iv) Magnetic flux into the plane of the paper is negative.

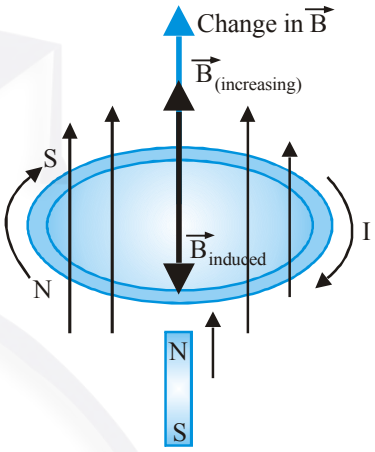
(v) The rate of change of an increasing positive flux is positive.

(vi) The rate of change of an decreasing positive flux is negative.

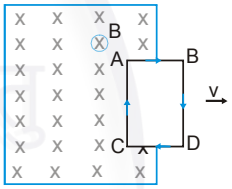
(vii) The rate of change of an increasing negative flux is negative.

(viii) The rate of change of an decreasing negative flux is positive.

Let us consider some of the cases regarding application of Lenz's law.



(ix) Suppose north pole of a bar magnet is moved towards a loop as shown in figure. Because of change in magnetic flux associated with the loop current is induced in it. Due to induced current, magnetic field is induced in such a way that it opposes the motion of the bar magnet. As the north pole is moving towards the loop, hence to oppose the motion of the bar magnet only the north pole will be induced on that face of the loop which faces the magnet. The induced current due to the change in $\vec{B}$ is clockwise, as seen from above the loop. The added field $\vec{B}_{induced}$ that it causes is downward, opposing the change in the upward field $\vec{B}$.



(x) Consider figure. A rectangular loop ABCD is being pulled out of the magnetic field directed into the plane of the paper. As the loop is dragged out of the field, the flux associated with the loop which is directed into the plane of the paper decreases. The induced current will flow in the loop in the sense to oppose the decrease of this flux. For this to happen, magnetic field due to the induced current in the loop must be directed into the plane of the paper. Hence current in the loop must flow in the clockwise sense.

Ex. A closed loop with the geometry shown in figure (a) is placed in a uniform magnetic field directed into the plane of the paper. If the magnetic field decreases with time, determine the direction of the induced e.m.f. in this loop.

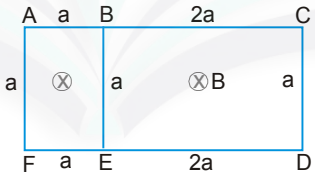


Figure (a)

Sol. There are two loops that are immersed in the magnetic field, namely, ABEFA and BCDEB.

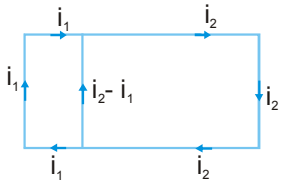


Figure (b)

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Consider loop ABEFA. magnetic flux is into the plane of the paper. For loop BCDEB too, the magnetic flux is into the plane of the paper.

In both loops, the magnetic flux is decreasing with time.

Therefore, the induced current in loop ABEFA, i_1, will be in a direction so as to induce a flux into the paper. The direction of i_1 is clockwise.

Like wise in loop BCDEB the current i_2 will be in a direction so as to induce a flux into the paper. The direction of i_2 is also clockwise. The final induced current in all the arms of the loop are shown Fig. (b).

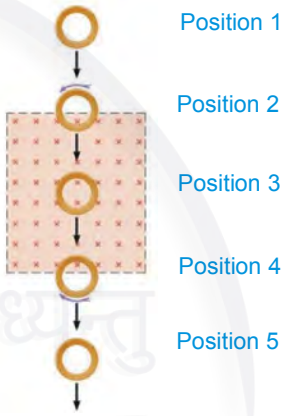
Lenz's Law (Deciding direction of induced e.m.f.)

The induced emf resulting from a changing magnetic flux has a polarity that leads to an induced current whose direction is such that the induced magnetic field opposes the original flux change. We shall discuss later on how it is in accordance with conservation of energy.

Ex. In figure there is a constant magnetic field in a rectangular region of space. This field is directed perpendicularly into the page. Outside this region there is no magnetic field. A copper ring moves through the region from position 1 to position 5. Find the induced current in the ring at it passes through positions.

(a) 1 **(b)** 2 **(c)** 3 **(d)** 4 **(e)** 5

Sol. **(a)** Since the field is zero outside the rectangular region, no flux passes through the region in position 1, there is no change in the flux through the ring, and there is no induced emf or current in the ring.



(b) In position 2 the flux increases. According to Lenz's law, the induced current must create an induced magnetic field that op poses the increase. To oppose the increase, the induced field must point opposite to the external field and, therefore, must point out of the page, for which the induced current must be counter clockwise.

(c) Here the field is not zero. Hence nonzero flux passes through the ring in position 3 but the flux through the ring is constant, and there is no induced emf or current in the ring.

(d) In position 4 the flux decreases. According to Lenz's law, the induced current must create an induced magnetic field that opposes the decrease. To oppose the decrease, the induced field must point in the direction of external field and, therefore, must point into the page. For which the induced current must be clock-wise.

(e) Since the field is zero outside the rectangular region, no flux passes through the ring in position 5, there is no change in the flux through the ring, and there is no induced emf or current in the ring.

Note down the following points regarding the Faraday's law :

1. As we have seen, induced emf is produced only when there is a change in magnetic flux passing through a loop. The flux passing through the loop is given by $\phi = BA \cos\theta$

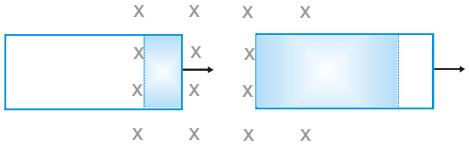
   Thus, flux can be changed in several ways "

   (i) The magnitude of $\vec{B}$ can change with time. In the problems if magnetic field is given as a function of time, it implies that the magnetic field is changing. Thus, B = B(t).

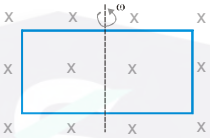
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(ii) The area enclosed by the loop can change with time.

This can be done by pulling a loop inside (or outside) a magnetic field. By doing so, the area enclosed by the loop (hatched area) can be changed.



(iii) The angle θ between $\vec{B}$ and the normal to the loop can change with time. This can be done by rotating a loop in a magnetic field.



(iv) Any combination of the above can occur.

2. When the magnetic field passing through a loop is changed, an induced emf and hence an induced current is produced in the circuit. If R is the resistance of the circuit, then induced current is given by

$$i = \frac{e}{R} = \frac{1}{R}\left(\frac{-d\phi_B}{dt}\right)$$

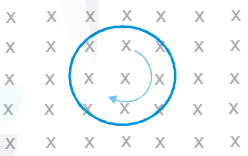
Current starts flowing in the circuit, i.e., flow of charge takes place. Charge flown in the circuit in time dt will be given by

$$dq = i.dt = \frac{1}{R}(-d\phi_B)$$

Thus, for a time interval Δt we can write $e = -\frac{\Delta\phi_B}{\Delta t}, i = \frac{1}{R}\left(\frac{-\Delta\phi_B}{dt}\right)$ and $\Delta q = i\Delta t = \frac{1}{R}(-\Delta\phi_B)$

From these equations we can see that e and i are inversely proportional to Δt and Δq is independent of Δt. It depends on the magnitude of change in flux, not the time taken by it.

Ex. A circular loop of radius a having n turns is kept in a horizontal plane. A uniform magnetic field B exists in a vertical direction shown in figure. Find the emf induced in the loop if the loop is rotated with a uniform angular velocity ω about

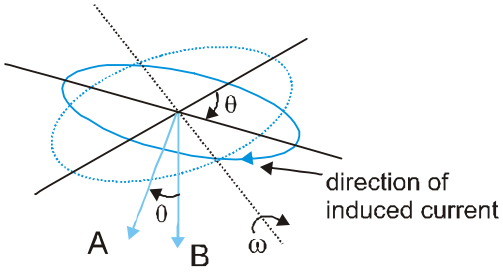


(a) an exist passing through the centre and perpendicular to the plane of the loop.

(b) the diameter.

Sol. **(a)** The emf induces when there is change of flux. As in this case(figure) there is no change of flux, hence no emf will be induced in the coil.

(b) If the loop is rotated about the diameter there will be change of flux with time. In this case e.m.f. will be induced in the coil. The area of the loop is $A - \pi a^2$. If the normal of the loop makes an angle θ = 0 with the magnetic field at t = 0, this angle will become θ = ωt at time t. The flux of the magnetic field at this time is



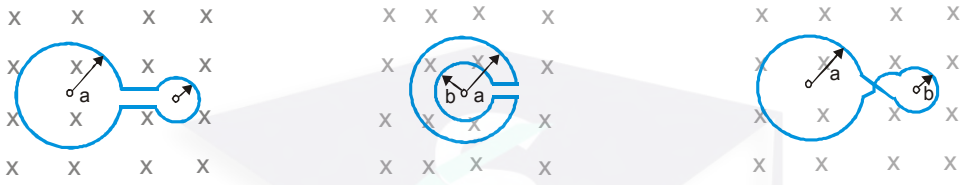
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$\phi = nB\pi a^2 \cos\theta = nB\pi a^2 \cos\omega t$

The induced e.m.f. is $\varepsilon = -\frac{d\phi}{dt} = \pi n a^2 B\omega \sin\omega t$

e is coming out to be positive, so direction of induced emf will be as shown in figure. Because here this sense is positive if we look at direction of area vector.

Ex. Figure **(a)** shows two circular rings of radii a and b (a > b) joined together with wires of negligible resistance. Figure **(b)** shows the pattern obtained by folding the small loop in the plane of the large loop.



The pattern shown in figure **(c)** is obtained by twisting the small loop of Fig. **(a)** through 180°.

All the three arrangements are placed in a uniform time varying magnetic field $\frac{dB}{dt} = k$, perpendicular to the plane of the loops. If the resistance per unit length of the wire is λ, then determine the induced current in each case.

Sol. **(a)** $\phi_B = \pi(a^2 + b^2)B$

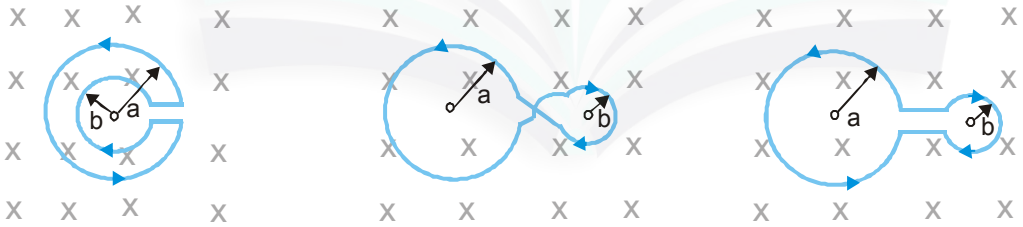
$$\varepsilon = \frac{d\phi_B}{dt} = \pi(a^2 + b^2) \times \frac{dB}{dt} = \pi(a^2 + b^2)k$$

Induced current, $I = \frac{\varepsilon}{R} = \frac{\pi(a^2 + b^2)k}{\lambda[2\pi(a+b)]} = \frac{k(a^2 + b^2)}{2\lambda(a+b)}$

(b) $\phi_B = \pi a^2 B - \pi b^2 B = \pi B(a^2 - b^2)$

$$\varepsilon = \frac{d\phi_B}{dt} = \frac{\pi dB}{dt} \times (a^2 - b^2) = \pi k(a^2 - b^2)$$

Induced current, $I = \frac{\varepsilon}{R} = \frac{\pi k(a^2 - b^2)}{2\pi\lambda(a+b)} = \frac{k(a-b)}{2\lambda}$



(c) Here induced emf in both loops will oppose each other, hence effective flux is given by

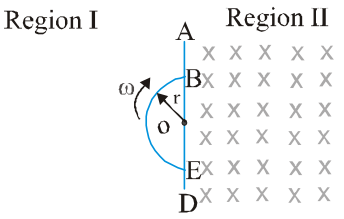
$$\Phi_B = \pi a^2 B - \pi b^2 B = \pi B(a^2 - b^2)$$

$$\Rightarrow \varepsilon = \frac{d\Phi_B}{dt} = \pi k(a^2 - b^2)$$

Induced current, $I = \frac{\varepsilon}{R} = \frac{k(a-b)}{2\lambda}$

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Ex. Space is divided by the line AD into two refions. Region I is field free and region II has a uniform magnetic field B directed into the plane of the paper. BCE is a semicircular conducting loop of radius r with centre at O, the plane of the loop being in the plane of the paper. The loop is now made to rotate with a constant angular velocity ω about an axis passing through O and the perpendicular to the plane of the paper. The effective resistance of the loop is R.

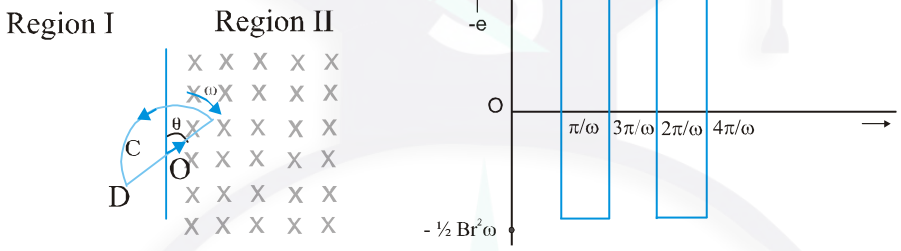


(i) Obtain an expression for the magnitude of the induced current in the loop.

(ii) Show the direction of the current when the loop is entering into Region II.

(iii) Plot a graph between the induced emf and the time of rotation for the two periods of the rotation.

Sol. **(i)** When the loop is rotated about an axis passing centre O and perpendicular to the plane of the paper, the angle between magnetic field vector B and area A is always 0°. When the loop is region I, the magnetic flux linked with loop = BA cos 0 = 0 the (since B = 0 in region I).



(a) **(b)**

When the loop enters the magnetic field in region II, the magnetic flux linked with it is given by ϕ = BA where $A = \frac{1}{2}r^2\theta$. Therefore, emf induced

$$e = -\frac{d\phi}{dt} = -\frac{d}{dt}(BA) = -B\frac{dA}{dt} = \frac{-Br^2}{2}\frac{d\theta}{dt}$$

$$\Rightarrow \quad e = -\frac{-Br^2}{2}\omega$$

A resistance of the loop is R, the current induced is given by

$$i = \frac{e}{R} = \frac{1}{2}\frac{Br^2\omega}{R}$$

This is the required expression for current induced in the loop.

(ii) According to Lenz's law, the direction of current induced is to oppose the change in magnetic flux. So, when entering into region II the field produced by the current induced must be upward. For this, the current in the loop must be anticlockwise as shown in Fig. (a).

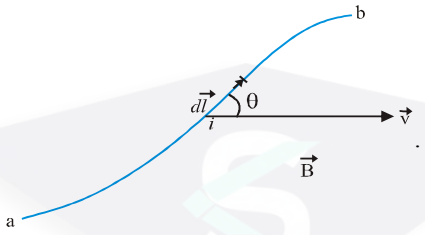
(iii) When the loop enters the magnetic field the magnetic flux linked with it increases and the emf $i = \frac{1}{2}Br^2\omega$ is induced in one direction. When the loop comes out of the field, the flux decreases and emf is induced in opposite sense. The graph for representing the emf induced versus time for two periods (T = 2π/ω) is shown in Fig. (b). Here we have taken anticlockwise direction as positive.

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MOTIONAL ELECTROMOTIVE FORCE

When a conductor moves in a magnetic field, then charges inside conductor experience magnetic force given by $\vec{F} = q\vec{v} \times \vec{B}$, where $\vec{v}$ is the velocity of conductor (here we assume that velocity of charges inside conductor is same as the velocity of conductor and random motion of charges inside the conductor is neglected). Due to this force charges start moving in a particular direction in the conductor or we say that an emf is induced in the conductor. This emf is known as motional emf.

Consider a conductor of arbitrary shape as shown in figure moving in some magnetic field $\vec{B}$



The different parts of the conductor may have different velocity. Consider an element $d\vec{l}$ have velocity $\vec{v}$. Force due to magnetic field on a charge in conductor.

$$\vec{F} = q\vec{v} \times \vec{B}$$

work done by this force on charge q in passing through $d\vec{l}$

$$dW = \vec{F}.d\vec{l} = q(\vec{v} \times \vec{B}).d\vec{l}$$

So emf induced within $d\vec{l}$: $d\varepsilon = \dfrac{dW}{q} = (\vec{v} \times \vec{B}).d\vec{l}$

Integrate this to find net emf : $\varepsilon = \int_a^b (\vec{v} \times \vec{B}).d\vec{l}$

This emf is directed from a to b.

Other Approach :

Due to the magnetic force, charges star moving in the conductor an electric field is set up in the conductor. In equilibrium force of electric field balances the force of magnetic field. Let electric field induced is $\vec{E}$, then

$$q\vec{v} \times \vec{B} + q\vec{E} = 0 \Rightarrow \vec{E} = -\vec{v} \times \vec{B}$$

Now potential difference developed across the ends of the conductor :

$$V_b - V_a = -\int_a^b E.d\vec{l} = \int_a^b (\vec{v} \times \vec{B}).d\vec{l}$$

If circuit is incomplete, then this terminal potential difference will be equal to emf induced. Hence emf induced :

$$\varepsilon = \int_a^b (\vec{v} \times \vec{B}).d\vec{l}$$

Note : We can also write $\varepsilon = \int_a^b \vec{B}.(d\vec{l} \times \vec{v})$

As $d\vec{l} \times \vec{v}$ is the area swept per unit time by length $d\vec{l}$ and hence $\vec{B}.(d\vec{l} \times \vec{v})$ is the flux of induction through the area.

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Therefore, the motional e.m.f. is equal to the flux of induction cut by the conductor per unit time.

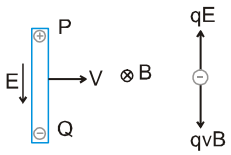
* We can write the expression for induced emf in various forms :

$$\varepsilon = \int_a^b (\vec{v} \times \vec{B}).d\vec{l} = \int_a^b (\vec{B} \times d\vec{l}).\vec{v} = \int_a^b (d\vec{l} \times \vec{v}).\vec{B}$$

If any two out of $\vec{v}$, $\vec{B}$ and $d\vec{l}$ become parallel or antiparallel, ε will become zero.

Explanation of emf induced in rod on the basis of magnetic force:

If a rod is moving with velocity v in a magnetic field B ,as shown , the free electrons in a rod will experience a magnetic force in downward direction and hence free electrons will accumulate at the lower end and there will be a deficiency of free electrons and hence a surplus of positive charge at the upper end. These charges at the ends will produce an electric field in downward direction which will exert an upward force on electron. If the rod has been moving for



quite some time enough charges will accumulate at the ends so that the two forces qE and qvB will balance each other. Thus E = v B.

$V_P - V_Q = V B \ell$

The moving rod is equivalent to the following diagram, electrically.

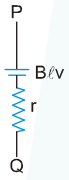
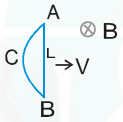
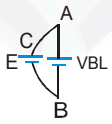


Figure shows a closed coil ABCA moving in a uniform magnetic field B with a velocity v. The flux passing through the coil is a constant and therefore the induced emf is zero.



Now consider rod AB , which is a part of the coil. Emf induced in the rod =B L v

Suppose the emf induced in part ACB is E , as shown.



Since the emf in the coil is zero, Emf (in ACB) + Emf (in BA) = 0

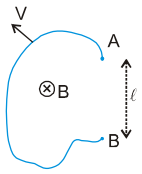
or -E + vBL = 0

or E = vBL

Thus emf induced in any path joining A and B is same, provided the magnetic field is uniform. Also the equivalent emf between A and B is BLv (here the two emf's are in parallel)

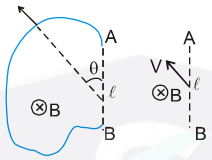
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Ex. Figure shows an irregular shaped wire AB moving with velocity v, as shown.



Find the emf induced in the wire.

Sol. The same emf will be induced in the straight imaginary wire joining A and B , which is $Bv\ell \sin\theta$

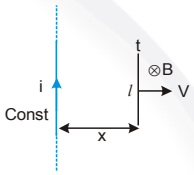


Ex. A rod of length l is kept parallel to a long wire carrying constant current i. It is moving away from the wire with a velocity v. Find the emf induced in the wire when its distance from the long wire is x.

Sol. $E = B\,l\,V = \dfrac{\mu_0 i\,l\,v}{2\pi x}$

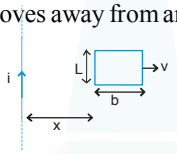
OR

Emf is equal to the rate with which magnetic field lines are cut . In dt time the area swept by the rod is l v dt. The magnetic field lines cut in dt time $= B\,l\,v dt = \dfrac{\mu_0 i\,l\,v dt}{2\pi x}$.

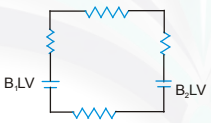


$\therefore$ The rate with which magnetic field lines are cut $= \dfrac{\mu_0 i\,l\,v}{2\pi x}$

Ex. A rectangular loop ,as shown in the figure ,moves away from an infinitely long wire carrying a current i. Find the emf induced in the rectangular loop.



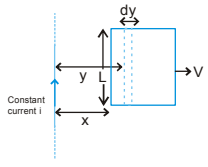
Sol. $E = B_1\,LV - B_2 Lv = \dfrac{\mu_0 i}{2\pi x} Lv - \dfrac{\mu_0 i}{2\pi(x+b)} Lv = \dfrac{\mu_0 iLbv}{2\pi x(x+b)}$



Aliter :

Consider a small segment of width dy at a distance y from the wire.

Let flux through the segment be $d\phi$.



$\therefore \quad d\phi = \dfrac{\mu_0 i}{2\pi y} L\,dy$

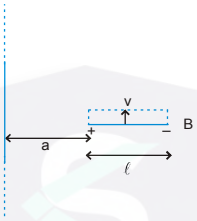
$\therefore \quad \phi = \dfrac{\mu_0 iL}{2\pi} \displaystyle\int_x^{x+b} \frac{dy}{y} = \frac{\mu_0 iL}{2\pi} \left(\ell n(x+b) - \ell n x\right)$

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Now $\frac{d\phi}{dt} = \frac{\mu_0 iL}{2\pi}\left[\frac{1}{x+b}\frac{dx}{dt} - \frac{1}{x}\frac{dx}{dt}\right] = \frac{\mu_0 iL}{2\pi}\left[\frac{(-b)}{x(x+b)}\right] v = \frac{-\mu_0 ibLv}{2\pi x(x+b)}$

$\therefore$ induced emf $= \frac{\mu_0 ibLv}{2\pi x(x+b)}$

Ex. A rod of length l is placed perpendicular to a long wire carrying current i. The rod is moved parallel to the wire with a velocity v. Find the emf induced in the rod , if its nearest end is at a distance 'a' from the wire.

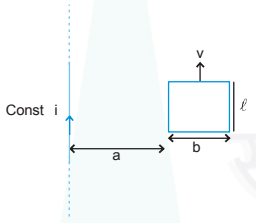


Sol. Consider a segment of rod of length dx , at a distance x from the wire. Emf induced in the segment

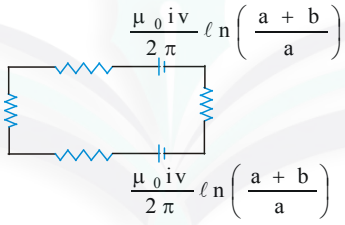
$$dE = \frac{\mu_0 i}{2\pi x} dx.v$$

$\therefore$ $E = \int_a^{a+\ell} \frac{\mu_0 ivdx}{2\pi x} = \frac{\mu_0 iv}{2\pi} \ell n\left(\frac{\ell + a}{a}\right)$

Ex. A rectangular loop is moving parallel to a long wire carrying current i with a velocity v. Find the emf induced in the loop , if its nearest end is at a distance 'a' from the wire. Draw equivalent electrical diagram.



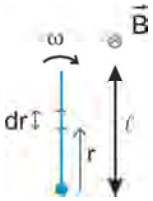
Sol. emf = 0 ;

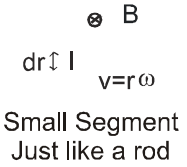


Induced emf Due to Rotation

Rotation of the Rod

Consider a conducting rod of length ℓ rotating in a uniform magnetic field.





$\perp$ $d\mathcal{E} = r\omega B\, dr$

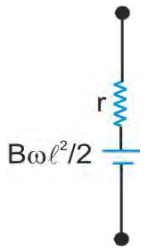
emf induced in a small segment

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Emf induced in a small segment of length dr, of the rod = v B dr = rω B dr

$\therefore$ emf induced in the rod $= \omega B\int_0^{\ell} r dr = \frac{1}{2}B\omega\ell^2$

equivalent of this rod is as following

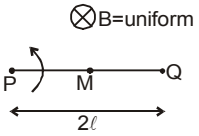


or $\varepsilon = \frac{d\Phi}{dt}$

$$\varepsilon = \frac{d\Phi}{dt} = \frac{\text{flux through the area swept by the rod in time dt}}{dt}$$

$$= \frac{B\frac{1}{2}\ell^2\omega dt}{dt} = \frac{1}{2}B\omega\ell^2$$

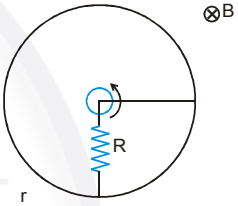
Ex. A rod PQ of length 2l is rotating about one end P in a uniform magnetic field B which is perpendicular to the plane of rotation of the rod. Point M is the mid point of the rod. Find the induced emf between M & Q if that between P & Q = 100V .



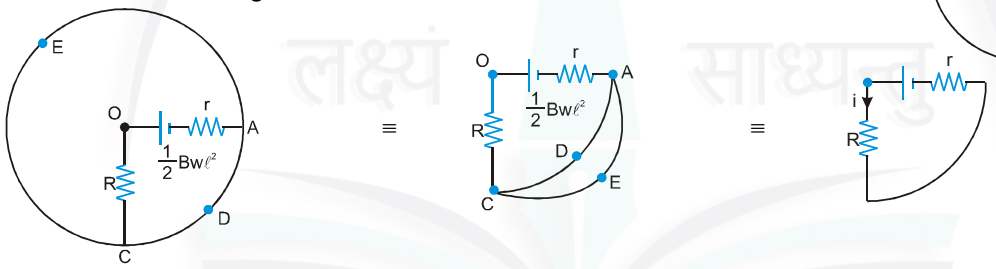
Sol. $E_{MQ} + E_{PM} = E_{PQ} \Rightarrow E_{PM} = \frac{Bw\ell^2}{2} = 100$

$$E_{MQ} + \frac{B\omega\left(\frac{\ell}{2}\right)^2}{2} = \frac{B\omega\ell^2}{2} \Rightarrow E_{MQ} = \frac{3}{8}B\omega\ell^2 = \frac{3}{4}\times 100\,V = 75\,V$$

Ex. A rod of length ℓ and resistance r rotates about one end as shown in figure. Its other end touches a conducting ring a of negligible resistance. A resistance R is connected between centre and periphery. Draw the electrical equivalence and find the current in the resistance R. There is a uniform magnetic field B directed as shown.

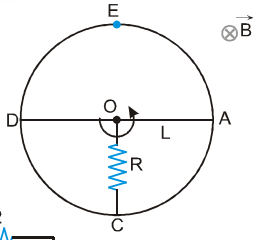


Sol.

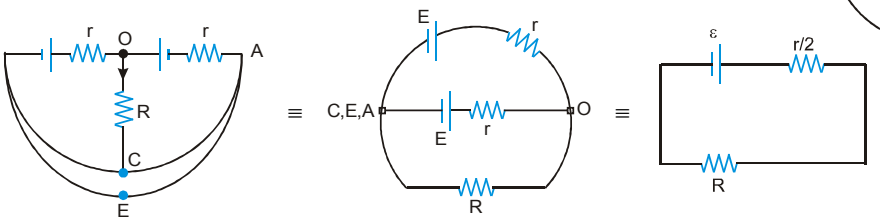


current $i = \frac{\frac{1}{2}B\omega\ell^2}{R+r}$

Ex. Solve the above question if the length of rod is 2L and resistance 2r and it is rotating about its centre. Both ends of the rod now touch the conducting ring



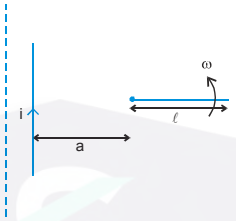
Sol.



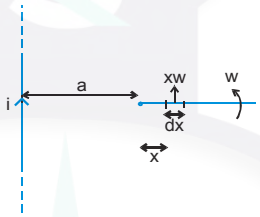
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$$i = \frac{\varepsilon}{R + \frac{r}{2}} = \frac{\frac{1}{2}B\omega L^2}{R + \frac{r}{2}}$$

Ex. A rod of length l is rotating with an angular speed ω about its one end which is at a distance 'a' from an infinitely long wire carrying current i. Find the emf induced in the rod at the instant shown in the figure.

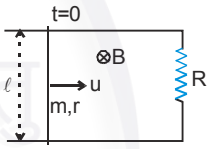


Sol. Consider a small segment of rod of length dx , at a distance x from one end of the rod. Emf induced in the segment

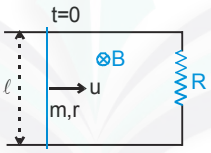


$$dE = \frac{\mu_0 i}{2\pi(x+a)}(x\omega)dx \qquad \therefore\ E = \int_0^{\ell} \frac{\mu_0 i}{2\pi(x+a)}(x\omega)dx = \frac{\mu_0 i\omega}{2\pi}\left[\ell - a.\ell n\left(\frac{\ell+a}{a}\right)\right].$$

Ex. A rod of mass m and resistance r is placed on fixed, resistanceless, smooth conducting rails (closed by a resistance R) and it is projected with an initial velocity u .Find its velocity as a function of time.

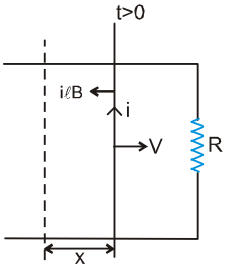


Sol. Let at an instant the velocity of the rod be v .The emf induced in the rod will be vBl. The electrically equivalent circuit is shown in the following diagram.



$\therefore$ Current in the circuit $i = \frac{B\ell v}{R+r}$

At time t



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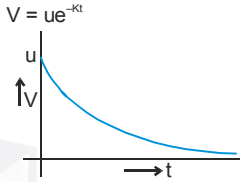
Magnetic force acting on the rod is F = i ℓ B, opposite to the motion of the rod.

$$i\ell B = -m\frac{dV}{dt} \qquad ...(1)$$

$$i = \frac{B\ell v}{R+r} \qquad ...(2)$$

Now solving these two equation

$$\frac{B^2\ell^2 V}{R+r} = -m\,.\,\frac{dV}{dt} \Rightarrow -\frac{B^2\ell^2}{(R+r)m}\,.\,dt = \frac{dV}{V}$$



let $\frac{B^2\ell^2}{(R+r)m} = k \Rightarrow -K\,.\,dt = \frac{dV}{V}$

$$\int_u^v \frac{dV}{V} = \int_0^t -K.dt \Rightarrow \ln\left(\frac{v}{u}\right) = -Kt \Rightarrow V = ue^{-Kt}$$

Ex. In the above question find the force required to move the rod with constant velocity v, and also find the power delivered by the external agent .

Sol. The force needed to keep the velocity constant

$$F_{ext} = i\ell B = \frac{B^2\ell^2 v}{R+r}$$

Power due to external force $= \frac{B^2\ell^2 v^2}{R+r} = \frac{\varepsilon^2}{R+r} = i^2(R+r)$

Note that the power delivered by the external agent is converted into joule heating in the circuit. That means magnetic field helps in converting the mechanical energy into joule heating.

Ex. In the above question if a constant force F is applied on the rod. Find the velocity of the rod as a function of time assuming it started with zero initial velocity.

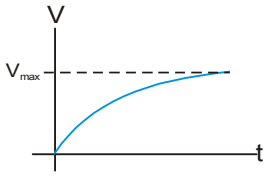
Sol. $m\frac{dv}{dt} = F - i\ell B \qquad ....(1) \qquad \Rightarrow i = \frac{B\ell v}{R+r} \qquad ....(2)$

$$m\frac{dv}{dt} = F - \frac{B^2\ell^2 v}{R+r}$$

let $K = \frac{B^2\ell^2}{R+r} \Rightarrow \int_0^v \frac{dV}{F-Kv} = \int_0^t \frac{dt}{m} \Rightarrow -\frac{1}{K}\left[\ell n(F-KV)\right]_0^V = \frac{t}{m}$

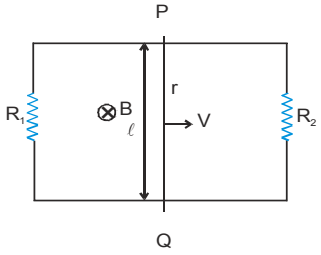
$$\ell n\left(\frac{F-kV}{F}\right) = -\frac{Kt}{m} \Rightarrow F - KV = Fe^{-kt/m}$$

$$V = \frac{F}{K}(1 - e^{-kt/m})$$



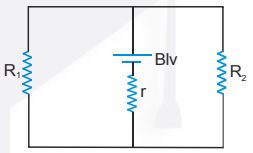
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Ex. A rod PQ of mass m and resistance r is moving on two fixed, resistanceless, smooth conducting rails (closed on both sides by resistances R_1 and R_2) .Find the current in the rod at the instant its velocity is v.



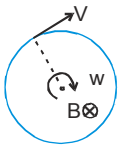
Sol. $$i = \frac{B\ell V}{r + \frac{R_1R_2}{R_1 + R_2}}$$

this circuit is equivalent to the following diagram.



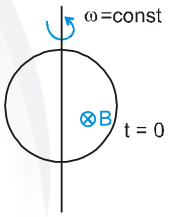
EMF Induced Due to Rotation of a Coil

Ex. A ring rotates with angular velocity ω about an axis perpendicular to the plane of the ring passing through the center of the ring. A constant magnetic field B exists parallel to the axis. Find the emf induced in the ring



Sol. Flux passing through the ring $\phi = B.A$ is a constant here, therefore emf induced in the coil is zero. Every point of this ring is at the same potential, by symmetry.

Ex. A ring rotates with angular velocity ω about an axis in the plane of the ring and which passes through the center of the ring. A constant magnetic field B exists perpendicular to the plane of the ring. Find the emf induced in the ring as a function of time.



Sol. At any time t , $\phi = BA\cos\theta = BA\cos\omega t$

Now induced emf in the loop

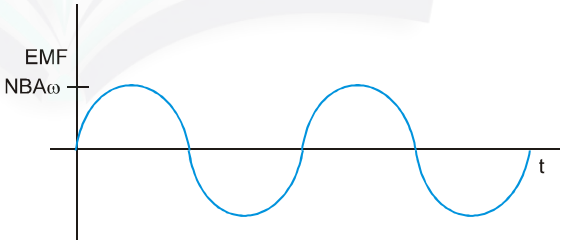
$$e = \frac{-d\phi}{dt} = BA\,\omega\sin\omega t$$

If there are N turns

emf = $BA\omega N\sin\omega t$

$BA\,\omega N$ is the amplitude of the emf

$e = e_m \sin\omega t$



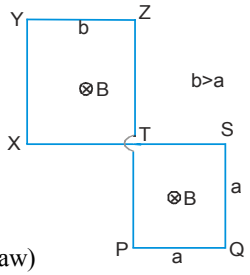
$$i = \frac{e}{R} = \frac{e_m}{R}\sin wt = i_m \sin wt$$

$$i_m = \frac{e_m}{R}$$

The rotating coil thus produces a sinusoidally varying current or alternating current. This is also the principle used in generator.

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Ex. Figure shows a wire frame PQSTXYZ placed in a time varying magnetic field given as B=βt, where β is a positive constant. Resistance per unit length of the wire is λ. Find the current induced in the wire and draw its electrical equivalent diagram.



Sol. Induced emf in part PQST = βa^2 (in anticlockwise direction, from Lenz's Law)

Similarly Induced emf in part TXYZ = βb^2 (in anticlockwise direction, from Lenz's Law)

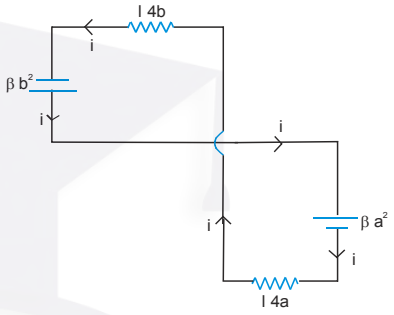
Total resistance of the part PQST = $\lambda 4a$.

Total resistance of the part TXYZ = $\lambda 4b$. The equivalent circuit is as shown in the following diagram.

writing KVL along the current flow

$$\beta b^2 - \beta a^2 - \lambda\, 4ai - \lambda\, 4bi = 0$$

$$i = \frac{\beta}{4\lambda}(b-a)$$



EMF Induced in a Rotating Disc :

Consider a disc of radius r rotating in a magnetic field B.

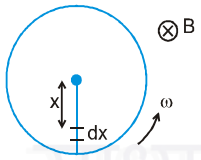
Consider an element dx at a distance x form the centre. This element is moving with speed v = ωx.

∴ Induced emf across dx

= B(dx) v = Bdxωx = Bωxdx

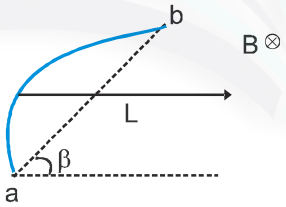
∴ emf between the centre and the edge of disc.

$$= \int_0^r B\omega x\,dx = \frac{B\omega r^2}{2}$$



A Conductor of Arbitary Shape

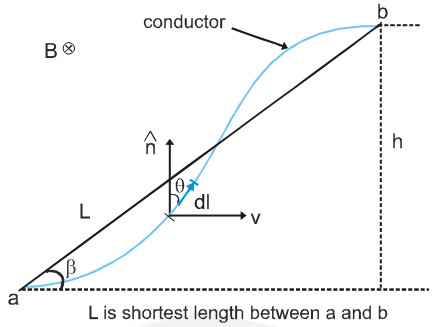
Consider a conductor ab of arbitary shape translating in a uniform magnetic field B.



Then induced emf in this conductor will be same as in a straight conductor connected between a and b, i.e. $\varepsilon = BvL\sin\beta$

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Proof : Consider an arbitrary shaped conductor ab

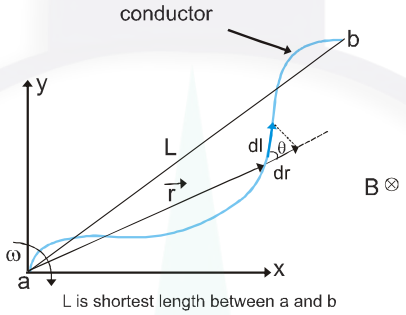


Emf induced in the conductor is given by :

$$\varepsilon = \int (\vec{v} \times \vec{B}).d\vec{l} = \int vB\hat{n}.d\vec{l} = vB\int dl\cos\theta = vBh = vBL\sin\beta$$

A Rotating Conductor of Arbitary Shape :

Consider an arbitary shaped conductor ab which is rotating about end a with angular velocity ω as shown. We want to find induced emf between ends a and b.



Induced emf developed between ends a and b is given by :

$$\varepsilon = \int (\vec{v} \times \vec{B}).d\vec{l}$$

$$\Rightarrow \quad \varepsilon = \int [(\vec{\omega} \times \vec{r}) \times \vec{B}].d\vec{l}$$

$$= \int [\{-\omega\hat{k} \times (x\hat{i} + y\hat{j})\} \times (-B\hat{k})].\, d\vec{l} \quad = \int [(-\omega x\hat{j} + \omega y\hat{i}) \times (-B\hat{k})].\, d\vec{l}$$

$$= \int [(-\omega xB\hat{i} + \omega By\hat{j}).d\vec{l} = B\omega\int (x\hat{i} + y\hat{j}).d\vec{l} \quad = B\omega\int \vec{r}.\, d\vec{l} = B\omega\int r\; dl\cos\theta = B\omega\int_0^L r dr$$

$$\Rightarrow \quad \varepsilon = \frac{1}{2}B\omega L^2$$

Motional EMF when the magnetic Field is Non-Uniform

In some of the cases motion of a conductor may be in a non-uniform magnetic field. Take the following steps while calculating motional emf.

Step 1 : Determine the magnetic field at all points on the rod.

Step 2 : Consider a small element at some distance from one end of the rod.

Step 3 : Assuming B to be uniform over this element, calculate the potential difference across this element using the procedures outlined earlier.

Step 4 : Integrate over the entire rod to calculate the total induced emf.

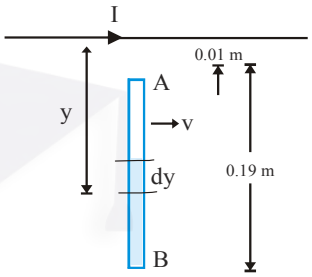
Let us learn to calculate the induced emf through the examples given below.

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Ex. A copper rod of length 0,19 m is moving with uniform velocity 10 m s^{-1} parallel to a long straight wire carrying a current of 0.5 A. The rod is perpendicular to the wire with its ends at distances 0.01 and 0.2 m from it. Calculate the emf induced in the rod.

Sol. As shown in figure, consider an element of length dy at a distance y from the wire, then at this position of the element, the magnetic field due to the current-carrying wire PQ will be $B = \frac{\mu_0}{4\pi}\frac{2I}{y}$ into the plane of the paper.

So, the emf induced in the element $d\varepsilon = Bv\ dy = \frac{\mu_0}{4\pi}\frac{2I}{y}v\ dy$ and hence the emf induced across the ends of the rod due to its motion in the field of the wire.

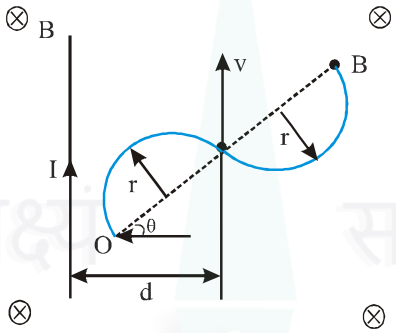


$$\varepsilon = \int_a^b d\varepsilon = \frac{\mu_0}{4\pi}2Iv\int_a^b \frac{dy}{y}, \quad \text{i.e. } \varepsilon = \frac{\mu_0}{4\pi}2Iv\log_e\left(\frac{b}{a}\right)$$

Substituting the given data with b = (a + ℓ),

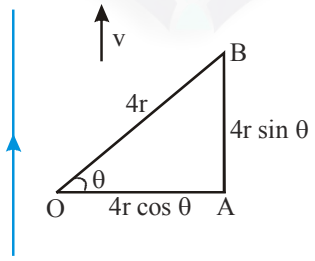
$$\varepsilon = 10^{-7}\times 2\times 5\times 10\log_e\frac{0.20}{0.01} = 10^{-5}\times\log_e 20 = 30\mu V$$

Ex. An infinite wire carries a current I. An 'S' shaped conducting rod of two semicircles each of radius r is placed at an angle q to the wire. The centre of the conductors at a distance d from the wire. If the rod translates parallel to the wire with a velocity v as shown in figure, calculate the emf induced across the ends OB of the rod.



Sol. Join the end point O and B and replace the two semicircles by a straight rod length 4r (in figure).

Induced emf in straight rod OB will be same as in the actual conductor. Now this straight rod can be replaced by a combination of two rods OA and AB. Induced emf in OB will be same as induced emf in OA+ induced emf in AB will be zero because its velocity will be parallel to its length. Hence induced emf in OA will be the net induced emf in actual conductor.



We now have a rod of effective length 4r cosq translating in a non-uniform magnetic field. Consider a small element of the wire of length dx located at a distance x from the wire. The magnetic field at this element is $B = \frac{\mu_0 I}{2\pi x}$

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The potential difference across this element is $dV = \frac{\mu_0 I}{2\pi x} v\, dx$.

The potential difference across the ends of the rod can be calculated by intergating over the whole end. Therefore,

$$V = \int dV = \int_{d-2r\cos\theta}^{d+2r\cos\theta} \frac{\mu_0 I}{2\pi x} v\, dx$$

or $$V = \frac{\mu_0 I v}{2\pi} \ln\left[\frac{d+2r\cos\theta}{d-2r\cos\theta}\right]$$

From the right hand rule we see that electrons will accumulate at end B. Therefore, end O is at a high potential than B.

Induced Electric Field

We have seen that the electric potential difference between two points A and B in an electric field $\vec{E}$ can be written as

$$\Delta V = V_B - V_A = -\int_A^B \vec{E}.d\vec{s}$$

When the electric field is conservative, as is the case of electrostatics, the line integral of it is path-independent, which implies $\oint \vec{E}.d\vec{s} = 0$

Faraday's law show that as magnetic flux changes with time, an induced current begins to flow. What cause the charges to move ? It is the induced emf which is the work done per unit charge. However, since magnetic field can do no work, as we have shown, the work done on the mobile charges must be electric, and the electric field in this situation cannot be conservative because the line integral of a conservative field must vanish. Therefore, we conclude that there is a non-conservative electric field $\vec{E}_{nc}$ associated with an induced emf $\varepsilon = \oint \vec{E}_{nc}.d\vec{s}$

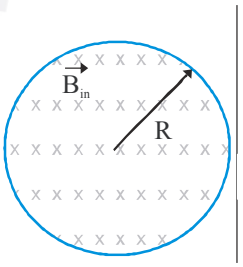
Combining with Faraday's law then yields :

$$\oint \vec{E}_{nc}.d\vec{s} = -\frac{d\Phi_B}{dt}$$

The above expression implies that a changing magnetic flux will induce a non-conservative electric field which can vary with time. It is important to distinguish between the induced, non-conservative electric field and the conservative electric field which arises from electric charges.

As an example, let's consider a uniform magnetic field which points into the page and is confined to a circular region with radius R, as shown in Figure. Suppose the magnetic of $\vec{B}$ increase with time, i.e., dB/dt>0. let's find the induced electric field everywhere due to the changing magnetic field.

Since the magnetic field is confined to a circular region, from symmetry arguments we choose the integration path to be a circle of radius r. The magnitude of the induced field $\vec{E}_{nc}$ at all points on a circle is the same. According to Lenz's law, the direction $\vec{E}_{nc}$ of must be such that it would drive the induced current to produce a magnetic field opposing the change in magnetic flux. With the area vector $\vec{A}$ pointing out of the page, the magnetic flux is negative or inward. With dB > dt > 0, the inward magnetic flux is increasing. Therefore, to counteract this change the induced current must flow counterclockwise to produce more outward flux. The direction of $\vec{E}_{nc}$ is shown in Figure.

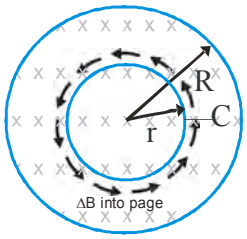


Let's proceed to find the magnitude of $\vec{E}_{nc}$.

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In the Region r > R

the rate of change of magnetic flux is :



$$\frac{d\Phi_B}{dt} = \frac{d}{dt}(\vec{B}.\vec{A}) = \frac{d}{dt}(-BA) = -\left(\frac{dB}{dt}\right)\pi r^2$$

Using equation, we have

$$\oint \vec{E}_{nc}.d\vec{s} = E_{nc}(2\pi r) = -\frac{d\Phi_B}{dt} = \left(\frac{dB}{dt}\right)\pi r^2$$

which implies

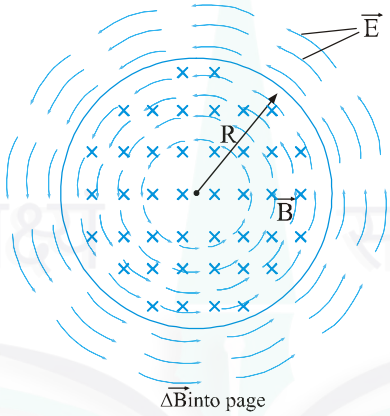
$$E_{nc} = \frac{r}{2}\frac{dB}{dt}$$

Similarly, for r > R

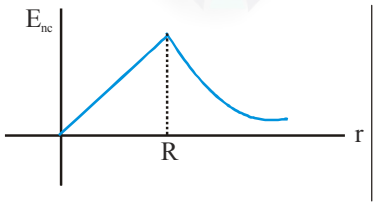
the induced electric field may be obtained as

$$E_{nc}(2\pi r) = -\frac{d\Phi_B}{dt} = \left(\frac{dB}{dt}\right)\pi r^2 \quad \text{or} \quad \vec{E}_{nc} = \frac{R^2}{2r}\frac{dB}{dt}$$

The pattern of E_{nc} as a function of r is shown in figure.



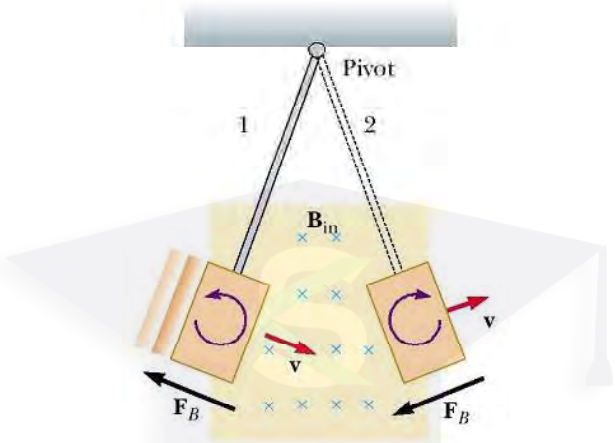
A Plot of E_{nc} as a function of r is shown in figure.



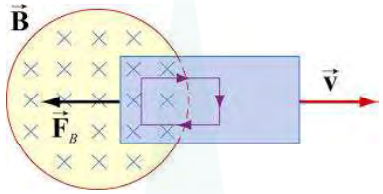
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Eddy Currents

We have seen that when a conducting loop moves through a magnetic field, current is induced as the result of changing magnetic flux. If a solid conductor were used instead of a loop, as shown in Figure. current can also be induced along any closed loop in the conductor. The induced current are called an early current.



The induced eddy currents also generate a magnetic force that opposes the motion, making it more difficult to move the conductor across the magnetic field (Figure).



Since the conductor has non-vanashing resistance R, joule heating causes a loss of power by an amount $P = \varepsilon^2 / R$. Therefore by increasing the value of R, power loss can be reduced. One way to increase R is to laminate the conducting slab, or construct the slab by using gluing together thin strips that are insulated from one another (see Fig.- a). Another way is to make cuts in the slab, thereby disrupting the conducting path (Figure - b).

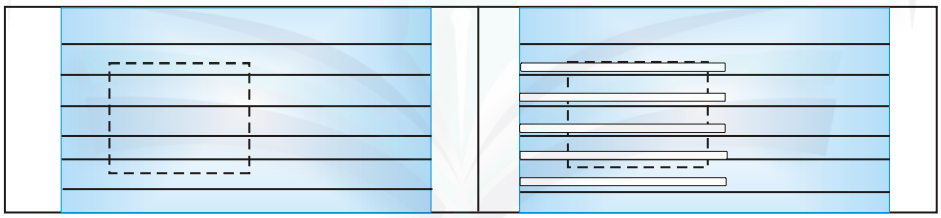


Figure (a) Figure (b)

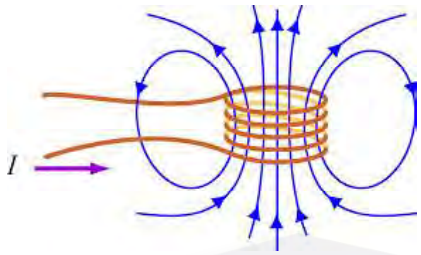
There are important applications of eddy currents. For example, the currents can be used to suppress unwanted mechanical oscillations. Another application is the magnetic braking system in high-speed transit cars.

Self-Inductance

Consider again a coil consisting of N turns and carrying current I in the counterclockwise direction, as shown in Figure. If the current is already, then the magnetic flux through the loop will remain constant. However, suppose the current I changes with time, then according to faraday's law, an induced emf will arise to oppose the change. According to lenz law the induced emf will be clockwise if $\frac{dI}{dt} > 0$, and counterclockwise if $\frac{dI}{dt} < 0$. The property of

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the loop in which its own magnetic field opposes any change in current is called :self-inductance", and the emf generated is called the self-induced emf or back emf, which we denote as ε_L. All current-carrying loops exhibit this property. In particular, an inductor is a circuit element (symbol ⎯∩∩∩⎯) which has a large self-inductance.



Mathematically, the self-induced emf can be written as

$$\varepsilon_L = -N\frac{d\Phi_B}{dt} = -N\frac{d}{dt}\int \vec{B}.d\vec{A}$$

and is related to the self-inductance L by

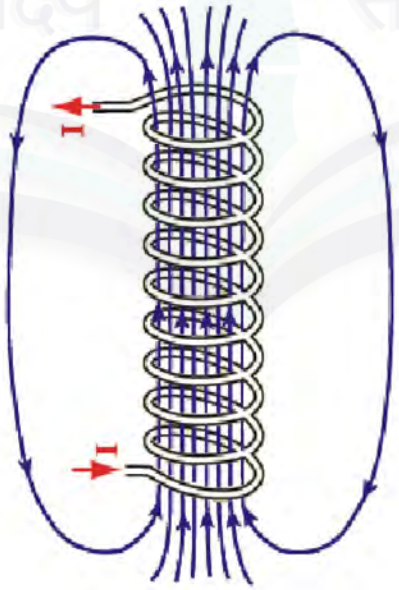
$$\varepsilon_L = -L\frac{dI}{dt}$$

The above two expression can be combined to yield

$$L = \frac{N\Phi_B}{I}$$

Physically, the inductance L is a measure of an inductor's "opposition" to the change of current ; larger the value of L, lower the rate of change of current.

Ex. Compute the self-inductance of a solenoid with N turns, length l , and the radius R with a current I flowing through each turn, as shown in Figure. Ignore edge effects



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Sol. Ignoring edge effects and applying Ampere's law, the magnetic field inside a solenoid is given by Eq. :

$$\vec{B}=\frac{\mu_0 NI}{l}\hat{k}=\mu_0 nI\,\hat{k}$$

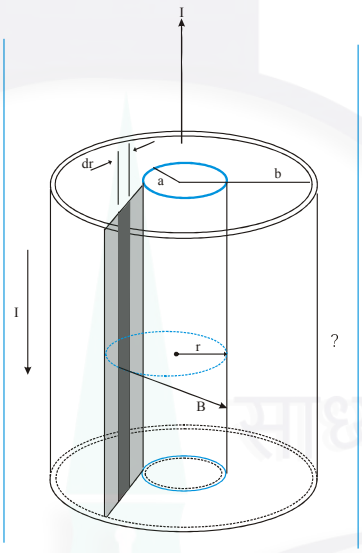
where $n = N / \ell$ is the number of turns per unit length. The magnetic flux through each turn is

$$\Phi_B = BA = \mu_0 nI.(\pi R^2) = \mu_0 nI\pi R^2$$

Thus, the self-inductance is $L=\frac{N\Phi_B}{l}\hat{k}=\mu_0 n^2\pi R^2\ell$

Note We see that L depends only on the geometrical factors (n, R and ℓ) and is independent of the current I.

Ex. A long coaxial cable as consisting of two thin concentric cylindrical conducting shells of radii a and b and length *l*. The conducting shells carry the same current I in opposite directions. Imagine that the inner conductor carries current to a device and that the outer one acts as a return path carrying the current back to the source. Calculate the self-inductance L of this cable.



Sol. Imagine a thin radial slice of the coaxial cable, such as the shaded rectangle in Figure. The magnetic field is perpendicular to the rectangle of length *l* and width b-a, the cross section of interest. Divide this rectangle into strips of width dr. We see that the area of each strip is Idr and that the flux through each strip is

$$B\,dA = BIdr$$

Hence, we find the total flux through the entire cross section by integrating

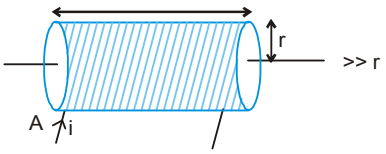
$$\left|\Phi_B = \int B\,dA = \int_a^b \frac{\mu_0 I}{2\pi r}\ell\,dr = \frac{\mu_0 I\ell}{2\pi}\int_a^b \frac{dr}{r} = \frac{\mu_0 I\ell}{2\pi} In\left(\frac{b}{a}\right)\right|$$

Using this result, we find that the self-inductance of the cable is

$$\left|L = \frac{\Phi_B}{I} = \frac{\mu_0\ell}{2\pi} In\left(\frac{b}{a}\right)\right|$$

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Self Inductance of Solenoid



Let the volume of the solenoid be V , the number of turns per unit length be n.

Let a current I be flowing in the solenoid. Magnetic field in the solenoid is given as $B=\mu_0 ni$.The magnetic flux through one turn of solenoid $\phi = \mu_0 n i A$.

The total magnetic flux through the solenoid = $N\phi = N\mu_0 ni A = \mu_0 n^2 i A \ell$

$\therefore \quad L = \mu_0 n^2 \ell A = \mu_0 n^2 V$

$\phi = \mu_0 n i \pi r^2 (n\ell)$

$$L = \frac{\phi}{i} = \mu_0 n^2 \pi r^2 \ell.$$

Inductance per unit volume = $\mu_0 n^2$.

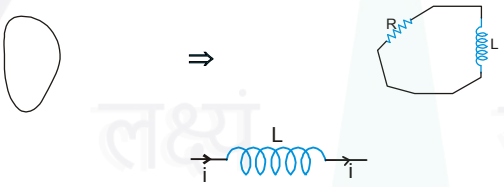
Self inductance is the physical property of the loop due to which it opposes the change in current that means it tries to keep the current constant. Current can not change suddenly in the inductor.

Inductor

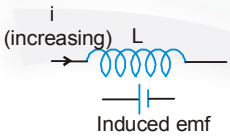
It is represent by

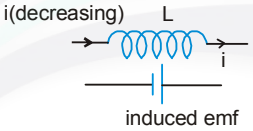


electrical equivalence of loop

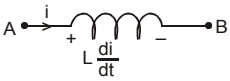


If current i through the inductor is increasing the induced emf will oppose the **increase** in current and hence will be opposite to the current. If current i through the inductor is decreasing the induced emf will oppose the **decrease** in current and hence will be in the direction of the current.



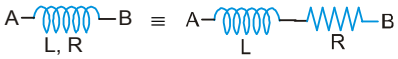


Over all result



$$V_A - L\frac{di}{dt} = V_B$$

Note : If there is a resistance in the inductor (resistance of the coil of inductor) then :



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Ex. A B is a part of circuit. Find the potential difference $v_A - v_B$ if

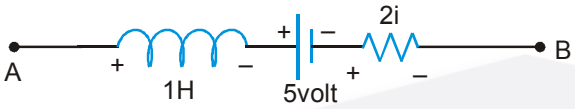


(i) current i = 2A and is constant

(ii) current i = 2A and is increasing at the rate of 1 amp/sec.

(iii) current i = 2A and is decreasing at the rate 1 amp/sec.

Sol.



$$L\frac{di}{dt} = 1\frac{di}{dt}$$

writing KVL from A to B

$$V_A - 1\frac{di}{dt} - 5 - 2i = V_B .$$

(i) Put $i = 2, \frac{di}{dt} = 0$

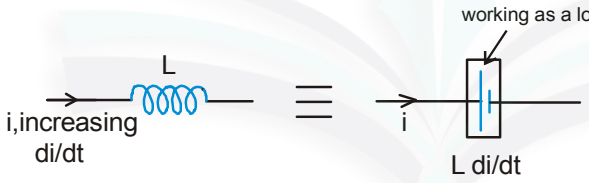
$V_A - 5 - 4 = V_B \quad \therefore V_A - V_B = 9$ volt

(ii) Put $i = 2, \frac{di}{dt} = 1 ; V_A - 1 - 5 - 4 = V_B$ or $V_A - V_B = 10\, V_0$

(iii) Put $i = 2, \frac{di}{dt} = -1 ; V_A + 1 - 5 - 2 \times 2 = V_B$ or $V_A = 8$ volt.

Energy Stored in an Inductor

If current in an inductor at an instant is i and is increasing at the rate di/dt,the induced emf will oppose the current . Its behaviour is shown in the figure.



Power consumed by the inductor = $i\,L\,\frac{di}{dt}$

Energy consumed in dt time = $i\,L\,\frac{di}{dt}\,dt$

$\therefore$ total energy consumed as the current increases from 0 to I = $\int_0^I iLdi = \frac{1}{2}LI^2$

$= \frac{1}{2}Li^2 \Rightarrow U = \frac{1}{2}LI^2$

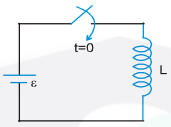
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Note : This energy is stored in the magnetic field with energy density

$$\frac{dU}{dV}=\frac{B^2}{2\mu}=\frac{B^2}{2\mu_0\mu_r}$$

Total energy $U=\int\frac{B^2}{2\mu_0\mu_r}dV$

Ex. A circuit contains an ideal cell and an inductor with a switch. Initially the switch is open .It is closed at t=0. Find the current as a function of time.



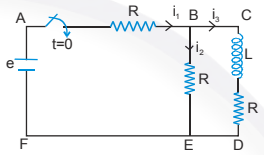
Sol. $\varepsilon=L\frac{di}{dt}\Rightarrow\int_0^i\varepsilon dt=\int_0^i Ldi$

$\varepsilon t=Li\Rightarrow i=\frac{\varepsilon t}{L}$

Ex. In the following circuit, the switch is closed at t = 0.

Find the currents i_1 ,i_2 ,i_3 and $\frac{di_3}{dt}$ at t=0 and at t = ∞.

Initially all currents are zero.



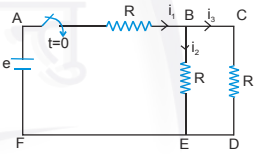
Sol. At **t = 0**

i_3 is zero ,since current cannot suddenly change due to the inductor. $\therefore\ i_1=i_2$ (from KCL)

applying KVL in the part ABEF we get $i_1=i_2=\frac{\varepsilon}{2R}$.

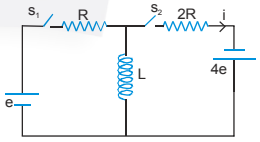
At t = ∞

i_3 will become constant and hence potential difference across the inductor will be zero. It is just like a simple wire and the circuit can be solved assuming it to be like shown in the following diagram.

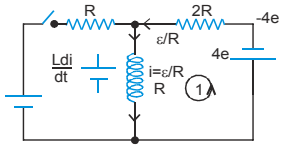


$$i_2=i_3=\frac{\varepsilon}{3R},\ i_1=\frac{2\varepsilon}{3R}.$$

Ex. In the circuit shown in the figure,S_1 remains closed for a long time and S_2 remains open. Now S_2 is closed and S_1 is opened. Find out the di/dt just after that moment.



Sol. Before S_2 is closed and S_1 is opened current in the left part of the circuit $=\frac{\varepsilon}{R}$.



Now when S_2 closed S_1 opened, current through the inductor can not change suddenly , current $\frac{\varepsilon}{R}$ will continue to move in the inductor.

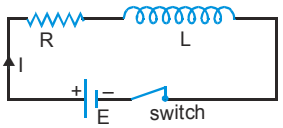
Applying KVL in loop 1.

$$L\frac{di}{dt}+\frac{\varepsilon}{R}(2R)+4\varepsilon=0\Rightarrow\frac{di}{dt}=-\frac{6\varepsilon}{L}$$

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R-L DC Circuit

Current Growth



(i) **EMF equation** $E = IR + L\frac{dI}{dt}$

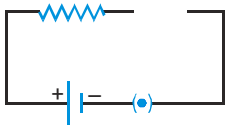
(ii) **Current at any instant**

When key is closed the current in circuit increases exponentially with respect to time. The current in circuit at any instant 't' given by $I = I_0\left[1 - e^{\frac{-t}{\lambda}}\right]$

$t = 0$ (just after the closing of key) $\Rightarrow I = 0$

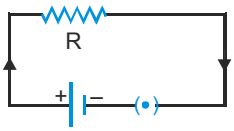
$t = \infty$ (some time after closing of key) $\Rightarrow I \to I_0$

(iii) Just after the closing of the key inductance behaves like open circuit and current in circuit is zero.



Open circuit, $t = 0$, $I = 0$ Inductor provide infinite resistence

(iv) Some time after closing of the key inductance behaves like simple connecting wire (short circuit) and current in circuit is constant.



Short circuit, $t \to \infty$, $I \to I_0$, Inductor provide zero resistence $I_0 = \frac{E}{R}$

(Final, steady, maximum or peak value of current) or ultimate current

Note : Peak value of current in circuit does not depends on self inductance of coil.

(v) **Time constant of circuit (λ)**

$\lambda = \frac{L}{R_{sec.}}$ It is a time in which current increases up to 63% or 0.63 times of peak current value.

(vi) **Half life (T)**

It is a time in which current increases upto 50% or 0.50 times of peak current value.

$$I = I_0(1 - e^{-t/\lambda}),\ t = T,\ I = \frac{I_0}{2} \Rightarrow \frac{I_0}{2} = I_0(1 - e^{-T/\lambda}) \Rightarrow e^{-T/\lambda} = \frac{1}{2} \Rightarrow e^{T/\lambda} = 2$$

$$\frac{T}{\lambda}\log_e e = \log_e 2 \Rightarrow T = 0.693\lambda \Rightarrow T = 0.693\frac{L}{R_{sec.}}$$

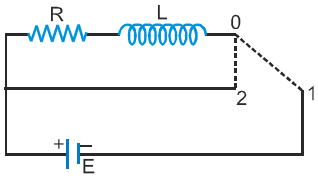
(vii) **Rate of growth of current at any instant :–**

$$\left[\frac{dI}{dt}\right] = \frac{E}{L}(e^{-t/\lambda}) \Rightarrow t = 0 \Rightarrow \left[\frac{dI}{dt}\right]_{max} = \frac{E}{L} \quad t = \infty \Rightarrow \left[\frac{dI}{dt}\right] \to 0$$

Note : Maximum or initial value of rate of growth of current does not depends upon resistance of coil.

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Current Decay



(i) Emf equation $IR + L\frac{dI}{dt} = 0$

(ii) Current at any instant

Once current acquires its final max steady value, if suddenly switch is put off then current start decreasing exponentially wrt to time. At switch put off condition $t = 0$, $I = I_0$, source emf E is cut off from circuit $I = I_0(e^{-t/\lambda})$

Just after opening of key $t = 0 \Rightarrow I = I_0 = \frac{E}{R}$

Some time after opening of key $t \to \infty \Rightarrow I \to 0$

(iii) Time constant (λ)

It is a time in which current decreases up to 37% or 0.37 times of peak current value.

(iv) Half life (T)

It is a time in which current decreases upto 50% or 0.50 times of peak current value.

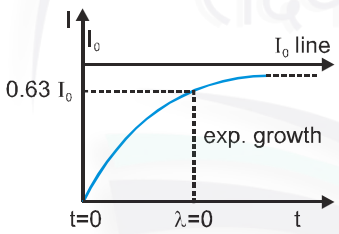
(v) Rate of decay of current at any instant

$$\left[-\frac{dI}{dt}\right] = \left[\frac{E}{L}\right]e^{-t/\lambda} \qquad t = 0, \quad \left[-\frac{dI}{dt}\right]_{max.} = \frac{E}{L} \qquad t \to \infty \Rightarrow \left[-\frac{dI}{dt}\right] \to 0$$

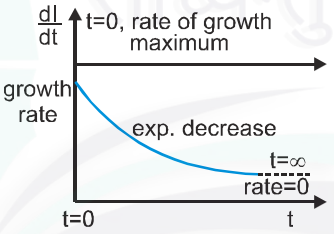
Graph for R–L circuit

Current Growth

(a)

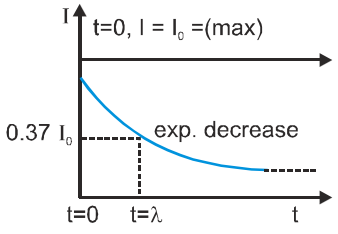


(b)

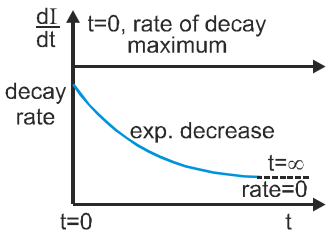


Current decay

(a)

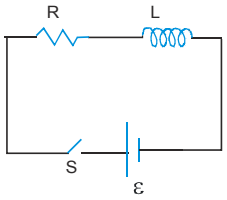


(b)



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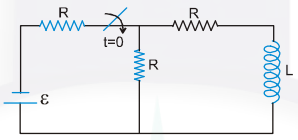
Ex. At t = 0 switch is closed (shown in figure) after a long time suddenly the inductance of the inductor is made η times lesser ($\frac{L}{\eta}$) then its initial value, find out instant current just after the operation.



Sol. Using above result (note 4)

$$L_1 i_1 = L_2 i_2 \Rightarrow i_2 = \frac{\eta\varepsilon}{R}$$

Ex. In the following circuit the switch is closed at t = 0. Initially there is no current in inductor. Find out current the inductor coil as a function of time.

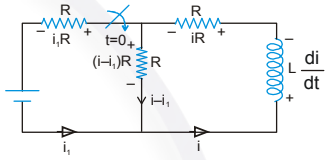


Sol. At any time t

$$-\varepsilon + i_1 R - (i - i_1) R = 0$$

$$-\varepsilon + 2i_1 R - iR = 0$$

$$i_1 = \frac{iR + \varepsilon}{2R}$$



Now, $-\varepsilon + i_1 R + iR + L.\frac{di}{dt} = 0$

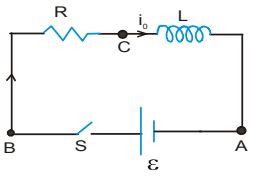
$$-\varepsilon + \left(\frac{iR + \varepsilon}{2}\right) + iR + L.\frac{di}{dt} = 0 \quad \Rightarrow \quad -\frac{\varepsilon}{2} + \frac{3iR}{2} = -L.\frac{di}{dt}$$

$$\left(\frac{-\varepsilon + 3iR}{2}\right) dt = -L.\,di \quad \Rightarrow \quad -\frac{-dt}{2L} = \frac{di}{-\varepsilon + 3iR}$$

$$-\int_0^t \frac{dt}{2L} = \int_0^i \frac{di}{-\varepsilon + 3iR} \quad \Rightarrow \quad -\frac{t}{2L} = \frac{1}{3R} \ln\left(\frac{-\varepsilon + 3iR}{-\varepsilon}\right)$$

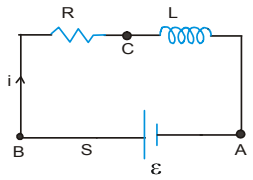
$$-\ln\left(\frac{-\varepsilon + 3iR}{-\varepsilon}\right) = \frac{3Rt}{2L} \quad \Rightarrow \quad i = +\frac{\varepsilon}{3R}\left(1 - e^{-\frac{3Rt}{2L}}\right)$$

Ex. Figure shows a circuit consisting of a ideal cell, an inductor L and a resistor R,connected in series. Let the switch S be closed at t = 0. Suppose at t = 0 current in the inductor is i_0 then find out equation of current as a function of time



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Sol. Let an instant t current in the circuit is i which is increasing at the rate di/dt.

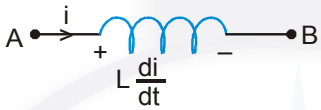


Writing KVL along the circuit , we have $\varepsilon - L\frac{di}{dt} - iR = 0$

$$\Rightarrow \quad L\frac{di}{dt} = \varepsilon - iR \Rightarrow \int_{i_0}^{i}\frac{di}{\varepsilon - iR} = \int_0^t \frac{dt}{L} \Rightarrow \ln\left(\frac{\varepsilon - iR}{\varepsilon - i_0R}\right) = -\frac{Rt}{L}$$

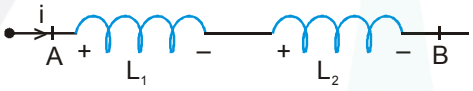
$$\Rightarrow \varepsilon - iR = (\varepsilon - i_0R)\, e^{-Rt/L} \Rightarrow i = \frac{\varepsilon - (\varepsilon - i_0R)e^{-Rt/L}}{R}$$

Equivalent Self Inductance



$$L = \frac{V_A - V_B}{di/dt} \qquad ..(1)$$

Series Combination



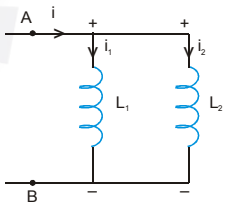
$$V_A - L_1\frac{di}{dt} - L_2\frac{di}{dt} = V_B \qquad ....(2)$$

from (1) and (2)

$L = L_1 + L_2$ (neglecting mutual inductance)

Parallel Combination

From figure $V_A - V_B = L_1\frac{di_1}{dt} = L_2\frac{di_2}{dt}$ .....(3)



also $i = i_1 + i_2$

or $$\frac{di}{dt} = \frac{di_1}{dt} + \frac{di_2}{dt}$$

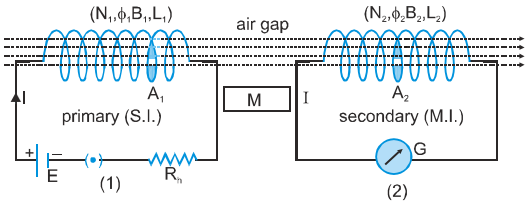
or $$\frac{V_A - V_B}{L} = \frac{V_A - V_B}{L_1} + \frac{V_A - V_B}{L_2}$$

$$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2}$$ (neglecting mutual inductance)

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Mutual Induction

Whenever the current passing through primary coil or circuit change then magnetic flux neighbouring secondary coil or circuit will also change. Acc. to Lenz for opposition of flux change, so an emf induced in the neighbouring coil or circuit. This phenomenon called as 'Mutual induction'. In case of mutual inductance for two coils situated close to each other, flux linked with the secondary due to current in primary.



Due to Air gap always $\phi_2 < \phi_1$ and $\phi_2 = B_1A_2$ $(\theta = 0°)$.

Case - I When current through primary is constant

Total flux of secondary is directly proportional to current flow through the primary coil

$N_2\phi_2 \propto I_1 \Rightarrow N_2\phi_2 = MI_1$, $M = \frac{N_2\phi_2}{I_1} = \frac{N_2B_1A_2}{I_1} = \frac{(\phi_T)_s}{I_p}$ where M : is coefficient of mutual induction.

Case - II When current through primary changes with respect to time

If $\frac{dI_1}{dt} \to \frac{dB_1}{dt} \to \frac{d\phi_1}{dt} \to \frac{d\phi_2}{dt} \Rightarrow$ Static EMI

$N_2\phi_2 = MI_1$ $\quad -N_2\frac{d\phi_2}{dt} = -M\frac{dI_1}{dt}, \left[-N_2\frac{d\phi}{dt}\right]$

$e_m = -M\left(\frac{dI_1}{dt}\right)$

Secondary ← → Primary

called total mutual induced emf of secondary coil em.

- The units and dimension of M are same as 'L'.
- The mutual inductance does not depends upon current through the primary and it is constant for circuit system.

'M' depends on :

(a) Number of turns (N_1, N_2).

(b) Cofficient of self inductance (L_1, L_2).

(c) Area of cross section.

(d) Magnetic permeability of medium (μr).

(e) Distance between two coils (As $d\downarrow = M\uparrow$).

(f) Orientation between two coils.

(g) Coupling factor 'K' between two coils.

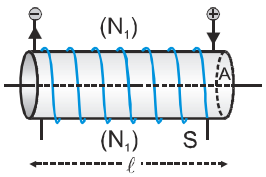
Different Coefficient of Mutual Inductance

(a) In terms of their number of turns

(b) In terms of their coefficient of self inductances

(c) In terms of their nos of turns (N_1, N_2)

(a) Two co–axial solenoids : $(M_{S_1S_2})$

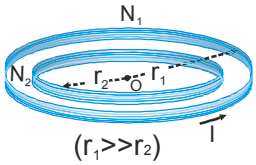


Coefficient of mutual inductance between two solenoids

$M_{s_1s_2} = \frac{N_2B_1A}{I_1} = \frac{N_2}{I_1}\left[\frac{\mu_0N_1I_1}{\ell}\right]A \Rightarrow M_{s_1s_2} = \left[\frac{\mu_0N_1N_2A}{\ell}\right]$

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(b) Two plane concentric coils : $(M_{C_1C_2})$



$$M_{c_1c_2} = \frac{N_2B_1A_2}{I_1} \quad \text{where} \quad B_1 = \frac{\mu_0 N_1 I_1}{2r_1},\ A_2 = \pi r_2^2$$

$$M_{c_1c_2} = \frac{N_2}{I_1}\left[\frac{\mu_0 N_1 I_1}{2r_1}\right](\pi r_2^2) \Rightarrow M_{c_1c_2} = \frac{\mu_0 N_1 N_2 \pi r_2^2}{2r_1}$$

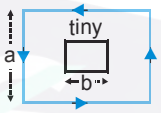
Two concentric loop

$M \propto \frac{r_2^2}{r_1}$ (r1 >> r2)



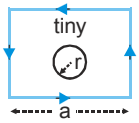
Two concentric square loops

$M \propto \frac{b^2}{a}$



A square and a circular loop

$M \propto \frac{r^2}{a}$

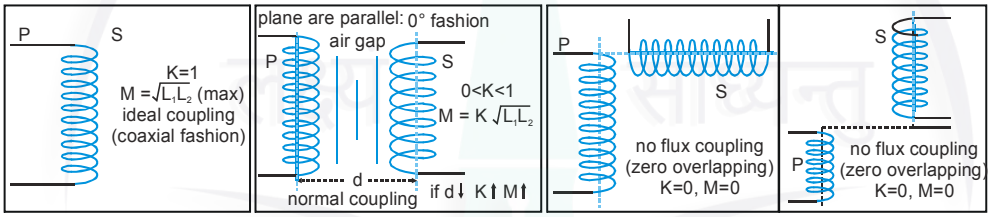


In terms of L_1 and L_2 : For two magnetically coupled coils :-

$M = K\sqrt{L_1L_2}$ here 'K' is coupling factor between two coils and its range $0 \le K \le 1$

- For ideal coupling Kmax = 1 $\Rightarrow$ $M_{max} = \sqrt{L_1L_2}$ (where M is geometrical mean of L_1 and L_2)
- For real coupling $(0 < K < 1)$ $M = K\sqrt{L_1L_2}$
- Value of coupling factor 'K' decided from fashion of coupling.

Different Fashion of Coupling



'K' also defined as $K = \frac{\phi_s}{\phi_p} = \frac{\text{mag. flux linked with secondary (s)}}{\text{mag. flux linked with primary (p)}}$

Inductance in Series and Parallel

Two coil are connected in series : Coils are lying close together (M)

If M = 0, $L = L_1 + L_2$ If $M \neq 0$ $L = L_1 + L_2 + 2M$

(a) When current in both is in the same direction Then $L = (L_1 + M) + (L_2 + M)$

(b) When current flow in two coils are mutually in opposite directions.

$L = L_1 + L_2 - 2M$

Two coils are connected in parallel :

(a) If M = 0 then $\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2}$ or $L = \frac{L_1L_2}{L_1 + L_2}$

(b) If $M \neq 0$ then $\frac{1}{L} = \frac{1}{(L_1 + M)} + \frac{1}{(L_2 + M)}$

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Ex. On a cylindrical rod two coils are wound one above the other. What is the coefficient of mutual induction if the inductance of each coil is 0.1 H ?

Sol. One coil is wound over the other and coupling is tight,so $K = 1$, $M = \sqrt{L_1 L_2} = \sqrt{0.1 \times 0.1} = 0.1H$

Ex. How does the mutual inductance of a pair of coils change when :

(i) the distance between the coils is increased ?

(ii) the number of turns in each coil is decreased ?

(iii) a thin iron rod is placed between the two coils, other factors remaining the same ?

Justify your answer in each case .

Sol. **(i)** The mutual inductance of two coils, decreases when the distance between them is increased. This is because the flux passing from one coil to another decreases.

(ii) Mutual inductance $M = \frac{\mu_0 N_1 N_2 A}{\ell}$ i.e., $M \propto N1\ N2$ Clearly, when the number of turns N1 and N2 in the two coils is decreased, the mutual inductance decreases.

(iii) When an iron rod is placed between th two coils the mutual inductance increases, because $M \propto$ permeability (μ)

Ex. A coil is wound on an iron core and looped back on itself so that the core has two sets of closely would wires in series carrying current in the opposite sense. What do you expect about its self-inductance ? Will it be larger or small ?

Sol. As the two sets of wire carry currents in opposite directions, their induced emf's also act in opposite directions. These induced emf's tend to cancel each other, making the self-inductance of the coil very small.

This situation is similar to two coils connected in series and producing fluxes in opposite directions. Therefore, their equivalent inductance must be $Leq = L + L - 2M = L + L - 2L = 0$

Ex. A solenoid has 2000 turns wound over a length of 0.3 m. The area of cross-section is 1.2 × 10–3 m2. Around its central section a coil of 300 turns is closely would. If an initial current of 2A is reversed in 0.25 s, find the emf induced in the coil.

Sol. $$M = \frac{\mu_0 N_1 N_2 A}{\ell} = \frac{4\pi \times 10^{-7} \times 2000 \times 300 \times 1.2 \times 10^{-3}}{0.3} = 3 \times 10^{-3} H$$

$$\mathcal{E} = -M\frac{dI}{dt} = -3 \times 10^{-3}\left[\frac{-2-2}{0.25}\right] = 48 \times 10^{-3} V = 48\,mV$$

Ex. Two insulated wires are wound on the same hollow cylinder, so as to form two solenoids sharing a common air-filled core. Let I be the length of the core, A the cross-sectional area of the core, N_1 the number of times the first wire is wound around the core, and N_2 the number of turns the second wire is wound around the core. Find the mutual inductance of the two solenoids, neglecting the end effects.

Sol. If a current I_1 flows around the first wire then a uniform axial magnetic field of strength $B_1 = \frac{\mu_0 N_1 I_1}{\ell}$ is generated in the core. The magnetic field in the region outside the core is of negligible magnitude. The flux linking a single turn of the second wire is $B_1 A$. Thus, the flux linking all N_2 turns of the second wire is

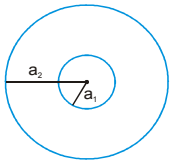
$$\phi_2 = N_2 B_1 A = \frac{\mu_0 N_1 N_2 A I_1}{\ell} = M I_1 .$$

$$\therefore \quad M = \frac{\mu_0 N_1 N_2 A}{\ell}$$

As described previously, M is a geometric quantity depending on the dimensions of the core and the manner in which the two wires are wound around the core, but not on the actual currents flowing through the wires.

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Ex. Find the mutual inductance of two concentric coils of radii a_1 and a_2 ($a_1 << a_2$) if the planes of coils are same.



Sol. Let a current i flow in coil of radius a_2.

Magnetic field at the centre of coil = $\frac{\mu_0 i}{2a_2}\ \pi a_1^2$

or $Mi = \frac{\mu_0 i}{2a_2}\ \pi a_1^2$ or $M = \frac{\mu_0 \pi a_1^2}{2a_2}$

Ex. Solve the above question, if the planes of coil are perpendicular.

Sol. Let a current i flow in the coil of radius a_1. The magnetic field at the centre of this coil will now be parallel to the plane of smaller coil and hence no flux will pass through it, hence M = 0.

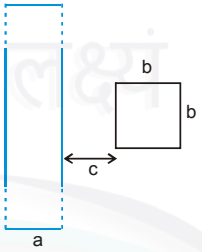
Ex. Solve the above problem if the planes of coils make θ angle with each other.

Sol. If i current flows in the larger coil, magnetic field produced at the centre will be perpendicular to the plane of larger coil. Now the area vector of smaller coil which is perpendicular to the plane of smaller coil will make an angle θ with the magnetic field.

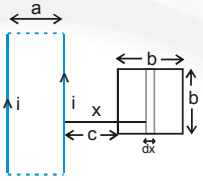
Thus flux = $\vec{B}.\vec{A} = \frac{\mu_0 i}{2a_2}.\pi a_1^2.\cos\theta$

or $M = \frac{\mu_0 \pi a_1^2 \cos\theta_1}{2a_2}$

Ex. Find the mutual inductance between two rectangular loops, shown in the figure



Sol.

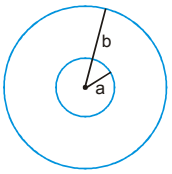


Let current i flow in the loop having ∞-by long sides. Consider a segment of width dx at a distance x as shown flux through the regent

$$d\phi = \left[\frac{\mu_0 i}{2\pi x} - \frac{\mu_0 i}{2\pi(x+a)}\right] b\,dx \ . \Rightarrow \phi = \int_c^{c+b}\left[\frac{\mu_0 i}{2\pi x} - \frac{\mu_0 i}{2\pi(x+a)}\right] b\,dx = \frac{\mu_0 i b}{2\pi}\left[\ln\frac{c+b}{c} - \ln\frac{a+b+c}{a+c}\right].$$

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Ex. Figure shows two concentric coplanar coils with radii a and b (a << b). A current i = 2t flows in the smaller loop. Neglecting self inductance of larger loop



(a) Find the mutual inductance of the two coils
(b) Find the emf induced in the larger coil
(c) If the resistance of the larger loop is R find the current in it as a function of time

Sol. **(a)** To find mutual inductance, it does not matter in which coil we consider current and in which flux is calculated

(Reciprocity theorem) Let current i be flowing in the larger coil. Magnetic field at the centre $= \frac{\mu_0 i}{2b}$.

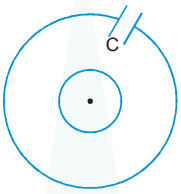
flux through the smaller coil $= \frac{\mu_0 i}{2b}\pi a^2 \quad \therefore M = \frac{\mu_0}{2b}\pi a^2$

(b) $\left|\text{emf induced in larger coil}\right| = M\left[\left(\frac{di}{dt}\right)\text{in smaller coil}\right]$

$= \frac{\mu_0}{2b}\pi a^2\ (2) = \frac{\mu_0 \pi a^2}{b}$

(c) current in the larger coil $= \frac{\mu_0 \pi a^2}{bR}$

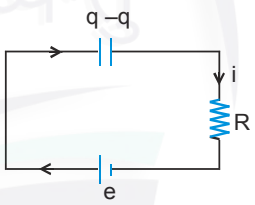
Ex. If the current in the inner loop changes according to $i = 2t^2$ then, find the current in the capacitor as a function of time.



Sol. $M = \frac{\mu_0}{2b}\pi a^2$

$\left|\text{emf induced in larger coil}\right| = M\left[\left(\frac{di}{dt}\right)\text{in smaller coil}\right]$

$e = \frac{\mu_0}{2b}\pi a^2\ (4t) = \frac{2\mu_0 \pi a^2 t}{b}$



Applying KVL :-

$$+e - \frac{q}{c} - iR = 0 \Rightarrow \frac{2\mu_0 \pi a^2 t}{b} - \frac{q}{c} - iR = 0$$

differentiate wrt time :-

$$\frac{2\mu_0 \pi a^2}{b} - \frac{i}{c} - \frac{di}{dt}R = 0$$

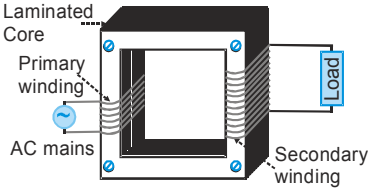
on solving it

$$i = \frac{2\mu_0 \pi a^2 C}{b}\left[1 - e^{-t/RC}\right]$$

Transformer

Working principle

Mutual induction



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Transformer has Basic Two Section

(a) **Shell :** Consist of primary and secondary coil of copper.

The effective resistance between primary and secondary coil is

infinite because electric circuit between two is open ($R_{ps} = \infty$)

(b) **Core :** Which is between two coil and magnetically coupled two coils. Two coils of transformer would on the same core. The alternating current passing through the primary creats a continuously changing flux through the core. This changing flux induces alternating emf in secondary.

Work

It regulates AC voltage and transfer the electrical electrical power without change in freqency of input supply. (The alternating current changes itself.)

Special Points

(i) It can't work with D.C. supply, and if a battery is connected to its primary, then output is across scondary is always zero ie. No working of transformer.

(ii) It can't called 'Amplifier' as it has no power gain like **transistor**.

(iii) It has no moving part, hence there are no mech. losses in transformer.

Types : According to voltage regulation it has two –

(i) Step up transformer : $N_S > N_P$ **(ii)** Step down transformer $N_S < N_P$

Step up transformer : Converts low voltage high current in to High voltage low current

Step down transformer : Converts High voltage low current into low voltage high current.

Power transmission is carried out always at **"High voltage low current"** so that voltage drop and power losses are minimum in transmission line.

voltage drop = $I_L R_L$, I_L = line current R_L = total line resistance,

$I_L = \dfrac{\text{power to be transmission}}{\text{line voltage}}$ power losses = $I_L^2 R_L$

High voltage coil having more number of turns and always **made of thin wire** and **high current coil** having less number of turns and always **made of thick wires.**

Ideal Transformer : ($\eta = 100\%$)

(a) **No flux leakage** $\phi_s = \phi_p \Rightarrow \dfrac{-d\phi_s}{dt} = \dfrac{-d\phi_p}{dt}$

$e_s = e_p = e$ induced emf per turn of each coil is also same.

total induced emf for secondary $E_s = N_s e$ total induced emf for primary $E_p = N_p e$

$\dfrac{E_s}{E_p} = \dfrac{N_s}{N_p} = n$ or p where n : turn ratio , p : transformation ratio

(b) **No load condition**

$V_P = E_P$ and $E_S = V_S$ $\dfrac{V_S}{V_P} = \dfrac{N_S}{N_P}$ from (i) and (ii) $\dfrac{V_S}{V_P} = \dfrac{N_S}{N_P} = n$ or p

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(c) No power loss

$P_{out} = P_{in}$ and $V_S I_S = V_P I_P$ $\quad \frac{V_S}{V_P} = \frac{I_P}{I_S}$ valid only for ideal transformer

from equation **(iii)** and **(iv)** $\frac{V_S}{V_P} = \frac{I_P}{I_S} = \frac{N_S}{N_P} = n$ or p

Note : Generally transformers deals in ideal condition i.e. $P_{in} = P_{out}$, if other information are not given.

Real transformer ($\eta \neq 100\%$)

Some power is always lost due to flux leakage, hysteresis, eddy currents, and heating of coils.

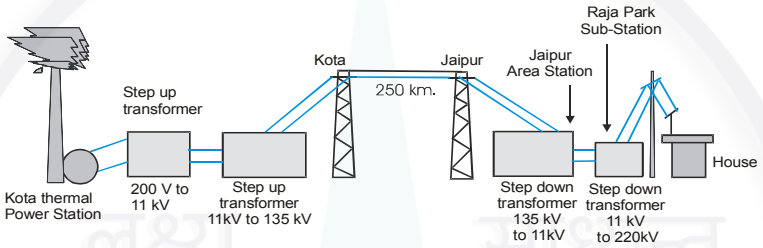
hence $P_{out} < P_{in}$ always. efficiency of transformer $\eta = \frac{P_{out}}{P_{in}} = \frac{V_S}{V_P} \cdot \frac{I_S}{I_P} \times 100$

Applications

The most important application of a transformer is in long distance transmission of electric power from generating station to consumers hundreds of kilometers away through transmission lines at reduced loss of power.

Transmission lines having resistance R and carrying current I have loss of power = I^2R.

This loss is reduced by reducing the current by stepping up the voltage at generating station. This high voltage is transmitted through high-tension transmission lines supported on robust pylons (iron girder pillars). The voltage is stepped down at consumption station. A typical arrangement is shown below :



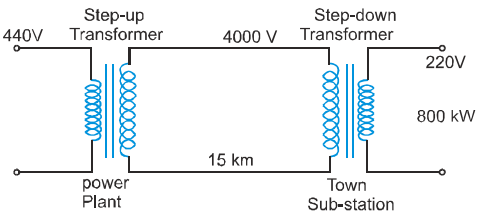
Ex. A small town with a demand of 800 kW of electric power at 220 V is situated 15 km away from an electric power plant generating power at 440 V. The resistance of the two wire line carrying power is 0.5 Ω per km. The town gets from the line through a 4000 – 220 V step down transformer at a sub-station in the town.

(a) Estimate the line power loss in the form of heat.

(b) How much power must be plant supply, assuming there is a negligible power loss due to leakage?

(c) Characterise the step up transformer at the plant.

Sol. The diagram shows the network :



For sub-station, $P = 800\ kW = 800 \times 10^3$ watts

$V = 220\ V$

$$I_S = \frac{P}{V} = \frac{800 \times 10^3}{220} = \frac{40}{11} \times 10^3\ A.$$

Primary current (I_p) in sub-station transformer will be given by

$$4000 \times I_P = 220 \times I_S,\ I_P = \frac{220 \times 40 \times 10^3}{11 \times 4000} = 200\ A$$

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(a) Hence transmission line current = 200 A

transmission line resistance = $2 \times 15 \times 0.5 = 15\ \Omega$

transmission line power loss = $I^2R = 200 \times 200 \times 15 = 6 \times 10^5$ watt = 600 kW.

(b) power to be supplied by plant = power required at substation + loss of power of transmission

= 800 + 600 = 1400 kW.

(c) Voltage in secondary at power plant has characteristics = $\frac{\text{Power}}{\text{Current}} = \frac{1400\ \text{kW}}{200\ \text{A}} = \frac{1400 \times 1000}{200} = 7000\ \text{V}$

Step-up transformer at power plant has characteristics 440 - 7000 V.

Ex. A power transmission line feeds input power at 2300 V to a step down transformer having 4000 turns in its primary. What should be the number of turns in the secondary to get output power at 230 V?

Sol. $E_p = 2300\ V\ ; N_p = 4000, E_S = 230\ V$ $\quad \frac{E_S}{E_P} = \frac{N_S}{N_P}\ \therefore N_S = N_P \times \frac{E_S}{E_P} = 4000 \times \frac{230}{2300} = 400$

Ex. The output voltage of an ideal transformer, connected to a 240 V a.c. mains is 24 V. When this transformer is used to light a bulb with rating 24V, 24W calculate the current in the primary coil of the circuit.

Sol. $E_p = 240\ V, E_S = 24\ V, \quad E_S I_S = 24\ W$

Current in primary coil $I_P = \frac{E_S I_S}{E_P} = \frac{24}{240} = 0.1A$

Losses of Transformer

(a) Copper or joule heating losses

Where : There losses occurs in both coils of shell part

Reason : Due to heating effect of current ($H = I^2Rt$)

Remmady : To minimise these losses, high current coil always made up with thick wire and for removal of produced heat circulation of mineral oil should be used.

(b) Flux leakage losses

Where : There losses occurs in between both the coil of shell part.

Cause : Due to air gap between both the coils.

Remmady : To minimise there losses both coils are tightly wound over a common soft iron core (high magnetic permeability) so a closed path of magnetic field lines formed itself within the core and tries to makes coupling factor $K \rightarrow 1$

(c) Iron losses

Where : There losses occurs in core part.

Types : **(i)** Hysteresis losses **(ii)** Eddy currents losses

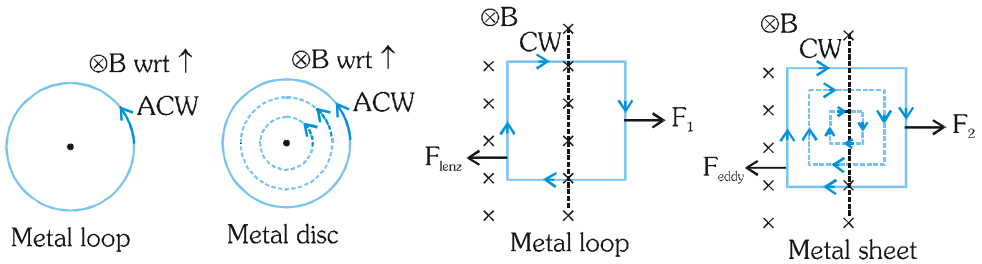
(i) Hysteresis losses

Cause : Transformer core always present in the effect of alternating magnetic field ($B = B_0 \sin\omega t$) so it will magnetised & demagnetised with very high frequeny (f = 50 Hz).During its demagnetization a part of magnetic energy left inside core part in form of residual magnetic field. Finally this residual energy waste as heat.

Remmady : To minimise these losses material of transformer core should be such that it can be easily magnetised & demagnetised. For this purpose soft ferromagnetic material should be used. For **Ex.** soft iron (low retentivity and low coercivity)

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Eddy Currents (or Focalt's currents)



$(F_1 <<< F_2)$

(i) Eddy currents are basically the induced currents set up inside the body of conductor whenever the magnetic flux linked with it changes.

(ii) Eddy currents tend to follow the path of least resistance inside a conductor. So they from irregularly shaped loops. However, their directions are not random, but guided by Lenz's law.

(iii) Eddy currents have both undesirable effects and practically useful applications.

Applications of eddy currents

(i)	Induction furnace	**(ii)**	Electromagnetic damping
(iii)	Electric brakes	**(iv)**	Speedometers
(v)	Induction motor	**(vi)**	Electromagnetic shielding
(vii)	Inductothermy	**(viii)**	Energy meters

(i) These currents are produced only in closed path within the entire volume and on the surface of metal body. Therefore their measurement is impossible.

(ii) Circulation plane of these currents is always perpendicular to the external field direction.

(iii) Generally resistance of metal bodies is low so magnitude of these currents is very high.

(iv) These currents heat up the metal body and some time body will melt out (Application : Induction furnace)

(v) Due to these induced currents a strong eddy force (or torque) acts on metal body which always apposes the translatory (or rotatory) motion of metal body, according to lenz.

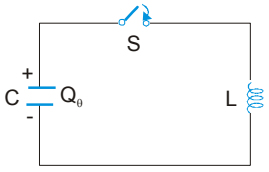
(vi) **Transformer**

Cause : Transformer core is always present in the effect of alternating magnetic field ($B = B_0 \sin\omega t$). Due to this eddy currents are produced in its volume, so a part of magnetic energy of core is wasted as heat.

Remmady : To minimise these losses transformer core should be laminated. with the help of lamination process, circulation path of eddy current is greatly reduced & net resistance of system is greatly increased. So these currents become

LC Oscillations

Consider an LC circuit in which a capacitor is connected to an inductor, as shown in Figure.



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Suppose the capacitor initially has charge Q_q . When the switch is closed, the capacitor begins to discharge and the electric energy is decreased. On the other hand, the current created from the discharging process generates magnetic energy which then gets stored in the inductor. In the absence of resistance, the total energy is transformed back and forthe between the electric energy in the capacitor and the magnetic energy in the inductor. This phenomenon is called electromagnetic oscillation.

The total energy in the LC circuit at some instant after closing the switch is

$$U = U_C + U_L = \frac{1}{2}\frac{Q^2}{C} + \frac{1}{2}LI^2$$

The fact that U remains constant implies that

$$\frac{dU}{dt} = \frac{d}{dt}\left(\frac{1}{2}\frac{Q^2}{C} + \frac{1}{2}LI^2\right) = \frac{Q}{C}\frac{dQ}{dt} + LI\frac{dI}{dt} = 0$$

$$\frac{Q}{C} + L\frac{d^2Q}{dt^2} = 0$$

where $$I = -\frac{dQ}{dt}$$

and $$\frac{dI}{dt} = -\frac{d^2Q}{dt^2}$$

Notice the sign convention we have adopted here. The negative sign implies that the current I is equal to the rate of decrease of charge in the capacitor plate immediately after the switch has been closed.

The general solution to equation is

$$Q = Q_0 \cos(\omega_0 t + \phi)$$

Where Q_0 is the amplitude of the charge and ϕ is the phase. The angular frequency ω_0 is given by

$$\omega_0 = -\frac{1}{\sqrt{LC}}$$

The corresponding current in the inductor is

$$I = -\frac{dQ}{dt} = \omega_0 Q_0 \sin\ (\omega_0 t + \phi) = I_0 \sin(\omega_0 t + \phi)$$

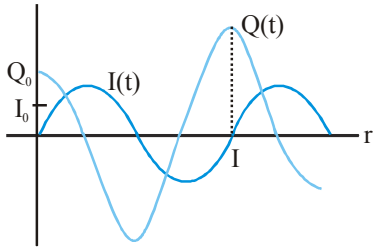
where $I_0 = \omega_0 Q_0$

From the initial conditions Q (at t = 0) = Q_0 and I (at t = 0) = 0, the phase ϕ can be determined $\phi = 0$. Thus, the solutions for the charge and the current in our LC circuit are

$$Q(t) = Q_0 \cos \omega_0 t$$

and $$I(t) = I_0 \sin \omega_0 t$$

The time dependence of Q(t) and I(t) are depicted in figure.



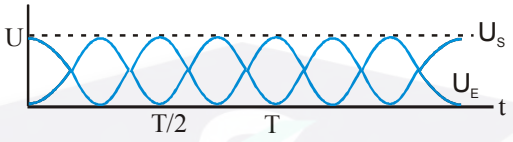
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Using eqs., we see that at any instant of time, the electric energy and the magnetic energies are given by

$$U_E = \frac{Q^2(t)}{2C} = \left(\frac{Q_0^2}{2C}\right)\cos^2 \omega_0 t$$

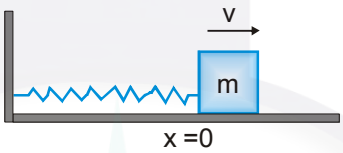
and $$U_B = \frac{1}{2}LI^2(t) = \frac{LI_0^2}{2}\sin^2 \omega t = \frac{L(-\omega_0 Q_0)^2}{2}\sin^2 \omega_0 t = \left(\frac{Q_0^2}{2C}\right)\sin^2 \omega_0 t$$

The electric and magnetic energy oscillation is illustrated in figure.



Mechanical analogy

The mechanical analog of the LC oscillations is the mass-spring system, shown in Figure.



If the mass is moving with a speed v and the spring having a spring constant k is displaced from its equilibrium by x, then the total energy of this mechanical system is

$$U = K + U_{sp} = \frac{1}{2}mv^2 + \frac{1}{2}kx^2$$

where K and U_{sp} are the kinetic energy of the mass and the potential energy of the spring, respectively.
In the absence of friction, U is conserved and we obtain

$$\frac{dU}{dt} = \frac{d}{dt}\left(\frac{1}{2}mv^2 + \frac{1}{2}kx^2\right) = mv\frac{dv}{dt} + kx\frac{dx}{dt} = 0$$

Using $$v = \frac{dx}{dt}$$ and $$\frac{dv}{dt} = \frac{d^2x}{dt^2}$$

the above equation may be rewritten as

$$m\frac{d^2x}{dt^2} + kx = 0$$

The general solution for the displacement is

$$x = x_0 \cos(\omega_0 t + \phi)$$

where $$\omega_0 = \sqrt{\frac{k}{m}}$$

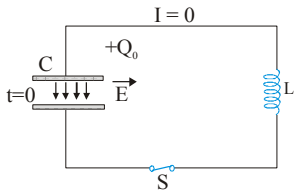
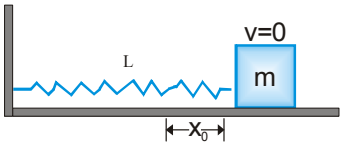
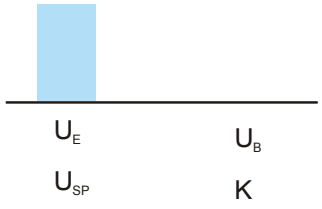
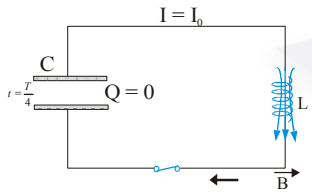
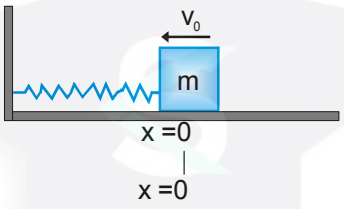
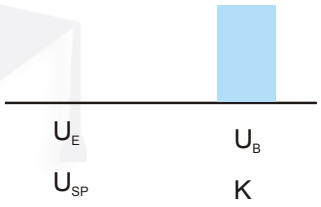
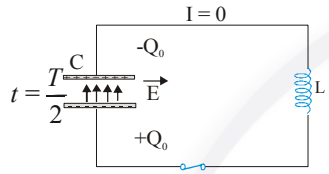
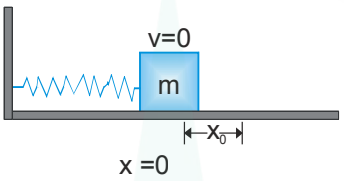
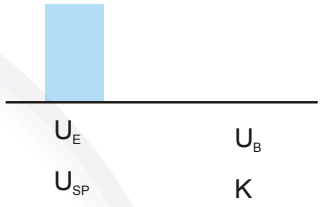
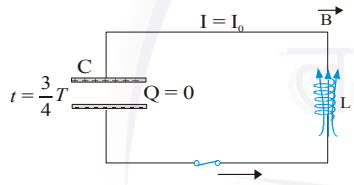
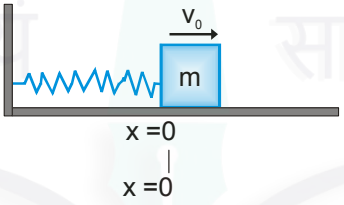
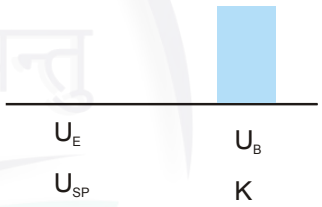
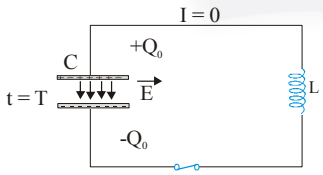
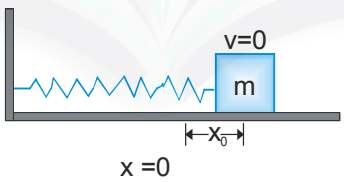
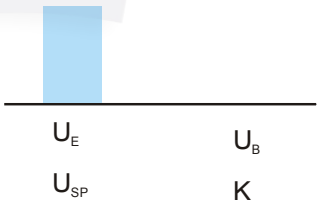
is the angular frequency and x_0 is the amplitude of the oscillations. Thus, at any instant in time, the energy of the system may be written as

$$U = \frac{1}{2}mx_0^2\omega_0^2 \sin^2(\omega_0 t + \phi) + \frac{1}{2}kx_0^2 \cos^2(\omega_0 t + \phi)$$

$$= \frac{1}{2}kx_0^2[\sin^2(\omega_0 t + \phi) + \cos^2(\omega_0 t + \phi) = \frac{1}{2}kx_0^2$$

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In figure we illustrate the energy oscillations in the LC circuit and the mass spring system (harmonic oscillator).

Lc Circuit	Mass spring System	Energy
		
		
		
		
		

Ex. An inductor of inductance 2mH is connected across a charged capacitor of 5μE. Let q denote the instantaneous charge on the capacitor, and i the current in the circuit. Maximum value of q is Q = 200 μC.

(a) When q = 100 μC, what is the value of |di/dt| ?

(b) When q = 200 μC, what is the value of i ?

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Sol. **(a)** Charge stored in the capacitor oscillates simple harmonically as

$Q = Q_0 \sin(\omega t - \phi)$ and

$$U = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{(2\times10^{-3}\,H)(5.0\times10^{-6}\,F)}} = 10^4\,s^{-1}$$

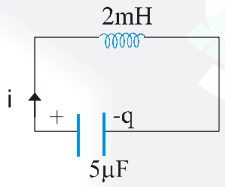
At t = 0, if $Q = Q_0$, then

$Q(t) = Q_0 \cos \omega t$ and if $Q = Q_0/2$, then $\cos \omega t = 1/2$

$$\frac{di(t)}{dt} = -Q_0\omega^2\cos(\omega t) = (200\times10^{-6})(10^4\,s^{-1})\left(\frac{1}{2}\right) = 10^4\,A/s$$

(b) When the energy of the capacitor is maximum, the energy stored in the inductor will be zero.

i.e. $\frac{1}{2}Li^2 = 0 \Rightarrow i = 0$



Ex. A capacitor of capacitance 2 μF is charged to a potential difference of 12 V. It is then connected across an indicator of inductance 0.6 mH. What is the current in the circuit at a time when the potential difference across the capacitor is 6.0 V ?

Sol. As the capacitor is discharged to a potential difference of 12 V, the initial charge on the capacitor is

$q_0 = CV_0 = 2 \times 10^6 \times 12$ C .....**(1)**

At any instant as the capacitor discharges through the inductor (LC circuit), the instantaneous charge on the capacitor is given by

$q = q_0 \cos \omega t$ .....**(2)** (because at t = 0, $q = q_0$)

But $q = CV$ .....**(3)**

where V is the potential difference at the instant 't'.

From **(1)** and **(3)** we obtain $\frac{q}{q_0} = \frac{V}{V_0}$

Putting the value of V and V_0 we obtain

$$\frac{q}{q_0} = \frac{1}{2} \Rightarrow \cos\omega t = \frac{1}{2} \Rightarrow \omega t = \cos^{-1}\left(\frac{1}{2}\right)$$

$\Rightarrow$ $\omega t = /3$ rad .....**(4)**

Here $\omega = \frac{1}{\sqrt{LC}} = \frac{1}{[0.6\times10^{-3}\times10^{-4}]}$

$\Rightarrow$ $\omega = \frac{10^5}{2\sqrt{3}}\,rad/\sec.$ .....**(5)**

The current through the circuit at that instant is given by

$$i = \frac{d}{dt}[q_0\cos\omega t] \Rightarrow i = -q_0\,\omega\sin\omega t$$

Putting the value of q_0 from **(1)**, ω from **(5)** and ωt from **(4)** we obtain

$$|i| = 2\times10^7\times12\times\frac{10^3}{2\sqrt{3}}\sin(\pi/3) = 0.6\,\text{A}$$

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TIPS& FOMULAS

1. Magnetic Flux :

$\phi = \vec{B}.\vec{A} = BA\cos\theta$ for uniform $\vec{B}$.

$\phi = \int \vec{B}.d\vec{A}$ = for non uniform $\vec{B}$.

2. FARADAY'S Laws of Electromagnetic Induction :

(a) An induced emf is setup whenever the magnetic flux linking that circuit changes.

(b) The magnitude of the induced emf in any circuit is proportional to the rate of change of the magnetic flux linking the circuit, $\varepsilon \propto \frac{d\varphi}{dt}$.

3. Lenz's Laws :

The direction of an induced emf is always such as to oppose the cause producing it.

4. Law of EMI : $e = -\frac{d\varphi}{dt}$

The negative sign indicates that the induced emf oppose the change of the flux.

5. EMF Induced in a Straight Conductor in Uniform Magnetic Field :

$E = BLv\sin\theta$

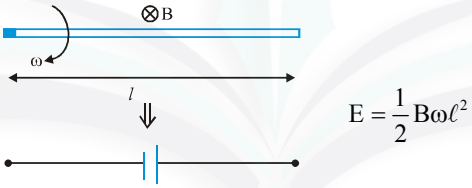
where B = flux density

L = length of the conductor

v = velocity of the conductor

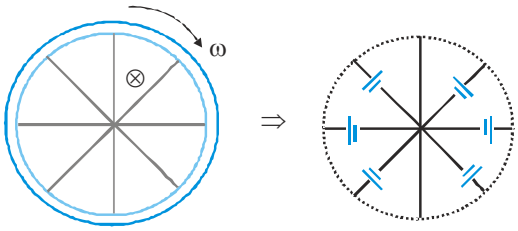
θ = angle between direction of motion of conductor & B.

6. EMF Induced in a Rod Rotating Perpendicular to Magnetic Field



$E = \frac{1}{2}B\omega\ell^2$

For a wheel rotating in a earth magnetic field effective emf induced between the periphery & centre = $\frac{1}{2}B\omega\ell^2$



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7. Coil Rotation in Magnetic Field such that Axis of Rotation is Perpendicular to the Magnetic Field:

Instantaneous induced emf. $E = NAB\omega \sin \omega t = E_0 \sin \omega t$

where N = number of turns in the coil

A = area of one turn B = magnetic induction

ω = uniform angular velocity of the coil E_0 = maximum induced emf

8. Self Induction & Self Inductance :

When a current flowing through a coil is changed the flux linking flux with the coil its own winding changes & due to the change in linking flux with the coil an emf is induced which is known as self induced emf & this phenomenon is known as self induction. This induced emf opposes the causes of induction. The property of the coil or the circuit due to which it opposes any change of the current coil or the circuit is known as **Self-Inductance.** Its unit is Henry.

Coefficient of self inductance $L = \frac{\varphi_s}{i}$ or $\phi_s = Li$

i = current in the circuit

ϕ_s = magnetic flux linked with the circuit due to the current i.

L depends only on ; **(i)** shape of the loop **(ii)** medium

self induced emf $e_s = \frac{d\varphi_s}{dt} = -\frac{d}{dt}(Li) = -L\frac{di}{dt}$ (if L is constant)

9. Combination of inductors

Series combination $L = L_1 + L_2 + ...$, i same, V in ratio of inductance, U in ratio of inductance, ϕ in ratio of inductance

Parallel combination $\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + ...$, V same, i in inverse ratio of inductance, U in inverse ratio of inductance, ϕ same

10. Mutual Induction :

If two electric circuits are such that the magnetic field due to a current in one is partly or wholly linked with the other, the two coils are said to be electromagnetically coupled circuits. Then any change of current in one produces a change of magnetic flux in the other & the later opposes the change by inducing an emf within itself. This phenomenon is called **MUTUAL INDUCTION** & the induced emf in the later circuit due to a change of current in the former is called **MUTUALLY INDUCED EMF.** The circuit in which the current is changed is called the primary & the other circuit in which the emf is induced is called the secondary. The Co-efficient of mutual induction (mutual inductance) between two electromagnetically coupled circuit is the magnetic flux linked with the secondary per unit current in the primary.

Mutual inducatnce = $M = \frac{\varphi_m}{I_p} = \frac{\text{flux linked with secondary}}{\text{current in the primary}}$

mutually induced emf : $E_m = \frac{d\varphi_m}{dt} = -\frac{d}{dt}(MI) = -M\frac{dI}{dt}$ (If M is constant)

M depends on **(1)** geometry of loops **(2)** medium **(3)** orientation & distance of loops.

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If two coils of self inductance L_1 and L_2 are wound over each other, the mutual inductance $M = K\sqrt{L_1L_2}$ where K is called coupling constant.

For two coils wound in same direction and connected in series

$L = L_1 + L_2 + 2M$

For two coils wound in opposite direction and connected in series

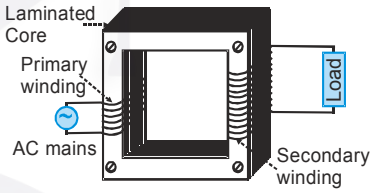
$L = L_1 + L_2 - 2M$

For two coils in parallel $L = \dfrac{L_1L_2 - M^2}{L_1 + L_2 \pm 2M}$

11. Transformer

(a) For ideal transformer $\dfrac{E_2}{E_1} = \dfrac{I_1}{I_2} = \dfrac{N_2}{N_1}$

(b) Efficiency $\eta = \dfrac{P_{out}}{P_{in}} \times 100\ \%$



12. SOLENOID

There is a uniform magnetic field along the axis of the solenoid

$B = \mu ni$ (ideal : length >> diameter)

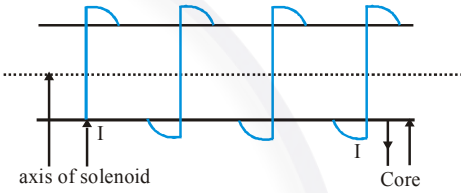
where m = magnetic permeability of the core material

n = number of turns in the solenoid per unit length

i = current in the solenoid

Self inductance of a solenoid $L = \mu_0 n^2 AI$

A = area of cross section of solenoid.



13. Super Conduction Loop in Magnetic Field :

$R = 0$; $\varepsilon = 0$. Therefore ϕ_{total} = constant. Thus in a superconducting loop flux never changes. (or it opposes 100 %)

14. Energy Stored in an Inductor : $W = \dfrac{1}{2}LI^2$

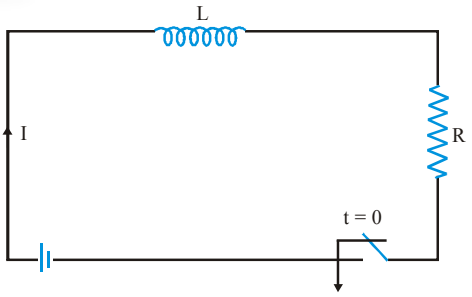
15. Energy of interaction of two loops $U = I_1\phi_2 = I_2\phi_1 = MI_1I_2$ where M is mutual inductance

16. Growth of a Current in an L - R Circuit :

$I = \dfrac{E}{R}\left(1 - e^{-Rt/L}\right)$. [If initial current = 0]

$\dfrac{L}{R}$ = time constant of the circuit.

$I_0 = \dfrac{E}{R}$.



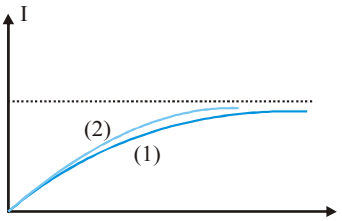
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(a) L behaves as open circuit at t = 0 [If $i = 0$]

(b) L behaves as short circuit at t = ∞ always.

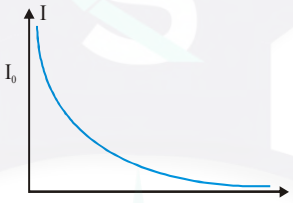
Curve (1) $\rightarrow \frac{L}{R}$ Large

Curve (2) $\rightarrow \frac{L}{R}$ Small



17. Decay of Current :

Initial current through the inductor = I_0 ; Current at any instant $i = I_0 e^{-Rt/L}$



18. An emf is induced in a closed loop where magnetic flux is varied. The induced electric field is not conservative field because for induced electric field, the line integral $\oint \vec{E}.d\vec{\ell}$ around a closed path is non- zero.

19. Acceleration of a magnet falling through a long solenoid decrease because the induced current produced in a circuit always flows in such direction that it opposes the change or the cause that produces it.

20. The mutual inductance of two coils is doubled if the self inductance of the primary and secondary coil is doubled because mutual inductance $M \propto \sqrt{L_1 L_2}$.

21. The possibility of an electric bulb fusing is higher at the time of switching ON and OFF because inductive effects produce a surge at the time of switch-off and switch-on.

22. Motional emf : If a conductor is moved in a magnetic field then motional emf will be $E = B \ell_{eff} v$

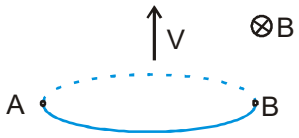
Here $v \perp \ell_{eff}$ & $v \perp B$ & $B \perp \ell_{eff}$

$\ell_{eff} \rightarrow$ effective length between the end points of conductor which is perpendicular to the velocity.

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SOLVED EXAMPLE

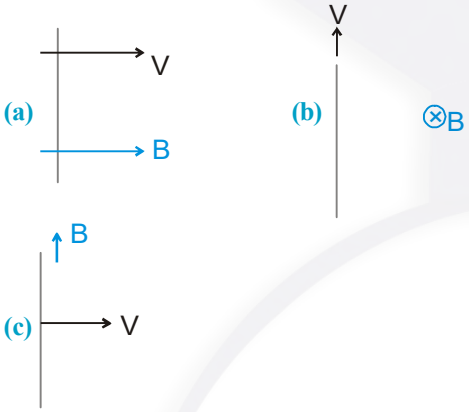
Ex. 1 A circular coil of radius R is moving in a magnetic field **B** with a velocity **v** as shown in the figure.



Find the emf across the diametrically opposite points A and B.

Sol. $\text{emf} = BVl_{\text{effective}} = 2RvB$

Ex. 2 Find the emf induced in the rod in the following cases. The figures are self explanatory.



Sol. **(a)** here $\vec{v} \parallel \vec{B}$ So $\vec{v} \times \vec{B} = 0$

$\text{emf} = \vec{\ell} \cdot (\vec{v} \times \vec{B}) = 0$

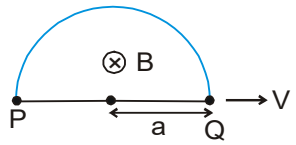
(b) here $\vec{v} \parallel \vec{\ell}$

So $\text{emf} = \vec{\ell} \cdot (\vec{v} \times \vec{B}) = 0$

(c) here $\vec{B} \parallel \vec{\ell}$

So $\text{emf} = \vec{\ell} \cdot (\vec{v} \times \vec{B}) = 0$

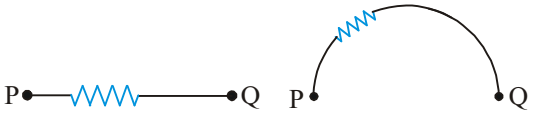
Ex. 3 Find the emf across the points P and Q which are diametrically opposite points of a semicircular closed loop moving in a magnetic field as shown.Also draw the electrical equivalent circuit of each branch.



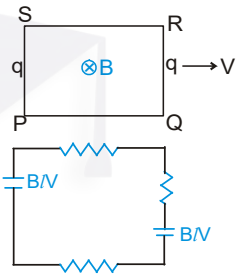
Sol. Here $\vec{v} \parallel \vec{\ell}$

So $\text{emf} = \vec{\ell} \cdot (\vec{v} \times \vec{B}) = 0$

Induced emf = 0

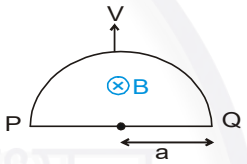


Ex. 4 Figure shows a rectangular loop moving in a uniform magnetic field .Show the electrical equivalence of each branch.

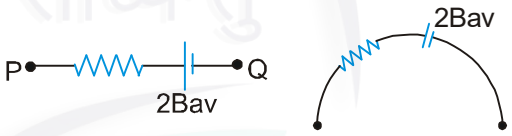


Sol.

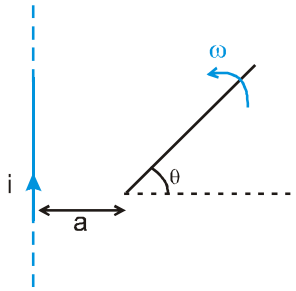
Ex. 5 Find the emf across the points P and Q which are diametrically opposite points of a semicircular closed loop moving in a magnetic field as shown. Also draw the electrical equivalence of each branch.



Sol. Induced emf = 2Bav



Ex. 6 A rod of length l is rotating with an angular speed ω about its one end which is at a distance 'a' from an infinitely long wire carrying current i. Find the emf induced in the rod at the instant shown in the figure.



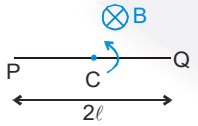
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Sol. $E = \int \frac{\mu_0 i}{2\pi(a + r\cos\theta)} \times (r\omega) \cdot (dr)$

$\Rightarrow \quad E = \frac{\mu_0 \omega i}{2\pi} \int_0^{\ell} \frac{r}{a + r\cos\theta}\, dr$

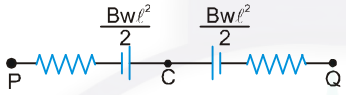
$E = \frac{\mu_0 i\omega}{2\pi\cos\theta}\left[\ell - \frac{a}{\cos\theta}\ell n\left(\frac{a + \ell\cos\theta}{a}\right)\right]$

Ex. 7 A rod PQ of length 2ℓ is rotating about its mid point C, in a uniform magnetic field B which is perpendicular to the plane of rotation of the rod. Find the induced emf between P Q and PC. Draw the circuit diagram of parts PC and CQ.

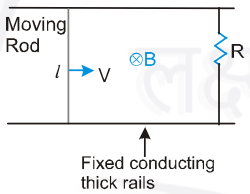


Sol. $emf_{PQ} = 0$;

$emf_{PC} = \frac{B\omega\ell^2}{2}$



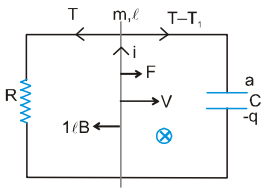
Ex. 8 Figure shows a rod of length ℓ and resistance r moving on two rails shorted by a resistance R.A uniform magnetic field B is present normal to the plane of rod and rails .Show the electrical equivalence of each branch.



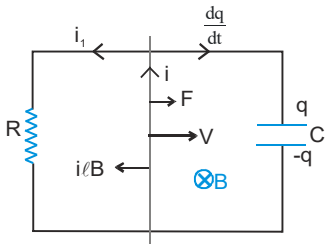
Sol.



Ex. 9 Find the velocity of the moving rod at time t if the initial velocity of the rod is v and a constant force F is applied on the rod. Neglect the resistance of the rod.



Sol. At any time t, let the velocity of the rod be v .



Applying Newtons law: $F - ilB = ma$ ... **(1)**

Also $B\ell v = i_1 R = \frac{q}{c}$

Applying Kcl,

$i = i_1 + \frac{dq}{dt} = \frac{B\ell V}{R} + \frac{d}{dt}(B\ell vC)$ or

$i = \frac{B\ell V}{R} + B\ell C\, a$

Putting the value of i in eq **(1)**,

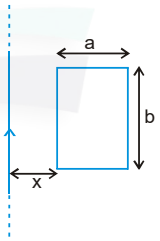
$F - \frac{B^2\ell^2 V}{R} = (m + B^2\ell^2 C)a = (m + B^2\ell^2 C)\frac{dv}{dt}$

$(m + B^2\ell^2 C)\frac{dv}{F - \frac{B^2\ell^2 v}{R}} = dt$

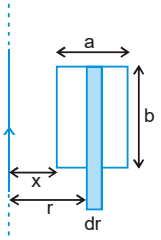
Integrating both sides, and solving we get

$v = \frac{FR}{B^2\ell^2}\left(1 - e^{-\frac{tB^2\ell^2}{R(m + CB^2\ell^2)}}\right)$

Ex. 10 Find the mutual inductance of a straight long wire and a rectangular loop, as shown in the figure



Sol.



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$$d\phi = \frac{\mu_0 i}{2\pi r} \times bdr \Rightarrow \phi = \int_x^{x+a} \frac{\mu_0 i}{2\pi r} \times bdr$$

$$M = \phi/i \Rightarrow M = \frac{\mu_0 b}{2\pi} \ln\left(1+\frac{a}{x}\right)$$

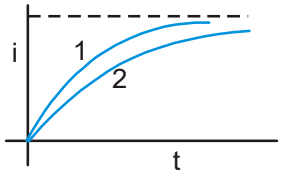
Ex. 11 A rod PQ of length ℓ is rotating about end P, with an angular velocity ω . Due to centrifugal forces the free electrons in the rod move towards the end Q and an emf is created. Find the induced emf.



Sol. The accumulation of free electrons will create an electric field which will finally balance the centrifugal forces and a steady state will be reached. In the steady state $m_e\omega^2 x = e\,E$.

$$V_P - V_Q = \int_{x=0}^{x=\ell} \bar{E}.d\bar{x} = \int_0^{\ell} \frac{m_e\omega^2 x}{e} dx = \frac{m_e\omega^2\ell^2}{2e}$$

Ex. 12 Which of the two curves shown has less time constant.



Sol. curve 1

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Exercise # 1 SINGLE OBJECTIVE NEET LEVEL

1. In electromagnetic induction, the induced e.m.f. in a coil is independent of

(A) Change in the flux

(B) Time

(C) Resistance of the circuit

(D) None of the above

2. Lenz's law is consequence of the law of conservation of

(A) Charge **(B)** Momentum

(C) Mass **(D)** Energy

3. In electromagnetic induction, the induced charge in a coil is independent of

(A) Change in the flux

(B) Time

(C) Resistance in the circuit

(D) None of the above

4. The magnetic flux through a circuit of resistance R changes by an amount $\Delta\phi$ in time Δt, Then the total quantity of electric charge Q, which passing during this time through any point of the circuit is given by

(A) $Q = \frac{\Delta\phi}{\Delta t}$ **(B)** $Q = \frac{\Delta\phi}{\Delta t} \times R$

(C) $Q = -\frac{\Delta\phi}{\Delta t} + R$ **(D)** $Q = \frac{\Delta\phi}{R}$

5. A cylindrical bar magnet is kept along the axis of a circular coil. If the magnet is rotated about its axis, then

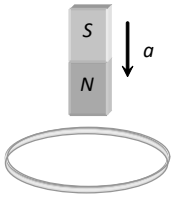
(A) A current will be induced in a coil

(B) No current will be induced in a coil

(C) Only an e.m.f. will be induced in the coil

(D) An e.m.f. and a current both will be induced in the coil

6. A metallic ring is attached with the wall of a room. When the north pole of a magnet is brought near to it, the induced current in the ring will be



(A) First clockwise then anticlockwise

(B) In clockwise direction

(C) In anticlockwise direction

(D) First anticlockwise then clockwise

7. A coil having an area A_0 is placed in a magnetic field which changes from B_0 to $4B_0$ in a time interval t. The e.m.f. induced in the coil will be

(A) $\frac{3A_0B_0}{t}$ **(B)** $\frac{4A_0B_0}{t}$

(C) $\frac{3B_0}{A_0t}$ **(D)** $\frac{4B_0}{A_0t}$

8. The magnetic flux linked with a coil is given by an equation ϕ (in *webers*) $= 8t^2 + 3t + 5$. The induced e.m.f. in the coil at the fourth second will be

(A) 16 *units* **(B)** 39 *units*

(C) 67 *units* **(D)** 145 *units*

9. The current flowing in two coaxial coils in the same direction. On increasing the distance between the two, the electric current will

(A) Increase

(B) Decrease

(C) Remain unchanged

(D) The information is incomplete

10. A copper ring is held horizontally and a bar magnet is dropped through the ring with its length along the axis of the ring. The acceleration of the falling magnet while it is passing through the ring is

(A) Equal to that due to gravity

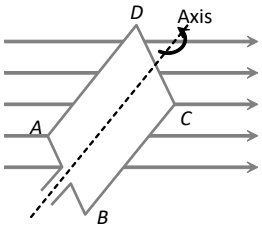
(B) Less than that due to gravity

(C) More than that due to gravity

(D) Depends on the diameter of the ring and the length of the magnet

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11. A rectangular coil ABCD is rotated anticlockwise with a uniform angular velocity about the axis shown in diagram below. The axis of rotation of the coil as well as the magnetic field B are horizontal. The induced e.m.f. in the coil would be maximum when



(A) The plane of the coil is horizontal

(B) The plane of the coil makes an angle of 45° with the magnetic field

(C) The plane of the coil is at right angles to the magnetic field

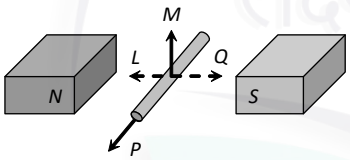
(D) The plane of the coil makes an angle of 30° with the magnetic field

12. A 10 *metre* wire kept in east-west falling with velocity 5 *m/sec* perpendicular to the field $0.3\times10^{-4}\,Wb/m^2$. The induced e.m.f. across the terminal will be

(A) 0.15 V **(B)** 1.5 mV

(C) 1.5 V **(D)** 15.0 V

13. An electric potential difference will be induced between the ends of the conductor shown in the diagram, when the conductor moves in the direction



(A) P **(B)** Q

(C) L **(D)** M

14. Two rails of a railway track insulated from each other and the ground are connected to a milli voltmeter. What is the reading of voltmeter, when a train travels with a speed of 180 *km/hr* along the track. Given that the vertical component of earth's magnetic field is $0.2\times10^{-4}\,weber/m^2$ and the rails are separated by 1 *metre*

(A) $10^{-2}\,volt$ **(B)** $10^{-4}\,volt$

(C) $10^{-3}\,volt$ **(D)** 1 *volt*

15. A conductor of 3 m in length is moving perpendicularly to magnetic field of 10^{-3} *tesla* with the speed of $10^{2}\,m/s$, then the e.m.f. produced across the ends of conductor will be

(A) 0.03 *volt* **(B)** 0.3 *volt*

(C) $3\times10^{-3}\,volt$ **(D)** 3 *volt*

16. When a wire loop is rotated in a magnetic field, the direction of induced e.m.f. changes once in each

(A) $\frac{1}{4}$ revolution **(B)** $\frac{1}{2}$ revolution

(C) 1 revolution **(D)** 2 revolution

17. An aeroplane in which the distance between the tips of wings is 50 m is flying horizontally with a speed of 360 *km/hr* over a place where the vertical components of earth magnetic field is $2.0\times10^{-4}\,weber/m^2$. The potential difference between the tips of wings would be

(A) 0.1 V **(B)** 1.0 V

(C) 0.2 V **(D)** 0.01 V

18. A copper disc of radius 0.1 m is rotated about its centre with 10 revolutions per second in a uniform magnetic field of 0.1 *Tesla* with its plane perpendicular to the field. The e.m.f. induced across the radius of disc is

(A) $\frac{\pi}{10}\,V$ **(B)** $\frac{2\pi}{10}\,V$

(C) $\pi\times10^{-2}\,V$ **(D)** $2\pi\times10^{-2}\,V$

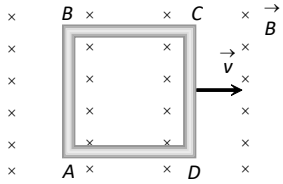
19. A metal conductor of length 1m rotates vertically about one of its ends at angular velocity 5 *radians per second*. If the horizontal component of earth's magnetic field is $0.2\times10^{-4}\,T$, then the e.m.f. developed between the two ends of the conductor is

(A) 5 mV **(B)** $5\times10^{-4}\,V$

(C) 50 mV **(D)** 50 μV

20. A conducting square loop of side L and resistance R moves in its plane with a uniform velocity v perpendicular to one of its sides. A magnetic induction B constant in time and space, pointing perpendicular and into the plane of the loop exists everywhere. The current induced in the loop is

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(A) $\frac{Blv}{R}$ clockwise (B) $\frac{Blv}{R}$ anticlockwise

(C) $\frac{2Blv}{R}$ anticlockwise (D) Zero

21. A player with 3 *m* long iron rod runs towards east with a speed of 30 *km/hr*. Horizontal component of earth's magnetic field is $4\times10^{-5}\ Wb/m^2$. If he is running with rod in horizontal and vertical positions, then the potential difference induced between the two ends of the rod in two cases will be

(A) Zero in vertical position and $1\times10^{-3}\ V$ in horizontal position

(B) 1×10^{-3} V in vertical position and zero is horizontal position

(C) Zero in both cases

(D) 1×10^{-3} V in both cases

22. A coil of area 80 *square cm* and 50 turns is rotating with 2000 *revolutions per minute* about an axis perpendicular to a magnetic field of 0.05 *Tesla*. The maximum value of the e.m.f. developed in it is

(A) 200π volt (B) $\frac{10\pi}{3}$ volt

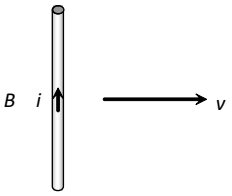
(C) $\frac{4\pi}{3}$ volt (D) *volt*

23. A conducting rod of length *l* is falling with a velocity *v* perpendicular to a uniform horizontal magnetic field *B*. The potential difference between its two ends will be

(A) $2Blv$ (B) Blv

(C) $\frac{1}{2}$Blv (D) $B^2l^2v^2$

24. A conducting wire is moving towards right in a magnetic field *B*. The direction of induced current in the wire is shown in the figure. The direction of magnetic field will be



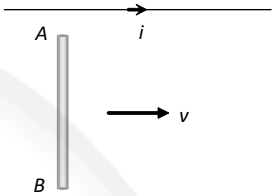
(A) In the plane of paper pointing towards right

(B) In the plane of paper pointing towards left

(C) Perpendicular to the plane of paper and down wards

(D) Perpendicular to the plane of paper and upwards

25. The current carrying wire and the rod *AB* are in the same plane. The rod moves parallel to the wire with a velocity *v*. Which one of the following statements is true about induced emf in the rod



(A) End *A* will be at lower potential with respect to *B*

(B) *A* and *B* will be at the same potential

(C) There will be no induced e.m.f. in the rod

(D) Potential at *A* will be higher than that at *B*

26. The back e.m.f. induced in a coil, when current changes from 1 ampere to zero in one *milli second*, is 4 *volts*, the self inductance of the coil is

(A) 1 *H* (B) 4 *H*

(C) 10^{-3} *H* (D) 4×10^{-3} *H*

27. An e.m.f. of 5 *volt* is produced by a self inductance, when the current changes at a steady rate from 3 *A* to 2 *A* in 1 millisecond. The value of self inductance is

(A) Zero (B) 5 *H*

(C) 5000 *H* (D) 5 *mH*

28. A 50 *mH* coil carries a current of 2 *ampere*. The energy stored in joules is

(A) 1 (B) 0.1

(C) 0.05 (D) 0.5

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29. The current passing through a choke coil of 5 henry is decreasing at the rate of 2 *ampere/sec*. The e.m.f. developing across the coil is

(A) 10 V **(B)** – 10 V

(C) 2.5 V **(D)** – 2.5 V

30. Average energy stored in a pure inductance L when a current i flows through it, is

(A) Li^2 **(B)** $2Li^2$

(C) $\frac{Li^2}{4}$ **(D)** $\frac{Li^2}{2}$

31. A solenoid has 2000 turns wound over a length of 0.30 *metre*. The area of its cross-section is $1.2 \times 10^{-3} m^2$. Around its central section, a coil of 300 turns is wound. If an initial current of 2 A in the solenoid is reversed in 0.25 *sec*, then the e.m.f. induced in the coil is

(A) $6 \times 10^{-4} V$ **(B)** $4.8 \times 10^{-3} V$

(C) $6 \times 10^{-2} V$ **(D)** 48 mV

32. A coil is wound as a transformer of rectangular cross-section. If all the linear dimensions of the transformer are increased by a factor 2 and the number of turns per unit length of the coil remain the same, the self inductance increased by a factor of

(A) 16 **(B)** 12

(C) 8 **(D)** 4

33. Two coils of self inductance L_1 and L_2 are placed closer to each other so that total flux in one coil is completely linked with other. If M is mutual inductance between them, then

(A) $M = L_1 L_2$ **(B)** $M = L_1 / L_2$

(C) $M = \sqrt{L_1 L_2}$ **(D)** $M = (L_1 L_2)^2$

34. The equivalent quantity of mass in electricity is

(A) Charge **(B)** Potential

(C) Inductance **(D)** Current

35. The momentum in mechanics is expressed as $m \times v$. The analogous expression in electricity is

(A) $I \times Q$ **(B)** $I \times V$

(C) $L \times I$ **(D)** $L \times Q$

36. In what form is the energy stored in an inductor or A coil of inductance L is carrying a steady current i. What is the nature of its stored energy

(A) Magnetic

(B) Electrical

(C) Both magnetic and electrical

(D) Heat

37. The coefficient of self inductance of a solenoid is 0.18 *mH*. If a crode of soft iron of relative permeability 900 is inserted, then the coefficient of self inductance will become nearly

(A) 5.4 *mH* **(B)** 162 *mH*

(C) 0.006 *mH* **(D)** 0.0002 *mH*

38. In a transformer, the coefficient of mutual inductance between the primary and the secondary coil is 0.2 *henry*. When the current changes by 5 *ampere/second* in the primary, the induced e.m.f. in the secondary will be

(A) 5 V **(B)** 1 V

(C) 25 V **(D)** 10 V

39. When the current in a coil changes from 8 *ampere* to 2 *ampere* in 3×10^{-2} *second*, the e.m.f. induced in the coil is 2 *volt*. The self inductance of the coil (in *millihenry*) is

(A) 1 **(B)** 5

(C) 20 **(D)** 10

40. The mutual inductance between two coils is 1.25 *henry*. If the current in the primary changes at the rate of 80 *ampere/second*, then the induced e.m.f. in the secondary is

(A) 12.5 V **(B)** 64.0 V

(C) 0.016 V **(D)** 100.0 V

41. Which of the following does not depend upon the magnetic effect of some sort

(A) Moving coil galvanometer

(B) Hot wire ammeter

(C) Dynamo

(D) Electric motor

42. Use of eddy currents is done in the following except

(A) Moving coil galvanometer

(B) Electric brakes

(C) Induction motor

(D) Dynamo

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43. Plane of eddy currents makes an angle with the plane of magnetic lines of force equal to

(A) 40° (B) 0°

(C) 90° (D) 180°

44. Which of the following is constructed on the principle of electromagnetic induction

(A) Galvanometer (B) Electric motor

(C) Generator (D) Voltmeter

45. A transformer is based on the principle of

(A) Mutual inductance (B) Self inductance

(C) Ampere's law (D) Lenz's law

46. Which of the following is not an application of eddy currents

(A) Induction furnace

(B) Galvanometer damping

(C) Speedometer of automobiles

(D) *X*-ray crystallography

47. The core of a transformer is laminated to reduce energy losses due to

(A) Eddy currents (B) Hysteresis

(C) Resistance in winding (D) None of these

48. The pointer of a dead-beat galvanometer gives a steady deflection because

(A) Eddy currents are produced in the conducting frame over which the coil is wound

(B) Its magnet is very strong

(C) Its pointer is very light

(D) Its frame is made of abonite

49. The device that does not work on the principle of mutual induction is

(A) Induction coil (B) Motor

(C) Tesla coil (D) Transformer

50. Eddy currents are produced when

(A) A metal is kept in varying magnetic field

(B) A metal is kept in the steady magnetic field

(C) A circular coil is placed in a magnetic field

(D) Through a circular coil, current is passed

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Exercise # 2 SINGLE OBJECTIVE AIIMS LEVEL

1. An inductor coil stores energy U when a current i is passed through it and dissipates heat energy at the rate of P. The time constant of the circuit when this coil is connected across a battery of zero internal resistance is :

(A) $\frac{4U}{P}$ **(B)** $\frac{U}{P}$

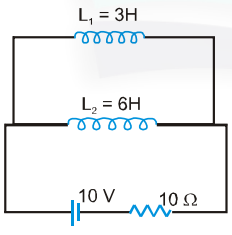
(C) $\frac{2U}{P}$ **(D)** $\frac{2P}{U}$

2. A metal rod of resistance 20 Ω is fixed along a diameter of conducting ring of radius 0.1 m and lies in x-y plane. There is a magnetic field $\vec{B} = (50T)\hat{k}$. The ring rotates with an angular velocity $\omega = 20$ rad/s about its axis. An external resistance of 10 Ω is connected across the centre of the ring and rim. The current through external resistance is

(A) $\frac{1}{4}$ A **(B)** $\frac{1}{2}$ A

(C) $\frac{1}{3}$ A **(D)** zero

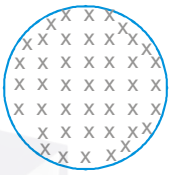
3. Two inductor coils of self inductance 3H and 6H respectively are connected with a resistance 10Ω and a battery 10 V as shown in figure. The ratio of total energy stored at steady state in the inductors to that of heat developed in resistance in 10 seconds at the steady state is(neglect mutual inductance between L_1 and L_2):



(A) $\frac{1}{10}$ **(B)** $\frac{1}{100}$

(C) $\frac{1}{1000}$ **(D)** 1

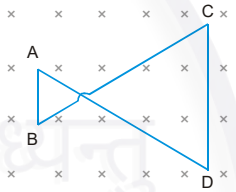
4. A non conducting ring of radius R and mass m having charge q uniformly distributed over its circumference is placed on a rough horizontal surface. A vertical time varying uniform magnetic field $B = 4t^2$ is switched on at time t=0. The coefficient of friction between the ring and the table, if the ring starts rotating at t =2 sec, is :



(A) $\frac{4qmR}{g}$ **(B)** $\frac{2qmR}{g}$

(C) $\frac{8qR}{mg}$ **(D)** $\frac{qR}{2mg}$

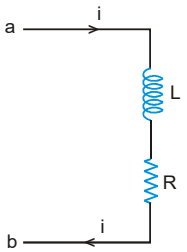
5. A conducting wire frame is placed in a magnetic field which is directed into the paper. The magnetic field is increasing at a constant rate. The directions of induced currents in wires AB and CD are :



(A) B to A and D to C **(B)** A to B and C to D

(C) A to B and D to C **(D)** B to A and C to D

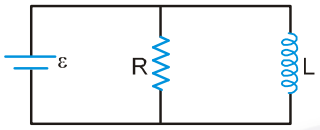
6. When the current in the portion of the circuit shown in the figure is 2A and increasing at the rate of 1 A/s, the measured potential difference $V_a - V_b = 8V$. However when the current is 2A and decreasing at the rate of 1A/s, the measured potential difference $V_a - V_b = 4V$. The values of R and L are :



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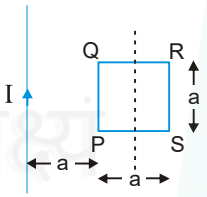
(A) 3 ohm and 2 Henry respectively
(B) 2 ohm and 3 Henry respectively
(C) 10 ohm and 6 Henry respectively
(D) 6 ohm and 1 Henry respectively

7. The battery shown in the figure is ideal. The values are $\varepsilon = 10\,V, R = 5\Omega, L = 2H$. Initially the current in the inductor is zero. The current through the battery at t = 2s is



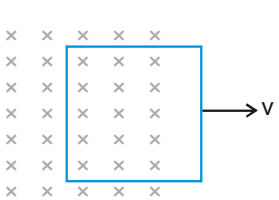
(A) 12 A **(B)** 7 A
(C) 3 A **(D)** none of these

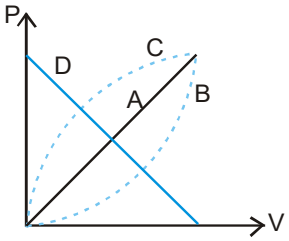
8. In the figure shown a square loop PQRS of side 'a' and resistance 'r' is placed near an infinitely long wire carrying a constant current I. The sides PQ and RS are parallel to the wire. The wire and the loop are in the same plane. The loop is rotated by 180° about an axis parallel to the long wire and passing through the mid points of the side QR and PS. The total amount of charge which passes through any point of the loop during rotation is :



(A) $\frac{\mu_0 Ia}{2\pi r}\ell n2$
(B) $\frac{\mu_0 Ia}{\pi r}\ell n2$
(C) $\frac{\mu_0 Ia^2}{2\pi r}$
(D) cannot be found because time of rotation not give.

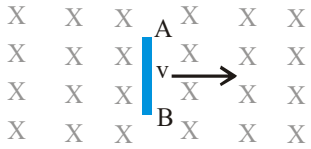
9. Fig. shows a conducting loop being pulled out of a magnetic field with a constant speed v. Which of the four plots shown in fig. may represent the power delivered by the pulling agent as a function of the constant speed v.





(A) A **(B)** B
(C) C **(D)** D

10. A conducting rod AB moves with a uniform velocity v in a constant magnetic field as shown in fig.

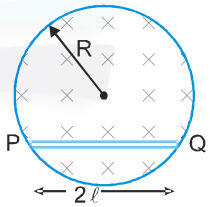


(A) The rod becomes hot because of Joule heating
(B) The end A becomes positively charged
(C) The end B become positively charged
(D) The rod becomes electrically charged

11. A conducting ring lies fixed on a horizontal plane. If a charged nonmagnetic particle is released from a point (on the axis) at some height from the plane, then :

(A) an induced current will flow in clockwise or anticlockwise direction in the loop depending upon the nature of the charge
(B) the acceleration of the particle will decrease as it comes down
(C) the rate of production of heat in the ring will increase as the particle comes down
(D) no heat will be produced in the ring.

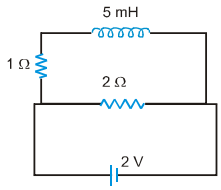
12. A uniform magnetic field, $B = B_0 t$ (where B_0 is a positive constant), fills a cylindrical volume of radius R, then the potential difference in the conducting rod PQ due to electrostatic field is :



(A) $B_0\ell\sqrt{R^2+\ell^2}$ **(B)** $B_0\ell\sqrt{R^2-\frac{\ell^2}{4}}$
(C) $B_0\ell\sqrt{R^2-\ell^2}$ **(D)** $B_0R\sqrt{R^2-\ell^2}$

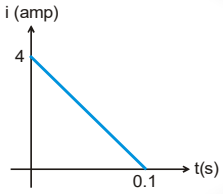
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13. When induced emf in inductor coil is 50% of its maximum value then stored energy in inductor coil in the given circuit will be : -



(A) 2.5 mJ **(B)** 5mJ
(C) 15 mJ **(D)** 20 mJ

14. Some magnetic flux is changed in a coil of resistance 10 ohm. As a result an induced current is developed in it, which varies with time as shown in figure. The magnitude of change in flux through the coil in Webers is (Neglect self inductance of the coil)

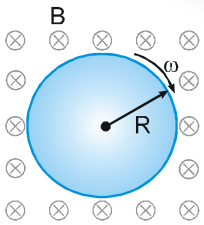


(A) 2 **(B)** 4
(C) 6 **(D)** 8

15. A bar magnet is released at one end from rest coaxially along the axis of a very long fixed, vertical copper tube. After some time the magnet
(A) will move with an acceleration g
(B) will move with almost constant speed
(C) will stop in the tube
(D) will oscillate

16. A conducting disc of radius R is placed in a uniform and constant magnetic field B parallel to the axis of the disc. With what angular speed should the disc be rotated about its axis such that no electric field develops in the disc.(the electronic charge and mass are e and m)

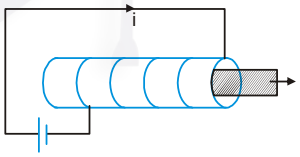
(A) $\frac{eB}{2m}$
(B) $\frac{eB}{m}$
(C) $\frac{2\pi m}{eB}$
(D) $\frac{\pi m}{eB}$



17. A closed circuit consists of a resistor R, inductor of inductance L and a source of emf E are connected in series. If the inductance of the coil is abruptly decreased to L/4 (by removing its magnetic core), the new current immediately after this moment is : (before decreasing the inductance the circuit is in steady state)

(A) zero **(B)** E/R
(C) $4\frac{E}{R}$ **(D)** $\frac{E}{4R}$

18. A solenoid having an iron core has its terminals connected across an ideal DC source and it is in steady state. If the iron core is removed, the current flowing through the solenoid just after removal of rod



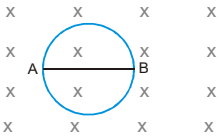
(A) increases
(B) decreases
(C) remains unchanged
(D) nothing can be said

19. When the current in a certain inductor coil is 5.0 A and is increasing at the rate of 10.0 A/s, the magnitude of potential difference across the coil is 140 V. When the current is 5.0 A and decreasing at the rate of 10.0 A/s, the potential difference is 60 V. The self inductance of the coil is :

(A) 2H **(B)** 4H
(C) 10H **(D)** 12H

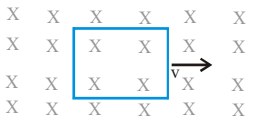
20. The radius of the circular conducting loop shown in figure is R. Magnetic field is decreasing at a constant rate α. Resistance per unit length of the loop is ρ. Then current in wire AB is (AB is one of the diameters)

(A) $\frac{R\alpha}{2\rho}$ from A to B
(B) $\frac{R\alpha}{2\rho}$ from B to A
(C) $\frac{2R\alpha}{\rho}$ from A to B
(D) Zero



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21. A square frame of wire of side l and resistance R moves in its plane with a uniform velocity v perpendicular to one of its sides. A uniform and constant magnetic field B exists along the perpendicular to the plane of the loop in fig. The current induced in the 3loop is -



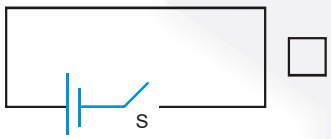
(A) 2Blυ/R anticlockwise

(B) Blυ/R anticlockwise

(C) Blυ/R clockise

(D) zero

22. Consider the conducting square loop shown in fig. If the switch is closed and after some time it is opened again, the closed loop will show



(A) a clockwise current-pulse

(B) an anticlockwise current-pulse

(C) an anticlockwise current-pulse and then a clockwise current-pulse

(D) a clockwise current-pulse and then an anticlockwise current-pulse

23. Solve the previous question if the square loop is completely enclosed in the circuit containing the switch.

(A) a clockwise current-pulse

(B) an anticlockwise current-pulse

(C) an anticlockwise current-pulse and then a clockwise current-pulse

(D) a clockwise current-pulse and then an anticlockwise current-pulse

24. A small, circular loop of wire is placed inside a long solenoid carrying a current. The plane of the loop contains the axis of the solenoid. If the current in the solenoid is varied, the current induced in the loop is

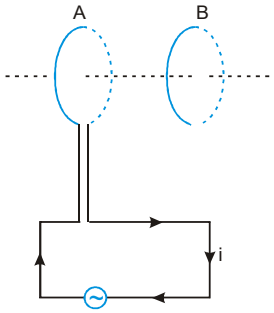
(A) anticlockwise

(B) clockwise

(C) zero

(D) clockwise or anticlockwise depending on whether the resistance in increased or decreased.

25. Two circular coils A and B are facing each other as shown in figure.



The current i through A can be altered

(A) there will be repulsion between A and B if i is increased

(B) there will be attraction between A and B if i is increased

(C) there will be neither attraction nor repulsion when i is changed

(D) attraction or repulsion between A and B depends on the direction of current.

It does not depend whether the current is increased or decreased.

26. A horizontal solenoid is connected to a battery and a switch (figure). A conducting ring is placed on a frictionless surface, the axis of the ring being along the axis of the solenoid. As the switch is closed, the ring will



(A) move towards the solenoid

(B) remain stationary

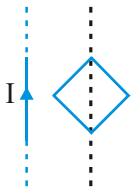
(C) move away from the solenoid

(D) move towards the solenoid or away from it depending on which terminal (positive or negative) of the battery is connected to the left end of the solenoid.

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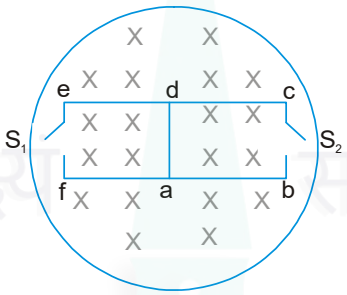
Exercise # 3 PART - 1 MATRIX MATCH COLUMN

1. A square loop of conducting wire is placed symmetrically near a long straight current carrying wire as shown. Match the statements in column-I with the corresponding results in column-II.



Column-I	Column-II
(A) If the magnitude of current I is increased	**(P)** Current will induce in clockwise direction in the loop
(B) If the magnitude of current I is decreased	**(Q)** Current will induce in anticlockwise direction in the loop
(C) If the loop is moved away from the wire	**(R)** wire will attract the loop
(D) If the loop is moved towards the wire	**(S)** wire will repel the loop
	(T) loop will rotate when current changes.

2. The magnetic field in the cylindrical region shown in figure increases at a constant rate of 10.0 mT/s Each side of the square loop abcd and defa has a length of 2.00 cm and resistance of 2.00 Ω . Correctly match the current in the wire 'ad' in four different situations as listed in column-I with the values given in column-II.



Column-I	Column-II
(A) the switch S_1 is closed but S_2 is open	**(P)** 5×10^{-7} A, d to a
(B) S_1 is open but S_2 is closed	**(Q)** 5×10^{-7} A, a to d
(C) both S_1 and S_2 are open	**(R)** 2.5×10^{-8} A, d to a
(D) both S_1 and S_2 are closed.	**(S)** 2.5×10^{-8} A, a to d
	(T) No current flows

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Exercise # 3 PART - 2 ASSERTION & REASONING

These questions contains, Statement I (assertion) and Statement II (reason).

(A) If both assertion and reason are true and the reason is the correct explanation of the assertion.

(B) If both assertion and reason are true but reason is not the correct explanation of the assertion.

(C) If assertion is true but reason is false.

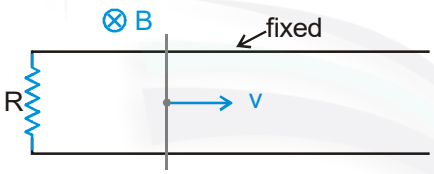
(D) If assertion is false but reason is true.

(E) If the assertion and reason both are false.

1. **Assertion :** Two coaxial conducting rings of different radii are placed in space. The mutual inductance of both the rings is maximum if the rings are coplanar also.

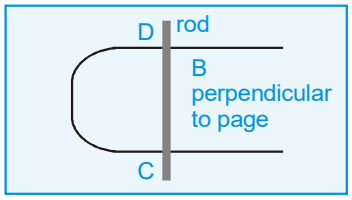
Reason : For two coaxial conducting rings of different radii, the magnitude of magnetic flux in one ring due to current in other ring is maximum when both rings are coplanar.

2. **Assertion :** A resistance R is connected between the two ends of the parallel smooth conducting rails. A conducting rod lies on these fixed horizontal rails and a uniform constant magnetic field B exists perpendicular to the plane of the rails as shown in the figure. If the rod is given a velocity v and released as shown in figure, it will stop after some time. The total work done by magnetic field is negative.



Reason : If force acts opposite to direction of velocity its work done is negative.

3. **Assertion :** Consider the arrangement shown below. A smooth conducting rod, CD, is lying on a smooth U-shaped conducting wire making good electrical contact with it. The U-shape conducting wire is fixed and lies in horizontal plane. There is a uniform and constant magnetic field B in vertical direction (perpendicular to plane of page in figure). If the magnetic field strength is decreased, the rod moves towards right.



Reason : In the situation of statement-1, the direction in which the rod will slide is that which tends to maintain constant flux through the loop. Providing a larger loop area counteracts the decrease in magnetic flux. So the rod moves to the right independent of the fact that the direction of magnetic field is into the page or out of the page.

4. **Assertion :** Eddy currents is produced in any metallic conductor when magnetic flux is changed around it.

Reason : Electric potential determines the flow of charge.

5. **Assertion :** The quantity L/R possesses dimensions of time.

Reason : To reduce the rate of increases of current through a solenoid should increase the time constant (L/R).

6. **Assertion :** Faraday's laws are consequences of conservation of energy.

Reason : In a purely resistive ac circuit, the current lags behind the e.m.f. in phase.

7. **Assertion :** Only a change in magnetic flux will maintain an induced current the coil.

Reason : The presence of large magnetic flux through a coil maintains a current in the coil if the circuit is continuous.

8. **Assertion :** Magnetic flux can produce induced e.m.f.

Reason : Faraday established induced e.m.f. experimentally.

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9. **Assertion :** The induced e.m.f. and current will be same in two identical loops of copper and aluminium, when rotated with same speed in the same magnetic field.

Reason : Induced e.m.f. is proportional to rate of change of magnetic field while induced current depends on resistance of wire.

10. **Assertion :** Inductance coil are made of copper.

Reason : Induced current is more in wire having less resistance.

11. **Assertion :** Self-inductance is called the inertia of electricity.

Reason : Self-inductance is the phenomenon, according to which an opposing induced e.m.f. is produced in a coil as a result of change in current or magnetic flux linked in the coil.

12. **Assertion :** When two coils are wound on each other, the mutual induction between the coils is maximum.

Reason : Mutual induction does not depend on the orientation of the coils.

13. **Assertion :** Acceleration of a magnet falling through a long solenoid decreases.

Reason : The induced current produced in a circuit always flow in such direction that it opposes the change or the cause the produced it.

14. **Assertion :** An aircraft flies along the meridian, the potential at the ends of its wings will be the same.

Reason : Whenever there is change in the magnetic flux e.m.f. induces.

15. **Assertion :** A spark occur between the poles of a switch when the switch is opened.

Reason : Current flowing in the conductor produces magnetic field.

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Exercise # 4 PART - 1 PREVIOUS YEAR (NEET/AIPMT)

1. In an inductor of self-inductance L = 2 mH, current changes with time according to relation $i = t^2 e^{-1}$. At what time emf is zero ?

(A) 4 s **(B)** 3 s
(C) 2 s **(D)** 1 s

2. The magnetic flux through a circuit of resistance R changes by an amount $\Delta\phi$ in a time Δt. Then the total quantity of electric charge q that passes any point in the circuit during the time Δt is represented by

(A) $q = \frac{1}{R} \cdot \frac{\Delta\phi}{\Delta t}$ **(B)** $q = \frac{\Delta\phi}{R}$
(C) $q = \frac{\Delta\phi}{\Delta t}$ **(D)** $q = R \cdot \frac{\Delta\phi}{\Delta t}$

3. As a result of change in the magnetic flux linked to the closed loop shown in the figure, an emf V volt is induced in the loop. The work done (joule) in taking a charge q coulomb once along the loop is



(A) qV **(B)** zero
(C) 2 qV **(D)** $\frac{qV}{2}$

4. Two coils of self-inductances 2 mH and 8 mH are placed so close together that the effective flux in one coil is completely linked with the other. The mutual inductance between these coils is

(A) 10 mH **(B)** 6 mH
(C) 4 mH **(D)** 16 mH

5. A long solenoid has 500 turns. When a current of 2 A is passed through it, the resulting magnetic flux linked with each turn of the solenoid is 4×10^{-3} Wb. the self-inductance of the solenoid is

(A) 2.5 H **(B)** 2 H
(C) 1 H **(D)** 4 H

6. A circular disc of radius 0.2 m is placed in ac uniform magnetic field of induction $\frac{1}{\pi}(Wb/m^2)$ in such a way that its axis makes an angle of 60° with B. The magnetic flux linked with the disc is

(A) 0.02 Wb **(B)** 0.06 Wb
(C) 0.08 Wb **(D)** 0.01 Wb

7. A conducting circular loop is placed in a uniform magnetic field 0.04 T with its plane perpendicular to the magnetic field. The radius of the loop starts shrinking at 2 mm s^{-1}. The induced emf in the loop when the radius is 2 cm is

(A) $3.2\pi\mu V$ **(B)** $4.8\pi\mu V$
(C) $0.8\pi\mu V$ **(D)** $1.6\pi\mu V$

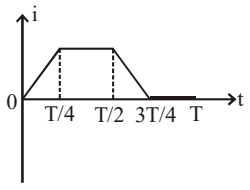
8. A rectangular, a square, a circular and an elliptical loop, all in the x y-plane, are moving out of a uniform magnetic field with a constant velocity, $v = v\hat{i}$. The magnetic field is directed along the during the passage of these loops, out ot the field region, will not remain constant for

(A) the rectangular, circular and elliptical loops
(B) the circular and the elliptical loops
(C) only the elliptical loop
(D) any of the four loops

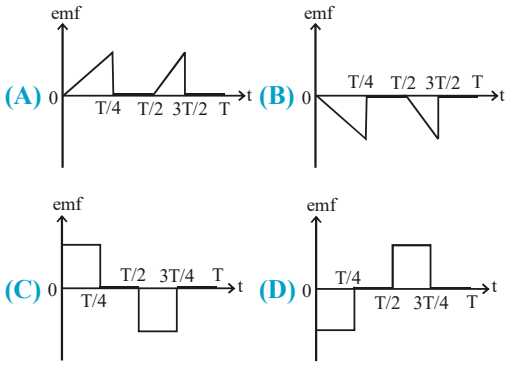
9. A conducting circular loop is placed in a uniform magnetic field, B = 0.025 T with its plane perpendicular to the loop. The radius of the loop is made to shrink at a constant rate of 1 mms^{-1}. The induced emf when the radius is 2 cm, is

(A) $2\pi\mu V$ **(B)** $\pi\mu V$
(C) $\frac{\pi}{2}\mu V$ **(D)** $2\mu V$

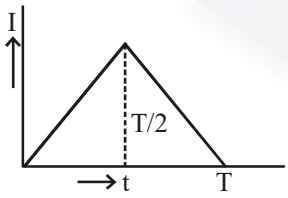
10. The current i in a coil varies with time as shown in the figure. The variation of induced emf with time would be



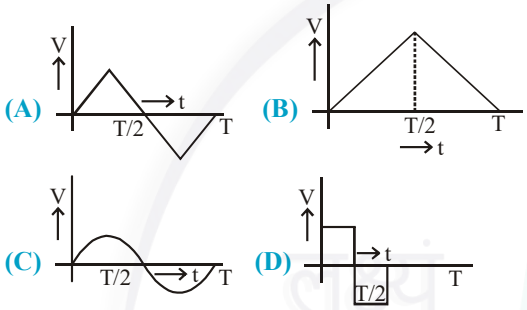
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11. The current (I) in the inductance is varying with time according to the plot shown in figure.



Which one of the following is the correct variation of voltage with time in the coil ?



12. A coil of resistance 400 Ω is placed in a magnetic field. If the magnetic flux ϕ (Wb) linked with the coil varies with time ti (second) as $\phi = 50t^2 + 4$.

The current in the coil at t = 2 s is

(A) 0.5 A **(B)** 0.1 A

(C) 2 A **(D)** 1 A

13. A wire loop is rotated in magnetic field. The frequency of change of direction of the induced emf is

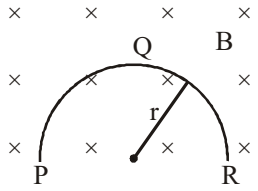
(A) once per revolution

(B) twice per revolution

(C) four times per revolution

(D) six times per revolution

14. A thin semicircular conducting ring (PQR) of radius r is falling with its plane vertical in a horizontal magnetic field B, as shown in figure. The potential difference developed across the ring when its speed is v, is



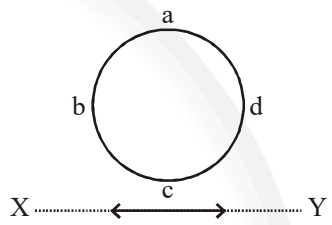
(A) zero

(B) $Bv\pi r^2/2$ and P is higher potential

(C) πrBv and R is at higher potential

(D) 2rBv and R is at higher potential

15. An electron moves on a straight line path XY as shown. The abcd is a coil adjacent in the path of electron. What will be the direction of current, if any induced in the coil?



(A) abcd

(B) adcb

(C) The current will reverse its direction as the electron goes past the coil

(D) No current induced

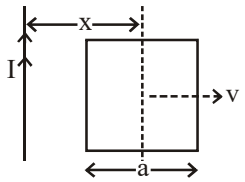
16. A rectangular coil of length 0.12 m and width 0.1 m having 50 turns of wire is suspended vertically in a uniform magnetic field of strength 0.2 Wb/m^2. The coil carries a current of 2 A. If the plane of the coil is inclined at an angle of 30° with the direction of the field, the troque required to keep the coil in stable equilibrium will

(A) 0.15 Nm **(B)** 0.20 Nm

(C) 0.24 Nm **(D)** 0.12 Nm

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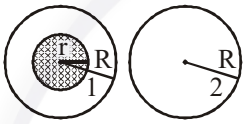
17. A conducting square frame of side 'a' and a long straight wire carrying current I are located in the same plane as shown in the figure. The frame moves to the right with a constant velocity 'v'. The emf induced in the frame will be proportional to



(A) $\frac{1}{x^2}$ **(B)** $\frac{1}{(2x-a)^2}$

(C) $\frac{1}{(2x+a)^2}$ **(D)** $\frac{1}{(2x-a)(2x+a)}$

18. A uniform magnetic field is restricted within a region of radius r. The magnetic field changes with time at a rate $\frac{dB}{dt}$. Loop 1 of radius R > r encloses the region r and loop 2 of radius R is outside the region of magnetic field as shown in the figure. Then, the emf generated is



(A) zero in loop 1 and zero in loop 2

(B) $-\frac{dB}{dt}\pi r^2$ in loop 1 and $-\frac{dB}{dt}\pi r^2$ in loop 2

(C) $-\frac{dB}{dt}\pi R^2$ in loop 1 and zero in loop 2

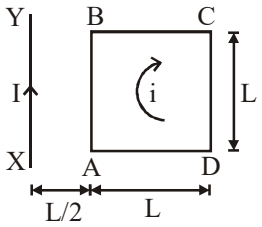
(D) $-\frac{dB}{dt}\pi r^2$ in loop 1 and zero in loop 2

19. Two identical charged spheres suspended from a common point by two massless strings of lengths *l*, are initially at a distance d (d << 1) apart because of their mutual repulsion. The charges begin to leak from the both the spheres at a constant rate. As a result, the spheres approach each other wtih a velocity v. Then, v varies as a function of the distance x between the sphere, as

(A) $v \propto x$ **(B)** $v \propto x^{-\frac{1}{2}}$

(C) $v \propto x^{-1}$ **(D)** $v \propto x^{\frac{1}{2}}$

20. A square loop ABCD carrying a current i, is placed near and coplanar with a long straight conductor XY carrying a current I, the net force on the loop will be



(A) $\frac{\mu_0 Ii}{2\pi}$ **(B)** $\frac{2\mu_0 IiL}{3\pi}$

(C) $\frac{\mu_0 IiL}{2\pi}$ **(D)** $\frac{2\mu_0 Ii}{3\pi}$

21. A long solenoid has 1000 turns. When a current of 4A flows through it, the magnetic flux linked with each turn of the solenoid is 4×10^{-3} Wb. The self-inductance of the solenoid is

(A) 3 H **(B)** 2 H

(C) 1 H **(D)** 4 H

22. A long solenoid of diameter 0.1 m has 2×10^4 turns per metre. At the centre of the solenoid, a coil of 100 turns and radius 0.01 m is placed with its axis coinciding with the solenoid axis. The current in the solenoid reduced at a constant rate to 0 A from 4 A in 0.05 s. If the resistance of the coil is $10\pi^2\ \Omega$, the total charge flowing through the coil during this time is

(A) $32\pi\ \mu C$ **(B)** 16 μC

(C) 32 μC **(D)** $16\pi\ \mu C$

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Exercise # 4 PART - 2 PREVIOUS YEAR (AIIMS)

1. Eddy currents are produced when

(A) a metal is kept in varying magnetic field

(B) a metal is kept in the steady magnetic field

(C) a circular coil is placed in a magnetic field

(D) through a circular coil current is passed.

2. Which of the following statements is true ?

(A) The presence of a large magnetic flux through a coil maintains a current in the coil if the circuit is continuous.

(B) A coil of a metal wire kept stationary in a non-uniform magnetic field has an emf induced in it.

(C) A charged particle enters a region of uniform magnetic field at an angle of 85° to the magnetic lines of force; the path of the particle is a circle.

(D) There is no change in the energy of a charged particle moving in a magnetic field although a magnetic force is acting on it.

3. A small piece of metal wire is dragged across the gap between the pole pieces of a magnet in 0.4 sec. If magnetic flux between the pole pieces is known to be 8×10^{-4} Wb, then induced emf in the wire, is

(A) 4×10^{-3} V **(B)** 8×10^{-3} V

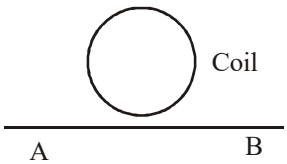
(C) 2×10^{-3} V **(D)** 6×10^{-3} V.

4. At a place earth's magnetic field, 5×10^{-5} Wb/m^2 is acting perpendicular to a coil of radius R = 5 cm. If $\mu_0/4\pi = 10^{-7}$, then how much current is induced in circular loop ?

(A) 0.2 A **(B)** 0 A

(C) 4 A **(D)** 40 A

5. If electron is moving from A to B in wire AB, then current induced in the coil is



(A) anticlockwise

(B) clock wise

(C) arbitrary direction

(D) no current will be induced.

6. The coefficient of mutual inductance, when magnetic flux changes by 2×10^{-2} Wb and current changes by 0.01 A is

(A) 2 H **(B)** 4 H

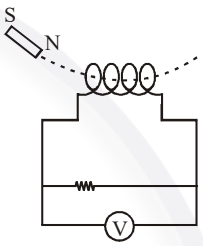
(C) 3 H **(D)** 8 H

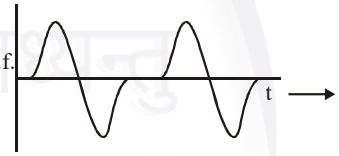
7. A conducting ring of radius 1 meter is placed in an uniform magnetic field B of 0.01 tesla oscillating with frequency 100 Hz with its plane at right angle to B. What will be the induced electric field ?

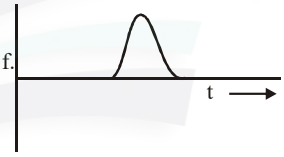
(A) π volt/m **(B)** 2 volt/m

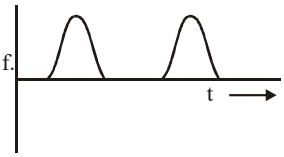
(C) 10 volt/m **(D)** 62 volt/m

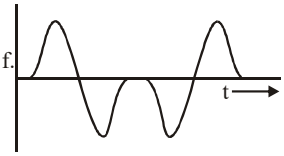
8. A magnet is made to oscillate with a particular frequency, passing through a coil as shown in figure. The time variation of the magnitude of e.m.f. generated across the coil during one cycle is



(A)


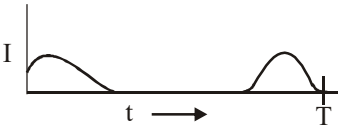
(B)


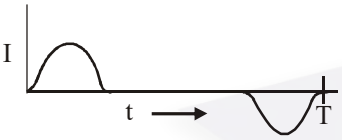
(C)


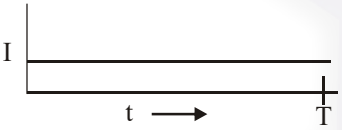
(D)


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9. A metallic ring is dropped down, keeping its plane perpendicular to a constant and horizontal magnetic field. The ring enters the region of magnetic field at t = 0 and completely emerges out at t = T sec. The current in the ring varies as

(A)


(B)


(C)


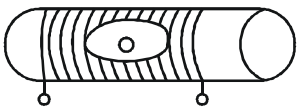
(D)


10. A coil of wire of a certain radius has 100 turns and a self inductance of 15 mH. The self inductance of a second similar coil of 500 turns will be

(A) 75 mH **(B)** 375 mH

(C) 15 mH **(D)** none of the these

11. A circular coil with a cross-sectional area of 4 cm^2 has 10 turns. It is placed at the center of a long solenoid that has 15 turns/cm and a cross-sectional area of 10 cm^2, as shown in the figure. The axis of the coil conicides with the axis of the solenoid. What is their mutual inductance ?



(A) 7.54 μH **(B)** 8.54 μH

(C) 9.54 μH **(D)** 10.54 μH

12. Mutual inductance M between two concentric coils of radii 1 m and 2 m is

(A) $\frac{\mu_0\pi}{2}$ **(B)** $\frac{\mu_0\pi}{4}$

(C) $\frac{\mu_0\pi}{8}$ **(D)** $\frac{\mu_0\pi}{10}$

13. Lenz law is consistent with conservation of

(A) energy **(B)** mass

(C) charge **(D)** momentum

14. Which of the following is the best method to reduce eddy currents ?

(A) Laminating core

(B) Using thick wires

(C) Reducing hysteresis loss

(D) None of these

15. Two solenoids of equal number of turns having their length and the radii in the same ratio 1 : 2. The ratio of their self-inductance will be

(A) 1 : 2 **(B)** 2 : 1

(C) 1 : 1 **(D)** 1 : 4

16. Two conducting circular loops of radii R_1 and R_2 are placed in the same plane with their centres coinciding. If $R_1 > R_2$, the mutual inductance M between them will be directly proportional to

(A) $\frac{R_1}{R_2}$ **(B)** $\frac{R_2}{R_1}$

(C) $\frac{R_1^2}{R_2}$ **(D)** $\frac{R_2^2}{R_1}$

17. The self inductance of a coil having 400 turns is 10 mH. The magnetic flux through the cross section of the coil corresponding to current 2 mA is

(A) 2×10^{-5} Wb **(B)** 2×10^{-3} Wb

(C) 3×10^{-5} Wb **(D)** 8×10^{-3} Wb

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18. Mutual inductance of two coils can be increased by

(A) decreasing the number of turns in the coils

(B) increasing the number of turns in the coils

(C) winding the coils on wooden cores

(D) none of these

ASSERTION AND REASON

19. **Assertion :** If current is flowing through a machine of iron eddy currents are produced.

Reason : Change in magnetic flux through an area causes eddy currents.

20. **Assertion :** The possibility of an electric bulb fusing is higher at the time of switching on and off.

Reason : Inductive effects produce a surge at the time of switch-off and switch-on.

21. **Assertion :** An emf $\vec{E}$ is induced in a closed loop where magnetic flux is varied. The induced $\vec{E}$ is not a conservative field.

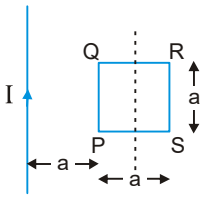
Reason : The line integral $\vec{E} \cdot d\vec{l}$ around the closed loop is non-zero.

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MOCK TEST

STRAIGHT OBJECTIVE TYPE

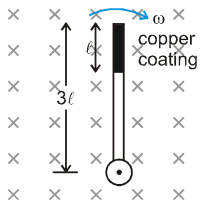
1. In the figure shown a square loop PQRS of side 'a' and resistance 'r' is placed near an infinitely long wire carrying a constant current I. The sides PQ and RS are parallel to the wire. The wire and the loop are in the same plane. The loop is rotated by 180° about an axis parallel to the long wire and passing through the mid points of the side QR and PS. The total amount of charge which passes through any point of the loop during rotation is :



(A) $\frac{\mu_0 Ia}{2\pi r}\ \ell n2$ **(B)** $\frac{\mu_0 Ia}{\pi r}\ \ell n2$

(C) $\frac{\mu_0 Ia^2}{2\pi r}$ **(D)** cannot be found because time of rotation not give.

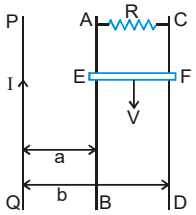
2. A wooden stick of length 3ℓ is rotated about an end with constant angular velocity ω in a uniform magnetic field B perpendicular to the plane of motion. If the upper one third of its length is coated with copper, the potential difference across the whole length of the stick is



(A) $\frac{9B\omega\ell^2}{2}$ **(B)** $\frac{4B\omega\ell^2}{2}$

(C) $\frac{5B\omega\ell^2}{2}$ **(D)** $\frac{B\omega\ell^2}{2}$

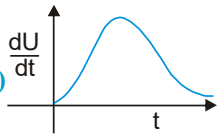
3. PQ is an infinite current carrying conductor. AB and CD are smooth conducting rods on which a conductor EF moves with constant velocity V as shown. The force needed to maintain constant speed of EF is.

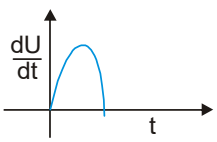


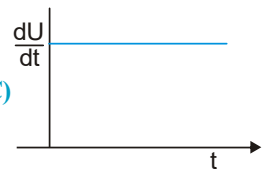
(A) $\frac{1}{VR}\left[\frac{\mu_0 IV}{2\pi}\ell n\left(\frac{b}{a}\right)\right]^2$ **(B)** $\left[\frac{\mu_0 IV}{2\pi}\ell n\left(\frac{b}{a}\right)\right]\frac{1}{R}$

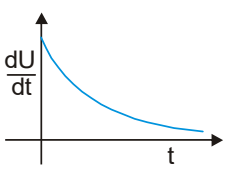
(C) $\left[\frac{\mu_0 IV}{2\pi}\ell n\left(\frac{b}{a}\right)\right]^2\frac{V}{R}$ **(D)** $\left[\frac{\mu_0 IV}{2\pi}\ell n\left(\frac{b}{a}\right)\right]$

4. Rate of increment of energy in an inductor with time in series LR circuit getting charge with battery of e.m.f. E is best represented by: [inductor has initially zero current]

(A)


(B)


(C)


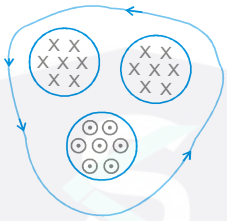
(D)


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5. A wire of fixed length is wound on a solenoid of length 'ℓ' and radius 'r'. Its self inductance is found to be L. Now if same wire is wound on a solenoid of length $\frac{\ell}{2}$ and radius $\frac{r}{2}$, then the self inductance will be :

(A) 2 L **(B)** L **(C)** 4 L **(D)** 8 L

6. Figure shows three regions of magnetic field, each of area A, and in each region magnitude of magnetic field decreases at a constant rate α. If $\vec{E}$ is induced electric field then value of line integral $\oint \vec{E} \cdot d\vec{r}$ along the given loop is equal to



(A) αA **(B)** $-\alpha A$ **(C)** $3\alpha A$ **(D)** $-3\alpha A$

7. In an ideal transformer, the voltage and the current in the primary are 200 volt and 2 amp respectively. If the voltage in the secondary is 2000 volt. Then value of current in the secondary will be :

(A) 0.2 amp **(B)** 2 amp **(C)** 10 amp **(D)** 20 amp

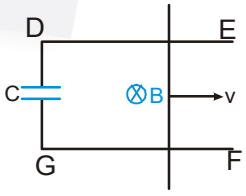
8. A superconducting loop of radius R has self inductance L. A uniform & constant magnetic field B is applied perpendicular to the plane of the loop. Initially current in this loop is zero. The loop is rotated by 180°. The current in the loop after rotation is equal to

(A) zero **(B)** $\frac{B\pi R^2}{L}$

(C) $\frac{2B\pi R^2}{L}$ **(D)** $\frac{B\pi R^2}{2L}$

9. In the figure shown the section EDFG is fixed. A rod having resistance 'R' is moved with constant velocity in a uniform magnetic field B as shown in the figure. DE & FG are smooth and resistanceless. Initially capacitor is uncharged. The charge on the capacitor:

(A) remains constant
(B) increases with time
(C) increases linearly with time
(D) oscillates.

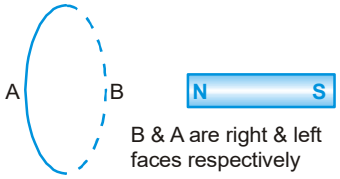


10. A rectangular loop of sides 'a' and 'b' is placed in xy plane. A very long wire is also placed in xy plane such that side of length 'a' of the loop is parallel to the wire. The distance between the wire and the nearest edge of the loop is 'd'. The mutual inductance of this system is proportional to :

(A) a **(B)** b **(C)** 1/d **(D)** current in wire

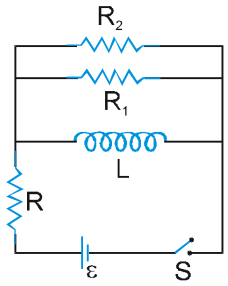
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11. In the figure shown, the magnet is pushed towards the fixed ring along the axis of the ring and it passes through the ring.



(A) when magnet goes towards the ring the face B becomes south pole and the face A becomes north pole
(B) when magnet goes away from the ring the face B becomes north pole and the face A becomes south pole
(C) when magnet goes away from the ring the face A becomes north pole and the face B becomes south pole
(D) the face A will always be a north pole.

12. Switch S is closed for a long time at t = 0. It is opened, then :



(A) total heat produced in resistor R after opening the switch is $\frac{1}{2}\frac{L\varepsilon^2}{R^2}$

(B) total heat produced in resistor R_1 after opening the switch is $\frac{1}{2}\frac{L\varepsilon^2}{R^2}\left(\frac{R_1}{R_1+R_2}\right)$

(C) heat produced in resistor R_1 after opening the switch is $\frac{1}{2}\frac{R_2 L\,\varepsilon^2}{(R_1+R_2)R^2}$

(D) no heat will be produced in R_1.

13. A rod of length ℓ having uniformly distributed charge Q is rotated about one end with constant frequency 'f'. Its magnetic moment is.

(A) $\pi f Q l^2$ **(B)** $\frac{\pi f Q \ell^2}{3}$ **(C)** $\frac{2\pi f Q \ell^2}{3}$ **(D)** $2\pi f Q l^2$

14. A vertical rod of length ℓ is moved with constant velocity v towards East. The vertical component of the earth's magnetic field is B and the angle of dip is θ. The induced e.m.f. in the rod is :

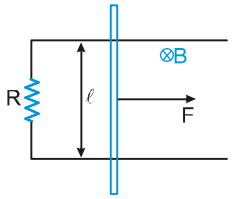
(A) $B\ \ell\ v \cot\theta$ **(B)** $B\ \ell\ v \sin\theta$ **(C)** $B\ \ell\ v \tan\theta$ **(D)** $B\ \ell\ v \cos\theta$

15. Two identical cycle wheels (geometrically) have different number of spokes connected from centre to rim. One is having 20 spokes and other having only 10 (the rim and the spokes are resistanceless). One resistance of value R is connected between centre and rim. The current in R will be :

(A) double in first wheel than in the second wheel
(B) four times in first wheel than in the second wheel
(C) will be double in second wheel than that of the first wheel
(D) will be equal in both these wheels.

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16. A constant force F is being applied on a rod of length 'ℓ' kept at rest on two parallel conducting rails connected at ends by resistance R in uniform magnetic field B as shown.



(A) the power delivered by force will be constant with time
(B) the power delivered by force will be increasing first and then will decrease
(C) the rate of power delivered by the external force will be increasing continuously
(D) the rate of power delivered by external force will be decreasing continuously.

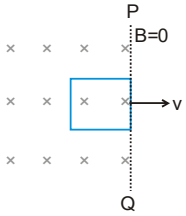
17. A uniform magnetic field exists in region given by $\vec{B} = 3\hat{i} + 4\hat{j} + 5\hat{k}$. A rod of length 5 m is placed along y−axis is moved along x−axis with constant speed 1 m/sec. Then induced e.m.f. in the rod will be:

(A) zero **(B)** 25 volt **(C)** 20 volt **(D)** 15 volt

18 In a L-R growth circuit, inductance and resistance used are 1 H and 20 Ω respectively. If at t = 50 millisecond, current in the circuit is 3.165 A then applied direct current emf is :

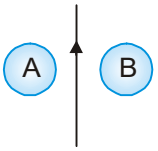
(A) 200 V **(B)** 100 V
(C) 50 V **(D)** Data is insufficient to find out the value.

19. Figure shows a square loop of side 1 m and resistance 1 Ω. The magnetic field on left side of line PQ has a magnitude B = 1.0T. The work done in pulling the loop out of the field uniformly in 1 s is



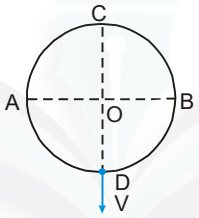
(A) 1 J
(B) 10 J
(C) 0.1 J
(D) 100 J

20. A and B are two metallic rings placed at opposite sides of an infinitely long straight conducting wire as shown. If current in the wire is slowly decreased, the direction of induced current will be :



(A) clockwise in A and anticlockwise in B
(B) anticlockwise in A and clockwise in B
(C) clockwise in both A and B
(D) anticlockwise in both A & B

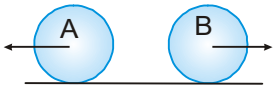
21. A vertical conducting ring of radius R falls vertically with a speed V in a horizontal uniform magnetic field B which is perpendicular to the plane of the ring :



(A) A and B are at same potential **(B)** C and D are at same potential
(C) current flows in clockwise direction **(D)** current flows in anticlockwise direction

22. Two identical conducting rings A & B of radius R are in pure rolling over a horizontal conducting plane with same speed (of center of mass)υ but in opposite direction. A constant magnetic field B is present pointing inside the plane of paper. Then the potential difference between the highest points of the two rings, is :

(A) zero **(B)** 2 Bvr
(C) 4Bvr **(D)** none of these

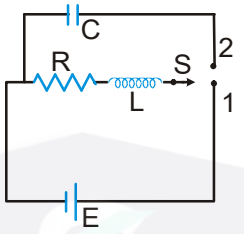


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23. An inductor L and a resistor R are connected in series with a direct current source of emf E. The maximum rate at which energy is stored in the magnetic field is :

(A) $\frac{E^2}{4R}$ **(B)** $\frac{E^2}{R}$ **(C)** $\frac{4E^2}{R}$ **(D)** $\frac{2E^2}{R}$

24. In the circuit shown in figure, the switch S was initially at position 1. After sufficiently long time, the switch S was thrown from position 1 to position 2. The voltage drop across the resistor at that instant is :



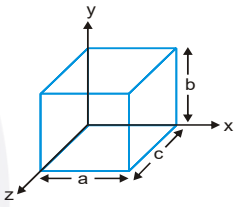
(A) zero **(B)** E **(C)** $\frac{E}{R}LC$ **(D)** none of these

MATRIX - MATCH TYPE

25. The figure shows a metallic solid block, placed in a way so that its faces are parallel to the coordinate axes. Edge lengths along axis x, y and z are a, b and c respectively. The block is in a region of uniform magnetic field of magnitude 30mT. One of the edge length of the block is 25 cm. The block is moved at 4 m/s parallel to each axis and in turn, the resulting potential difference V that appears across the block is measured. When the motion is parallel to the y axis, V = 24 mV; with the motion parallel to the z axis, V = 36 mV; with the motion parallel to the x axis, V = 0. Using the given information, correctly match the dimensions of the block with the values given.

(A) a
(B) b
(C) c
(D) $\frac{bc}{a}$

(P) 20 cm
(Q) 24 cm
(R) 25 cm
(S) 30 cm
(T) 26 cm



26. A square loop of conducting wire is placed near a long straight current carrying wire as shown. Match the statements in column-I with the corresponding results in column-II.



Column-I	Column-II
(A) If the magnitude of current I is increased	**(P)** Induced current in the loop will be clock wise
(B) If the magnitude of current I is decreased	**(Q)** Induced current in the loop will be anticlockwise
(C) If the loop is moved away from the wire	**(R)** wire will attract the loop
(D) If the loop is moved towards the wire	**(S)** wire will repel the loop
	(T) Torque about centre of mass of loop is zero due to magnetie force

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ASSERTION AND REASON TYPE

These questions contains, Statement 1 (assertion) and Statement II (reason).

(A) Statement-1 is True, Statement-2 is True; Statement-2 **is** a correct explanation for Statement-1

(B) Statement-1 is True, Statement-2 is True; Statement-2 **is NOT** a correct explanation for Statement-1

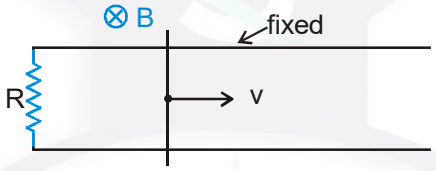
(C) Statement-1 is True, Statement-2 is False

(D) Statement-1 is False, Statement-2 is True.

27. **Assertion :** Two coaxial conducting rings of different radii are placed in space. The mutual inductance of both the rings is maximum if the rings are also coplanar.

Reason : For two coaxial conducting rings of different radii, the magnitude of magnetic flux in one ring due to current in other ring is maximum when both rings are coplanar.

28. **Assertion :** A resistance R is connected between the two ends of the parallel smooth conducting rails. A conducting rod lies on these fixed horizontal rails and a uniform constant magnetic field B exists perpendicular to the plane of the rails as shown in the figure. If the rod is given a velocity v and released as shown in figure, it will stop after some time. The total work done by magnetic field is negative.



Reason : If force acts opposite to direction of velocity its work done is negative.

29. **Assertion :** No electric current will be present within a region having uniform and constant magnetic field.

Reason : Within a region of uniform and constant magnetic field $\vec{B}$, the path integral of magnetic field $\oint \vec{B}\cdot d\vec{\ell}$ along any closed path is zero. Hence from Ampere circuital law $\oint \vec{B}\cdot d\vec{\ell} = \mu_o I$ (where the given terms have usual meaning), no current can be present within a region having uniform and constant magnetic field.

30. **Assertion :** Electric field produced by changing magnetic field is nonconservative.

Reason : For the electric field $\vec{E}$ induced by a changing magnetic field which has closed lines of force, $\oint \vec{E} d\vec{\ell} = 0$

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ANSWER KEY

EXERCISE - 1

1. C **2.** D **3.** B **4.** D **5.** B **6.** C **7.** A **8.** C **9.** A **10.** B **11.** A **12.** B **13.** D
14. C **15.** B **16.** B **17.** B **18.** C **19.** D **20.** D **21.** B **22.** C **23.** B **24.** C **25.** D **26.** D
27. D **28.** B **29.** A **30.** D **31.** D **32.** C **33.** C **34.** C **35.** C **36.** A **37.** B **38.** B **39.** D
40. D **41.** B **42.** D **43.** C **44.** C **45.** A **46.** D **47.** A **48.** A **49.** C **50.** A

EXERCISE - 2

1. C **2.** C **3.** B **4.** C **5.** A **6.** A **7.** A **8.** B **9.** B **10.** B **11.** D **12.** C **13.** A
14. A **15.** B **16.** B **17.** C **18.** A **19.** B **20.** D **21.** D **22.** D **23.** C **24.** C **25.** A **26.** D

EXERCISE - 3 : PART # 1

1. A → Q,S ; B → P,R ; C → P,R ; D → Q,S **2.** A → Q ; B → P ; C → T ; D → T

PART # 2

1. A **2.** D **3.** A **4.** B **5.** B **6.** C **7.** C **8.** E **9.** E **10.** A **11.** B **12.** C **13.** A
14. A **15.** B

EXERCISE - 4 : PART # 1

1. C **2.** B **3.** A **4.** C **5.** C **6.** A **7.** A **8.** B **9.** B **10.** D **11.** D **12.** A **13.** B
14. D **15.** D **16.** B **17.** D **18.** C **19.** B **20.** D **21.** C **22.** C

PART # 2

1. A **2.** B **3.** C **4.** B **5.** D **6.** A **7.** B **8.** A **9.** B **10.** B **11.** A **12.** B **13.** A
14. A **15.** A **16.** D **17.** A **18.** B **19.** D **20.** A **21.** A

MOCK TEST

1. B **2.** C **3.** A **4.** A **5.** A **6.** B **7.** A **8.** C **9.** B **10.** A **11.** C **12.** C **13.** B
14. A **15.** D **16.** D **17.** B **18.** B **19.** A **20.** B **21.** B **22.** C **23.** A **24.** B
25. A → R ; B → S ; C → P; D → Q **26.** A → Q,S ; B → P,R → C → P,R ; D → Q,S
27. A **28.** D **29.** A **30.** C

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HINTS & SOLUTIONS

EXERCISE - 1
NEET LEVEL

1. **(C)** Because induced e.m.f. is given by $E = -N\frac{d\phi}{dt}$.

2. **(D)** The energy of the field increases with the magnitude of the field. Lenz's law infers that there is an opposite field created due to increase or decrease of magnetic flux around a conductor so as to hold the law of conservation of energy.

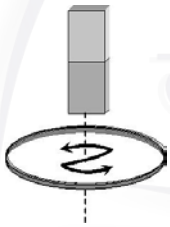
3. **(B)** We know that $e = \frac{d\phi}{dt}$

But $e=iR$ and $i = \frac{dq}{dt} \Rightarrow \frac{dq}{dt}R = \frac{d\phi}{dt} \Rightarrow dq = \frac{d\phi}{R}$

4. **(D)** Similar to Q.3

5. **(B)** Because there is no change in flux linked with coil

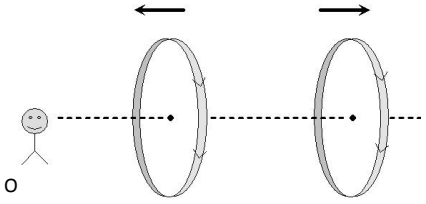
6. **(C)** As it is seen from the magnet side induced current will be anticlockwise.



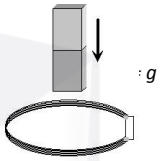
7. **(A)** $e = -\frac{d\phi}{dt} = \frac{-3B_0A_0}{t}$

8. **(C)** $e = -\frac{d\phi}{dt} = -(16t+3) = -67 units$

9. **(A)** Induced current in both the coils assist the main current so current through each coil increases.



10. **(B)** When the magnet is allowed to fall vertically along the axis of loop with its north pole towards the ring. The upper face of the ring will become north pole in an attempt to oppose the approaching north pole of the magnet. Therefore the acceleration in the magnet is less than *g*.



Note : If coil is broken at any point then induced *emf* will be generated in it but no induced current will flow. In this condition the coil will not oppose the motion of magnet and the magnet will fall freely with acceleration *g*. (*i.e.* $a = g$)

11. **(A)** Emf = $e = e_0 \sin\theta$; e will be maximum when θ is 90^o *i.e.* plane of the coil will be horizontal.

12. **(B)** Induced e.m.f. $= Blv = 0.3\times10^{-4}\times10\times5$

$= 1.5\times10^{-3} V = 1.5\, mV$

13. **(D)** Conductor cuts the flux only when, if it moves in the direction of *M*.

14. **(C)** $e = B_v.vl = 0.2\times10^{-4}\times\left(\frac{180\times1000}{3600}\right)\times1 = 10^{-3} V$

15. **(B)** $e = Bvl = 3\times10^{-3}\times10^2 = 0.3\, volt$

16. **(B)** This is the case of periodic EMI

17. **(B)** $e = B_v.v.l = 2\times10^{-4}\times\left(\frac{360\times1000}{3600}\right)\times50$

$\Rightarrow e = 1\, V$

18. **(C)** $e = \frac{1}{2}B\omega r^2 = \frac{1}{2}\times0.1\times2\pi\times10\times(0.1)^2 = \pi\times10^{-2} V$

19. **(D)** $e = \frac{1}{2}B\omega r^2 = \frac{1}{2}\times0.2\times10^{-4}\times5\times(1)^2 = 50\mu V$

20. **(D)** No flux change is taking place because magnetic field exists everywhere and is constant in time and space.

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21. (B) If player is running with rod in vertical position towards east, then rod cuts the magnetic field of earth perpendicularly (magnetic field of earth is south to north).

Hence Maximum emf induced is

$$e = Bvl = 4\times10^{-5}\times\frac{30\times1000}{3600}\times3 = 1\times10^{-3}\,volt$$

When he is running with rod in horizontal position, no field is cut by the rod, so $e = 0$.



22. (C) $e = NBA\omega;\ \omega = 2\pi f = 2\pi\times\frac{2000}{60}$

$$\therefore e = 50\times0.05\times80\times10^{-4}\times2\pi\times\frac{2000}{60} = \frac{4\pi}{3}$$

23. (B)

24. (C) According to Fleming right hand rule, the direction of B will be perpendicular to the plane of paper and act downward.

25. (D) By Fleming's right hand rule.

26. (D) $e = -L\frac{di}{dt}$ but $e = 4V$ and $\frac{di}{dt} = \frac{0-1}{10^{-3}} = -1/10^{-3}$

$$\therefore \frac{-1}{10^{-3}}(-L) = 4 \Rightarrow L = 4\times10^{-3}\,henry$$

27. (D) $L = \frac{e}{di/dt} = \frac{5}{(3-2)/10^{-3}} = \frac{5}{1}\times10^{-3} = 5 milli\ henry$

28. (B) Energy stored

$$E = \frac{1}{2}Li^2 = \frac{1}{2}\times50\times10^{-3}\times4 = 0.1\,J$$

29. (A) Given

$$\frac{di}{dt} = 2A/sec.,\ L = 5\,H\ \therefore e = L\frac{di}{dt} = 5\times2 = 10\,V$$

30. (D) As we know $e = -\frac{d\phi}{dt} = -L\frac{di}{dt}$

Work done against back e.m.f. e in time dt and current i is

$$dW = -eidt = L\frac{di}{dt}idt = Li\,di \Rightarrow W = L\int_0^i i\,di = \frac{1}{2}Li^2$$

31. (D) Induced emf $e = M\frac{di}{dt} = \frac{\mu_0 N_1 N_2 A}{l}\cdot\frac{di}{dt}$

$$= \frac{4\pi\times10^{-7}\times2000\times300\times1.2\times10^{-3}}{0.30}\times\frac{|2-(-2)|}{0.25}$$

$$= 48.2\times10^{-3}\,V = 48\,mV$$

32. (C) Self inductance $L = \mu_0 N^2 A/l = \mu_0 n^2 lA$

Where n is the number of turns per unit length and N is the total number of turns and $N = nl$

In the given question n is same. A is increased 4 times and l is increased 2 times and hence L will be increased 8 times.

33. (C) $M = -\frac{e_2}{di_1/dt} = -\frac{e_1}{di_2/dt}$

Also $e_1 = -L_1\frac{di_1}{dt}.e_2 = -L_2\frac{di_2}{dt}$

$$M^2 = \frac{e_1 e_2}{\left(\frac{di_1}{dt}\right)\left(\frac{di_2}{dt}\right)} = L_1L_2 \Rightarrow M = \sqrt{L_1L_2}$$

34. (C) Inductance is inherent property of electrical circuits. It will always be found in an electrical circuit whether we want it or not. The circuit in which a large emf is induced when the current in the circuit changes is said to have greater inductance. A straight wire carrying current with no iron part in the circuit will have lesser value of inductance while if the circuit contains a circular coil having many number of turns, the induced emf to oppose the cause will be greater and the circuit is therefore said to have greater value of inductance.

35. (C) Magnetic flux $\phi = LI$

By analogy, since physical quantities mass *(m)* and linear velocity *(v)* are equivalent to electrical quantities inductance *(L)* and current *(I)* respectively. Thus magnetic flux $\phi = LI$ is equivalent to momentum $p = m\times v$.

36. (A) Energy stored $= \frac{1}{2}Li^2$, where Li is a magnetic flux.

37. (B) $L = \mu ni \Rightarrow \frac{L_2}{L_1} = \frac{\mu}{\mu_0}$ (n and i are same)

$$\Rightarrow\ L_2 = \mu_r L_1 = 900\times0.18 = 162\,mH$$

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38. **(B)** $e = M\frac{di}{dt} = 0.2 \times 5 = 1\,V$

39. **(D)** $e = -L\frac{di}{dt} \Rightarrow 2 = -L\left(\frac{8-2}{3\times10^{-2}}\right)$

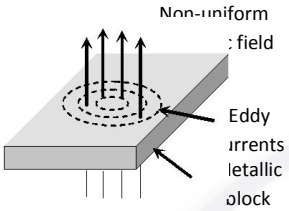
$\Rightarrow L = 0.01\,H = 10\,mH$

40. **(D)** $e = M\frac{di}{dt} = 1.25 \times 80 = 100\,V$

41. **(B)** Hot wire ammeter is not based on the phenomenon of electromagnetic induction.

42. **(D)**

43. **(C)** Direction of eddy currents is given by Lenz's rule.



44. **(C)** In a generator. e.m.f. is induced according as Lenz's rule.

45. **(A)** **46.** **(D)**

47. **(A)** Circulation of eddy currents is prevented by use of laminated core.

48. **(A)** **49.** **(C)** **50.** **(A)**

EXERCISE - 2
AIIMS LEVEL

1. **(C)** $U = \frac{1}{2}LI^2$

$P = I^2R$ or $\frac{2U}{P} = \frac{L}{R} = \tau.$

2. **(C)**

3. **(B)** $L_{eff} = 2H$

Energy stored in inductor $= \frac{1}{2}LI^2 = \frac{1}{2} \times (2) \times (1)^2 = 1J.$

Energy developed in resistance $= I^2RT = 1^2 \times 10 \times 10$
$= 100\,J$

Hence the required ratio is $\frac{1}{100}$.

4. **(C)**

5. **(A)** In the loop containing wire AB the flow of current will be from B to A because emf generated in that loop is less than the emf generated in the loop containing CD.

7. **(A)** $I = I_1 + I_2$

$I_1 = E/R$

$L\frac{dI}{dt} = E.$ $I_2 = \frac{Et}{L}$

$I = E/R + \frac{Et}{L}$

$I = 12A.$

8. **(B)**

9. **(B)** $P = F.V = Bi\ell V = B\left(\frac{Bv\ell}{R}\right)\ell\,V, P \propto V^2$

11. **(D)** Since the magnitude flux in the ring due to motion of charge particle is zero hence the induced emf will be zero.

12. **(C)**

13. **(A)** $E = \frac{1}{2}LI^2$

$E = \frac{1}{2}L\frac{V^2}{R^2} = \frac{1}{2} \times 5 \times 10^{-3} \times (1)^2 = 2.5\,mJ.$

14. **(A)**

15. **(B)** Since the tube is very long the force on magnet due to induced current will continue to oppose its motion till it acquires a constant speed.

16. **(B)**

17. **(C)** Flux through a closed circuit containing an inductor does not change instantaneously.

$\therefore \quad L\left(\frac{E}{R}\right) = \frac{L}{4}(i) \Rightarrow i = \frac{4E}{R}$ **Ans.**

18. **(A)**

19. **(B)** Using ; $V_A - V_B = RI + L\frac{dI}{dt}$



$140 = 5R + 10\,L$

$60 = 5R - 10\,L$

$\Rightarrow L = 4H.$ **Ans.**

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20. **(D)**

21. (D) Since $\Delta\phi = 0$ hence EMF induced is zero.

22. **(D)** The direction of current in the loop such that it opposes the the change in magnetic flux in it.

23. **(C)**

24. **(C)** Since the magnetic flux in the loop is zero hence the current induced in it is zero.

25. **(A)** The repulsion is to resist the increasing magnetic flux in coil B.

26. **(D)** By moving away from solenoid the ring will resist the changing flux in it.

EXERCISE - 3
P-1 (Matrix Match)

1. **A → Q,S ; B → P,R ; C → P,R ; D → Q,S**

2. **A → Q ; B → P ; C → T ; D → T**

When both S_1 and S_2 are either open or closed; current through ad is zero. With S_1 closed, current 2×10^{-7} A flows from a to d. With S_2 closed, current 2×10^{-7} A flows from d to a.

EXERCISE - 3
P-2 (Assertion & Reason)

1. **(A)**

2. **(D)** Magnetic field cannot do work, hence statement-1 is false.

3. **(A)** Obviously statement 2 is correct explanation of statement-1

4. **(B)** When a metallic conductor is moved in a magnetic field; magnetic flux is varied. It disturbs the free electrons of the metal and set up an induced emf in it. As there are no free ends of the metal i.e. it will be closed in itself so there will be induced current.

5. **(B)** The relation of induced emf is $e = \frac{Ldi}{dt}$ and current i is given by $i = \frac{e}{R} = \frac{1}{R}.\frac{L.di}{dt} \Rightarrow \frac{di}{dt} = i\frac{R}{L} = \frac{i}{L/R}$. In order to decreases the rate of increase of current through solenoid. We have to increase the time constant L/R.

6. **(C)** According to Faraday's laws, the conversion of mechanical energy into electrical energy. This is in accordance with the law of conservation of energy. It is also clearly known that in pure resistance, the emf is in phase with the current.

7. **(C)** Presence of magnetic flux cannot produce current.

8. **(E)** E.M.F. induces, when there is change in magnetic flux. Faraday did experiment in which, there is relative motion between the coil and magnet, the flux linked with the coil changes and e.m.f. induces.

9. **(E)**Since both the loops are identical (same area and number of turns) and moving with a same speed in same ma gnetic field. Therefore same emf is induced in both the coils. But the induced current will be more in the copper loop as its resistance will be lesser as compared to that of the aluminium loop.

10. **(A)** The inductance coils made of copper will have very small ohmic resistance. Due to change in magnetic flux a large induced current will be produced in such an inductance, which will offer appreciable opposition to the flow of current.

11. **(B)** Self-inductance of a coil is its property virtue of which the coil opposes any change in the current flowing through it.

12. **(C)** The manner in which the two coils are oriented, determines the coefficient of coupling between them. $M = K^2.L_1L_2$

When the two coils are wound on each other, the coefficient of coupling is maximum and hence mutual inductance between the coil is maximum.

13. **(A)** The induced current in the ring opposes the motion of falling magnet. Therefore, the acceleration of the falling magnet will be less than that due to gravity.

14. **(E)** As the aircraft flies, magnetic flux changes through its wings due to the vertical component of the earth's magnetic field. Due to this, induced emf is produced across the wings of the aircraft. Therefore, the wings of the aircraft will not be at the same potential.

15. **(B)** According to Lenz's law, induced emf are in a direction such as to attempt to maintain the original magnetic flux when a change occurs. When the switch is opened, the sudden drop in the magnetic field in the circuit induces an emf in a direction that attempts to keep the original current flowing. This can cause a spark as the current bridges the air gap between the poles of the switch. (The spark is more likely in circuits with large inductance).

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EXERCISE - 4

P-1 (NEET/AIPMT)

1. **(C)** It is given that emf is zero i.e.,

$$e = -L\frac{di}{dt} = 0$$

or $$L\frac{di}{dt} = 0$$

or $$\frac{d}{dt}(t^2e^{-t}) = 0 \qquad (\text{As, } i = t^2e^{-t})$$

or $$2t \times e^{-t} + t^2 \times (-1)e^{-t} = 0$$

or $$te^{-t}(2 - t) = 0 \text{ or } t = 2\text{ s} \qquad (\because te^{-t} \neq 0)$$

2. **(B)** From Faraday's second law, emf induced in the circuit

$$e = \frac{\Delta\phi}{\Delta t}$$

If R is the resistance of the circuit, then

$$i = \frac{e}{R} = \frac{\Delta\phi}{R\Delta t}$$

Thus, charge passing through the circuit,

$$q = i \times \Delta t$$

$$\Rightarrow \quad q = \frac{\Delta\phi}{R\Delta t} \cdot \Delta t$$

$$\Rightarrow \quad q = \frac{\Delta\phi}{R}$$

3. **(A)** Work done in moving a charge through potential difference V is given by W = qV

4. **(C)** When the total flux associated with one coil links with the other i.e. a case of maximum flux linkage, then mutual induction in coil 1 due coil 2 is

$$M_{12} = \frac{N_2\phi_{B_2}}{i_1}$$

and mutual induction in coil 2 due to coil 1 is

$$M_{21} = \frac{N_2\phi_{B_1}}{i_2}$$

Similarly, self-inductance in coil 1 is

$$L_1 = \frac{N_1\phi_{B_1}}{i_1}$$

and self-inductance in coil 2 is

$$L_2 = \frac{N_2\phi_{B_2}}{i_2}$$

If all the flux of coil 2 links coil 1 and vice-versa, then

$$\phi_{B_2} = \phi_{B_1}$$

Since, $M_{12} = M_{21} = M^2$

$$= \frac{N_1N_2\phi_{B_1}\phi_{B_2}}{i_1i_2} = L_1L_2$$

$$\therefore \quad M_{max} = \sqrt{L_1L_2}$$

Given, $L_1 = 2$ mH, $L_2 = 8$ mH

$$\therefore \quad M_{max} = \sqrt{2\times8} = \sqrt{16}$$

$$= 4 \text{ mH}$$

5. **(C)** Net flux through solenoid is,

$$\phi_{net} = N\phi$$

$$\therefore \quad \phi_{net} = 500 \times 4 \times 10^{-3} = 2 \text{ Wb}$$

where, ϕ = flux through each turn, and

N = total number of turns

Also, $\phi_{net} = Li = 2$ Wb

Now, $L \times 2 = 2$

$\Rightarrow$ Self-inductance, L = 1 H

6. **(A)** Magnetic flux $\phi = B \cdot A$

$$\phi = BA\cos\theta$$

$$= \frac{1}{\pi} \times \pi(0.2)^2 \cos 60° = 0.02 \text{Wb}$$

7. **(A)** Magnetic field, B = 0.04 T and rate of change of radius of coil due to shrinkage, $\frac{-dt}{dt} = 2\text{mms}^{-1}$

Induced emf, $e = \frac{-d\phi}{dt} = -B\frac{dA}{dt} = -B\frac{d(\pi r^2)}{dt}$

$$= -B\pi 2r\frac{dr}{dt}$$

Now, if $r = 2$ cm

$$e = -0.04 \times \pi \times 2 \times 2 \times 10^{-2} \times 2 \times 10^{-3}$$

$$= 32\,\pi\mu\text{V}$$

8. **(B)** Area coming out per second from the magnetic field is not constant for elliptical and circular loops, so induced emf, durig the passage out of these loops, from the field region will not remain constant.

9. **(B)** Magnetic flux ϕ linked with magnetic field B and area A is given by

$$\phi = B \cdot A = |B||A|\cos\theta$$

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10. (D) As we know that,

emf induced, $e = -L\frac{di}{dt}$

During 0 to $\frac{T}{4}, \frac{di}{dt} = \text{constant}$

So, e = negative

For $\frac{T}{4}\text{to}\frac{T}{2}, \frac{di}{dt} = 0$

So, $e = 0$

For $\frac{T}{4}\text{to}\frac{3T}{4}, \frac{di}{dt} = \text{constant}$

So, e = positive

11. (D) For inductor, as we know induced voltage for

$$V = L\frac{dI}{dt} = L\frac{d}{dt}\left(\frac{2I_0 t}{T}\right) = \text{constant}$$

For $t = T/2$ to $t = T$,

$$V = L\frac{dI}{dt} = \left(\frac{-2I_0 t}{T}\right) = -\text{constant}$$

So, answer can be represented with graph (D).

12. (A) Induced emf in a coil is given by

$$E = \left|-\frac{d\phi}{dt}\right|$$

Given, $\phi = 50t^2 + 4$

and resistance, $R = 400\ \Omega$

So, $E = \left|-\frac{d\phi}{dt}\right|_{t=2} = |100t|_{t=2} = 200V$

So, current in the coil will be

$$I = \frac{E}{R} = \frac{200}{400} = \frac{1}{2} = 0.5A$$

13. (B) If a wire loop is rotated in a magnetic field, the frequency of change in the direction of the induced emf is twice per revolution.

14. (D) Concept An induced emf (BLv) called motional emf is produced by moving a conductor instead of varying the magnetic field.

For emf, $e = Bv(L_{eff}) = Bv \times (2r) = 2Bvr$

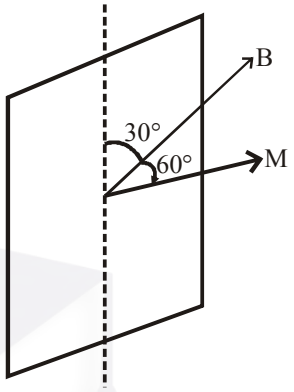
$(\because L_{eff} = \text{diameter} = 2r)$

15. (D) First current develops in direction of *abcd* but when electron moves away then magnetic field inside loop decreases and current changes its direction.

16. (B) Given, N = 50

$B = 02\ Wb/m^2, I = 2\ A$

$\theta = 60°, A = 0.12 \times 0.1 = 0.012\ m^2$

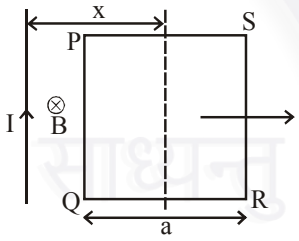


Thus, torque required to keep the coil in stable equilibrium, i.e.

$$\tau = NIAB\sin\theta = 50 \times 2 \times 0.012 \times 0.2 \times \sin 60°$$

$$= 50 \times 2 \times 0.12 \times 0.2 \times \frac{\sqrt{3}}{2} = 0.20Nm$$

17. (D)



Potential difference across PQ is

$$V_P - V_Q = B_1(A)v = \frac{\mu_0 I}{2\pi\left(x - \frac{a}{2}\right)}av$$

Potential difference across side RS of frame is

$$V_S - V_R = B_2(A)v = \frac{\mu_0 I}{2\pi\left(x + \frac{a}{2}\right)}av$$

Hence, the net potential difference in the loop will be

$$V_{net} = (V_P - V_Q) - (V_S - V_R)$$

$$= \frac{\mu_0 iav}{2\pi}\left[\frac{1}{\left(x - \frac{a}{2}\right)} - \frac{1}{\left(x + \frac{a}{2}\right)}\right]$$

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$$= \frac{\mu_0 iav}{2\pi}\left(\frac{a}{\left(x-\frac{a}{2}\right)\left(x+\frac{a}{2}\right)}\right)$$

Thus, $V_{net} \propto \frac{1}{(2x-a)(2x+a)}$

18. (C) Induced emf in the region is given by

$$|e| = \frac{d\phi}{dt}$$

where, $\phi = BA = \pi r^2 B$

$$\Rightarrow \frac{d\phi}{dt} = -\pi r^2 \frac{dB}{dt}$$

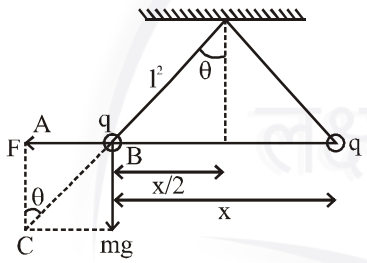
Rate of change of magnetic flux associated with loop 1

$$e_1 = -\frac{d\phi_1}{dt} = -\pi r^2 \frac{dB}{dt}$$

Similarly e_2 = emf associated with loop 2

$$= -\frac{d\phi_2}{dt} = 0 \qquad [\because \phi_2 = 0]$$

19. (B) According to question, two identical charged spheres suspended from a common point by two massless strings of length L.



$\because$ In ΔABC

$$\tan\theta = \frac{F}{mg} \text{ or } \frac{F}{mg} = \tan\theta \qquad ...(i)$$

Since, the charge begins to leak from both the spheres at a constant rate. As a result, the spheres approach each other with velocity v.

Therefore, Eq. (i) can be rewritten as

$$\frac{Kq^2}{x^2 mg} = \frac{x/2}{\sqrt{l^2 - \frac{x^2}{4}}}$$

$$\Rightarrow \frac{Kq^2}{x^2 mg} = \frac{x}{2l} \text{ or } q^2 \propto x^3$$

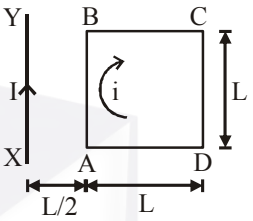
$$\Rightarrow q \propto x^{3/2}$$

$$\Rightarrow \frac{dq}{dt} \propto \frac{d(x^{3/2})}{dx} \cdot \frac{dx}{dt}$$

$$\Rightarrow \frac{dq}{dt} \propto x^{1/2}.v$$

$$\Rightarrow v \propto \frac{1}{x^{1/2}} \text{ or } v \propto x^{-1/2}$$

20. (D) Consider the given figure,



From the above figure, it can be seen that the direction of currents in a long straight conductor XY and arm AB of a square loop ABCD are in the same direction. So, there exist a force of attraction between the two, which will be experienced by F_{BA} as

$$F_{BA} = \frac{\mu_0 IiL}{2\pi\left(\frac{L}{2}\right)}$$

In the case of XY and arm CD, the direction of currents are in the opposite direction. So, there exist a force of repulsion which will be experienced by CD as

$$F_{CD} = \frac{\mu_0 IiL}{2\pi\left(\frac{3L}{2}\right)}$$

Therefore, net force on the loop ABCD will be

$$F_{loop} = F_{BA} - F_{CD} = \frac{\mu_0 IiL}{2\pi}\left[\frac{1}{(L/2)} - \frac{1}{(3L/2)}\right]$$

$$F_{loop} = \frac{2\mu_0 iI}{3\pi}$$

21. (C) Given, Number of turns of solenoid, N = 1000.

Current, I = 4 A

Magnetic flux, $\phi_B = 4 \times 10^{-3}$ Wb

$\because$ Self inductance of solenoid is given by

$$L = \frac{\phi_B . N}{I} \qquad ...(i)$$

Substitute the given values in Eq. (i), we get

$$L = \frac{4\times10^{-3}\times1000}{4} = 1H$$

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22. **(C) Thinking Process** Current induced in the coil is given by

$$i = \frac{1}{R}\left(\frac{d\phi}{dt}\right)$$

$$\Rightarrow \quad \frac{\Delta q}{\Delta t} = \frac{1}{R}\left(\frac{\Delta\phi}{\Delta t}\right)$$

Given, resistance of the solenoid,

$R = 10\,\pi^2\,\Omega$

Radius of second and coil $r = 10^{-2}$

$\Delta t = 0.05$ s, $\Delta i = 4 - 0 = 4$ A

Charge flowing through the coil is given by

$$\Delta q = \left(\frac{\Delta\phi}{\Delta t}\right)\frac{1}{R}(\Delta t)$$

$$= \mu_0 N_1 N_2 \pi r^2 \left(\frac{\Delta i}{\Delta t}\right)\frac{1}{R}\Delta t$$

$$= 4\pi\times10^{-7}\times2\times10^{4}\times100\times\pi\times(10^{-2})^2\times$$

$$\left(\frac{4}{0.05}\right)\times\frac{1}{10\pi^2}\times0.05$$

$= 32 \times 10^{-6}\,C = 32\,\mu C$

EXERCISE - 4

P-2 (AIIMS)

1. **(A)** Suppose a metal plate is kept in a magnetic field. On the surface of the metal plate, we can imagine a loop, which will be associated with a magnetic flux due to the magnetic field. As the magnetic field is changing, there is change of magnetic flux through this loop and so an electric current is going to be induced in the loop, which is known as the eddy current.

2. **(B)** Non-uniform magnetic field causes change in flux.

3. **(C)** Given : Time (t) = 0.4 sec and magnetic flux (ϕ) = 8×10^{-4} Wb. From the Faraday's law of electromagnetic induction that the induced e.m.f. in the wire

$$\varepsilon = \frac{d\phi}{dt} = \frac{8\times10^{-4}}{0.4} = 2\times10^{-3}\,V.$$

4. **(B)** As the earth's magnetic field is acting perpendicular to the coil and as here is no change of magnetic flux through the coil, the current induced in the coil is zero.

5. **(D)** Due to the current flowing in the wire, there is no change of magnetic flux linked with the wire and so there is no induced current.

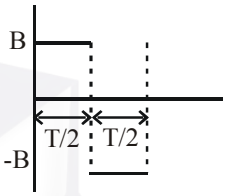
6. **(A)** Change in magnetic flux (ϕ) = 2×10^{-2} Wb and change in current (I) = 0.01 A.

Change in magnetic flux, $\phi = 2 \times 10^{-2} = MI$

$$\phi = M \times 0.01 \quad \text{or} \quad M = \frac{2\times10^{-2}}{0.01} = 2\ H$$

(where M = coefficient of mutua inductance).

7. **(B)** As in constant magnetic field conducting ring oscillates with a frequency of 100 Hz.



i.e. $T = \frac{1}{100}$ s, for $\frac{T}{2}$,

ir goes up to B

$\therefore$ The corresponding frequency is 200 Hz.

Induced emf $\varepsilon = \frac{\text{change in flux}}{\text{time}}$

$$= \frac{2BA\cos\theta}{T} = 2BA\ f\cos\theta = 2\times0.01\times\pi r2\times200$$

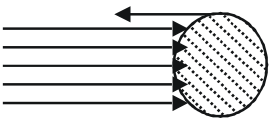
$= 4\pi$ V as r = 1 m

Non-electrostatic induced electric field along the circle.

$$E = \frac{1}{2\pi r}\times\left(\pi r^2\times\frac{dB}{dt}\right) = \frac{\varepsilon}{2\pi r} = \frac{4\pi}{2\pi r} = 2V/m.$$

8. **(A)** As the north pole approaches, a north pole is developed at that face i.e. the current flows anticlockwise. Finally when it completes the oscillation, when it is ready, no emf is present. Now south pole approaches the other side R.H.S. the current flows clockwise to repel the south pole. This means the current is anticlockwise at the L.H.S. as before. This is possible in **(A)**. The breaks show when the pendulum is at the extreme and momentarily stationary.

9. **(B)**



1. When the ring is just entering the magnetic field, emf is induced and the current flows in one direction.
2. When the whole ring is surrounding the flux inside, there is no change in the flux.

   Induced emf = 0, current is zero.

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3. When the ring just goes out of the region of flux, a pulse of current is produced which is opposite to that of 1 given above.

(B) is the only figure that describes this.

10. (B) Inductance of a coil is given by

$$L = \frac{1}{2}\mu_0 \pi N^2 R \Rightarrow \frac{L_2}{L_1} = \frac{N_2^2}{N_1^2}$$

$$\therefore \quad L_2 = L_1 \frac{N_2^2}{N_1^2} = \left(\frac{500}{100}\right) 15\,\text{mH} = 375\,\text{mH}$$

11. (A) Let us refer to the coil as circuit 1 and the solenoid as circuit 2. The field in the central region of the solenoid is uniform, so the flux through the coil is $\Phi_{12} = B_2 A_1 = (\mu_0 n_2 I_2) A_1$

Where $n_2 = N_2/l = 1500$ turns/m. The mutual inductance is

$$M = \frac{N_1 \Phi_{12}}{I_2} = \mu_0 n_2 N_1 L_1$$

$$= (4\pi \times 10^{-7}\,\text{T} \cdot \text{m/A})\,(1500\,\text{m}^{-1})\,(10)\,(4 \times 10^{-4}\,\text{m}^2)$$

$$= 7.54 \times 10^{-6}\,\text{H}$$

12. (B) Here, $r_1 = \text{m}, r_2 = 2\,\text{m}$

Mutual inductance, $M = \frac{\mu_0 \pi r_1^2}{2r_2}$

$$= \frac{\mu_0 \pi \times 1}{2 \times 2} = \frac{\mu_0 \pi}{4}$$

13. (A) Lenz's law is accordance with the principle of conservation of energy.

14. (A) To reduce the eddy currents in the metal armature of motors the wire is wrapped around a number of thin metal sheets called lamination.

15. (A) for solenoids, self inductance is given by,

$$L = \frac{\mu_0 N^2 A}{l}$$

$$\therefore \quad \frac{L_1}{L_2} = \frac{\left(\frac{\pi r_1^2}{l_1}\right)}{\left(\frac{\pi r_2^2}{l_2}\right)} = \frac{\left(\frac{r_1^2}{l_1}\right)}{\left(\frac{r_2^2}{l_1}\right)}$$

or $\frac{L_1}{L_2} = \frac{1}{2}$ $\qquad \left(\because \frac{r_1^2}{l_1} \Big/ \frac{r_2^2}{l_2} = 1/2\right)$

16. (D) Magnetic field at the centre of primary coil $B = \mu_0 i_1 / 2R_1$. considering it to be uniform, magnetic flux passing through secondary coil is

$$\phi_2 = BA = \frac{\mu_0 i_1}{2R_1}(\pi R_2^2)$$

Now, $M = \frac{\phi_2}{i_1} = \frac{\mu_0 \pi R_2^2}{2R_1}$ $\qquad \therefore \quad M \propto \frac{R_2^2}{R_1}$.

17. (A) Here, $N = 400, L = 10\,\text{mH} = 10 \times 10^{-3}\,\text{H}$

$I = 2\,\text{mA} = 2 \times 10^{-3}\,\text{A}$

Total magnetic flux linked with the coil,

$\phi = NLI = 400 \times 10^{-3}\,\text{Wb}$

Magnetic flux through the cross-section of the coil

= Magnetic flux linked with each turn

$$= \frac{\phi}{N} = \frac{8 \times 10^{-3}}{400} = 2 \times 10^{-5}\,\text{Wb}$$

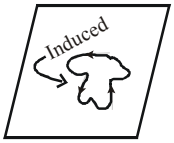
18. (B) Mutual inductance of

$$M = \frac{\mu_0 \mu_r N_1 N_2 A}{l}$$

It is clear that mutual inductance of coils can be increased by increasing the number of turns in the coils.

19. (D) Eddy currents are produced when a metal sheet is placed in a changing magnetic field. In the metal sheet, we can consider closed loops as shown in the figure, through which an induced current flows due to a change of magnetic flux. This current is called eddy current and it gives rise to loss of thermal energy.

20. (A) The assertion is true. The reason is also true. It explains assertion. The bulb fuses when potential difference across it becomes more than 220 volt. Line voltage is 220 V At on and off hour, inductive effect may produce a surge in voltage and the bulb may by fused under higher voltage.



21. (A)

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MOCK TEST

1. **(B)** $q = \int Idt = \int -\frac{1}{r}\frac{d\varphi}{dt}\,dt = -\frac{\Delta\varphi}{r} = \frac{\mu_0 Ia}{\pi r}\ell n2$.

2. **(C)** When the rod rotates, there will be an induced current in the rod. The given situation can be treated as if a rod 'A' of length '3ℓ' rotating in the clockwise direction, while an other say rod 'B' of length '2ℓ' rotating in the anti clockwise direction with same angular speed 'ω'.

As we know that $e = \frac{1}{2}B\omega\ell^2$

For 'A' : For 'B' :

$e_A = \frac{1}{2}B\omega(3\ell)^2$ & $e_B = \frac{1}{2}B(-\omega)(2\ell)^2$

Resultant induced emf will be :

$e = e_A + e_B = \frac{1}{2}B\omega\ell^2(9-4)$ $e = \frac{5}{2}B\omega\ell^2$

3. **(A)** Induced emf $\int_a^b Bvdx = \int_a^b \frac{\mu_0 I}{2\pi x}vdx$

$\Rightarrow$ Induced emf $= \frac{\mu_0 Iv}{2\pi}\ell n\left(\frac{b}{a}\right)$

$\Rightarrow$ Power dissipated $= \frac{E^2}{R}$

Also, power = F.V $\Rightarrow F = \frac{E^2}{VR}$

$\Rightarrow F = \frac{1}{VR}\left[\frac{\mu_0 IV}{2\pi}\ell n\left(\frac{b}{a}\right)\right]^2$ **Ans.**

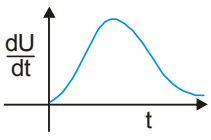
4. **(A)** Rate of increment of energy in inductor $= \frac{dU}{dt} = \frac{d}{dt}$

$\left(\frac{1}{2}Li^2\right) = Li\frac{di}{dt}$

Current in the inductor at time t is:

$i = i_0(1-e^{-\frac{t}{\tau}})$ and $\frac{di}{dt} = \frac{i_0}{\tau}e^{-\frac{t}{\tau}}$

$\therefore \frac{dU}{dt} = \frac{Li_0^2}{\tau}e^{-\frac{t}{\tau}}(1-e^{-\frac{t}{\tau}})$



$\frac{dU}{dt} = 0$ at $t = 0$ and $t = \infty$

Hence E is best represented by :

5. **(A)** $L = \frac{\mu_0 N^2 \pi r^2}{\ell}$

length of wire = $N\,2\pi r$ = Constant (= C, suppose)

$\therefore L = \mu_0\left(\frac{C}{2\pi r}\right)^2\frac{\pi r^2}{\ell}$

$\therefore L \propto \frac{1}{\ell}$

$\therefore$ Self inductance will become 2L.

6. **(B)** $\int \vec{E}.d\vec{r} = -\frac{d\varphi}{dt}$

and take the sign of flux according to right hand curl rule.

$\int \vec{E}.d\vec{r} = -(-(-\alpha A) - (-\alpha A) + (-\alpha A)) = -\alpha A$

7. **(A)** Given :

Voltage in primary $V_p = 200$ volt

Current in primary $i_p = 2$ amp

Voltage in secondary $V_s = 2000$ volt

The relation for the current in the secondary is

$\frac{V_s}{V_p} = \frac{i_p}{i_s}$

$\frac{2000}{200} = \frac{2}{i_s}$ or $i_s = \frac{2\times 200}{2000} = 0.2$ amp.

8. **(C)** Flux can't change in a superconducting loop.

$\Delta\phi = 2\pi R^2.B$

Initially current was zero. So self flux was zero.

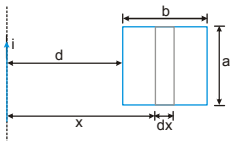
$\therefore$ Finally $Li = 2\pi R^2 \times B$.

$i = \frac{2\pi R^2 \times B}{L}$

9. **(B)** $BlV = iR + \frac{q}{C}$ or $BlV = \left(\frac{dq}{dt}\right)R + \frac{q}{C}$

Hence the charge on capacitor increases with time.

10. **(A)** The flux in rectangular loop due to current i in wire is



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$$\phi = \int_{d}^{d+b} \frac{\mu_0 i}{2\pi x}\, a\, dx = \frac{\mu_0 ia}{2\pi}\, \ell n\, \frac{b+d}{d}$$

Mutual inductance is

$$M = \frac{\varphi}{i} = \frac{\mu_0 a}{2\pi}\, \ell n\, \frac{b+d}{d}$$

$\therefore$ Mutual inductance is proportional to 'a'.

11. **(C)** When the magnetic goes away from the ring the flux in the ring decreases hence the induced current will be such that it opposes the decreasing flux in it hence ring will behave like a magnet having face A as north pole and face B as south pole.

12. **(C)** Just before opening the switch, the current in the inductor is ε/R. Energy stored in it $= \frac{1}{2} L \left(\frac{\varepsilon}{R}\right)^2$.

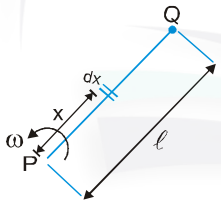
This energy will dissipate in the resistors R_1 and R_2 in the ratio $\frac{1}{R_1}$ & $\frac{1}{R_2}$.

13. **(B)** Charge on the differential element dx, $dq = \frac{Q}{\ell}.dx$

equivalent current di = f dq

$\therefore$ magnetic moment of this element $d\mu = (di)\, NA$ (N = 1)

$$= \left(\pi x^2\right) f \frac{Q}{\ell} dx$$



$$\Rightarrow \mu = \int_0^{\mu} d\mu = \frac{\pi f Q}{\ell} \int_0^{\ell} x^2\, dx \quad ;$$

$$\mu = \frac{1}{3} \pi f Q \ell^2 \ .....$$

14. **(A)** $B_H = B_v \cot\theta = B \cot\theta$

Hence the induced e.m.f. in the rod is B ℓ v cot θ

15. **(D)** Since all the wires are connected between rim and axle so they will generate induced emf in parallel, hence it is same for any number of spokes.

16. **(D)** $\frac{dP}{dt} = \frac{dF.v}{dt} = \frac{Fdv}{dt} = Fa$

as 'a' is decreasing continuously hence the rate of power delivered by external force will be decreasing continuously.

17. **(B)** $e = (\vec{v} \times \vec{B}).\ell$

$e = [\hat{i} \times (3\hat{i} + 4\hat{j} + 5\hat{k})].5\hat{j} \Rightarrow e = 25$ volt

18. **(B)** Time constant $= \frac{1}{20} = 50$ msec

So $i = 0.633\, i_{max} = 0.633\, \frac{E}{R}$

$\Rightarrow E = \frac{3.165 \times 20}{0.633} = 100$ V

19. **(A)** $W = (L)F$

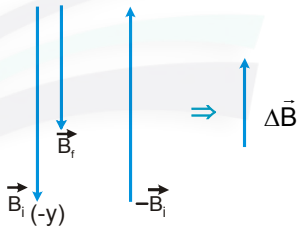
$= L \times ILB = L \times \frac{L^2 B^2 V}{R} = 1$ J

20. **(B)** The field at A and B are out of the paper and inside the paper respectively.



As the current in the straight wire decreases the field also decreases.

For B :



The change in the magnetic field which causes induced current $(\Delta\vec{B})$ is along (+)z direction.

Hence, induced emf and hence current should be such as to oppose this change $\Delta\vec{B}$.

Hence, induced emf should be along – z direction which results in a clockwise current in 'B'. Similarly, there will be anticlockwise current in 'A'. Hence (B).

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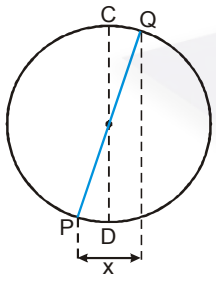
21. **(B)** When the ring falls vertically, there will be an induced emf across A & B (e = Bv (2r)).

Note that there will be a potential difference across any two points on the ring of line joining them has a projected length in the horizontal plane.

For example, between points 'P' & 'Q' there is a projected length 'x' in the horizontal plane.

$\therefore$ P.d. across P & Q is :

$V = Bvx$.



But for points C and D : $x = 0$.

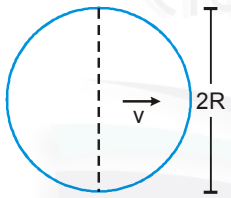
Therefore; P.d. = 0.

Hence **(B)**.

22. **(C)** Considering a projected length 2R on the ring in vertical plane.

This length will move at a speed v perpendicular to the field. This results in an induced emf :

$e = Bv(2R)$ in the ring.



In Ring "A" : $eA = B(-v)(2R)$

In Ring "B" : $eB = B(v)(2R)$

Therefore, potential difference between

A & B = B(v)(2R) - B(-v)(2R) = 4 BvR.

Note : there will be no p.d. across a diameter due to rotation.

$$e = \frac{B\omega(2r)^2}{2} = 2Bvr \text{ in A (since pure rotation).}$$

and $e = -2Bvr$ in B.

Hence **(C)**

23. **(A)** The graph of current is given by :

$$i = i_0(1 - e^{-t/\tau}) \Rightarrow \frac{di}{dt} = \frac{i_0}{\tau} e^{-t/\tau}$$

Energy stored in the form of magnetic field energy is :

$$U_B = \frac{1}{2} Li^2$$

$\therefore$ Rate of increase of magnetic field energy is :

$$R = \frac{dU_B}{dt} = Li\frac{di}{dt} = \frac{Li_0^2}{\tau}(1 - e^{-t/\tau})\, e^{-t/\tau}$$

This will be maximum when $\frac{dR}{dt} = 0$

$$\frac{dR}{dt} = 0 \Rightarrow e^{-t/\tau} = 1/2$$

Substituting :

$$R_{max} = \frac{Li_0^2}{\tau}\left(1 - \frac{1}{2}\right)\left(\frac{1}{2}\right) = \frac{Li_0^2}{4\tau} = \left[\frac{L(E/R)^2}{4(L/R)}\right]$$

$$= \frac{E^2}{4R}$$

24. **(B)** When the switch is at position 1 :

$$U_B = \frac{1}{2} Li_0^2 = \frac{LE^2}{2R^2}$$

Just after the switch is shifted to position 2, current $I = \frac{E}{R}$ is flowing across the resistance. Hence, at that instant P.d. across resistance will be :

$$\Delta V = IR = \frac{E}{R}.R = E$$

Hence **(B)**.

25. **A → R ; B → S ; C → P; D → Q**

Magnetic field is along x axis because when the cube is moved along x-axis, there is no motional emf as $\vec{v} \times \vec{B} = 0$. When the block is moved along y axis, force on the electrons is in direction

$-(j \times i) = k$

Therefore electric field will be created along z-axis.

Now, $c \cdot v \cdot B = 24mV \Rightarrow c = 20$ cm

similarly $b\,vB = 36\,mV \Rightarrow b = 30$ cm

$\therefore$ $a = 25$ cm

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26. **A → Q,S ; B → P,R → C → P,R ; D → Q,S**

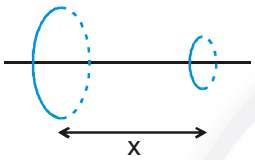
(A) Due to current carrying wire, the magnetic field in loop will be inwards w.r.t. the paper. As current is increased, magnetic flux associated with loop increases. So a current will be induced so as to decrease magnetic flux inside the loop. Hence Induced current in the loop will be anticlockwise. The current in left side of loop shall be downwards and hence repelled by wire. The current in right side of loop is upwards and hence attracted by wire. Since left side of loop is nearer to wire, repulsive force will dominate. Hence wire will repel the loop

(B) Options in (B) will be opposite of that in (A)

(C) When the loop is moved away from wire, mag netic flux decreases in the loop. Hence the op tions for this case shall be same as in (B)

(D) When the loop is moved towards the wire, mag netic flux increases in the loop. Hence the op tions for this case shall be same as in (A)

27. **(A)**



It is obvious that flux linkage in one ring due to current in other coaxial ring is maximum when x = 0 (as shown) or the rings are also coplanar. Hence under this condition their mutual induction is maximum.

28. **(D)** Magnetic field cannot do work, hence statement-1 is false.

29. **(A)** $\oint \vec{B} \cdot d\vec{\ell}$ along any closed path within a uniform magnetic field is always zero. Hence the closed path can be chosen of any size, even very small size enclosing a very small area. Hence we can prove that net current through each area of infinitesimally small size within region of uniform magnetic field is zero. Hence we can say no current (rather than no net current) flows through region of uniform magnetic field. Hence statement -2 is correct explanation of statement-1.

30. **(C)**

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CHAPTER 06

ALTERNATING CURRENT

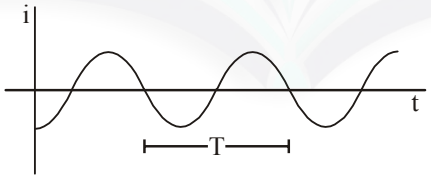
The magnetic force is animate, or imitates a soul; in many respects it surpasses the human soul while it is united to an organic body.

"WILLIAM GILBERT"

INTRODUCTION

When a resistor is connected across the terminals of a battery, a current is established in the circuit. The current has a unique direction, it goes from the positive terminal to the negative terminal via the external resistor. The magnitude of the current also remains almost constant. If the direction of the current in a resistor or in any other element changes alternately, the current is called an alternating current (AC). In this chapter, we shall study the alternating current that varies sinusoidally with time. Such a current is given by

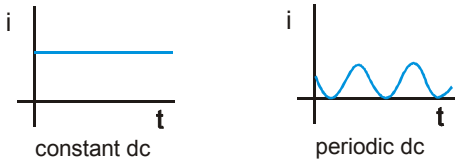
$$i = i_0 \sin(\omega t + \varphi).$$



The current repeats its value after each time interval $T = 2\pi/\omega$. This time interval is called the time period. The current is positive for half the time period and is negative for the remaining half period. This means, its direction reverses after each half time period. The maximum value of the current is i_0 which is called the peak current or the current amplitude. To get sinusoidally varying alternating current, we need a source which can generate sinusoidally varying emf. An AC generator, also called an AC dynamo, can be used as such a source. It converts mechanical energy into electrical energy, producing an alternating emg.

AC and DC Current :

A current that changes its direction periodically is called alternating current (AC). If a current maintains its direction constant it is called direct current (DC).

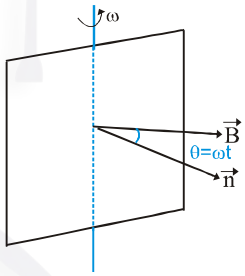


Basic Principle of AC Generation

Alternating voltage is generated by rotating a coil of conducting wire in a strong magnetic field. The magnetic flux linked with the coil changes with time and an alternating emf is thus induced. Instantaneous flux linked with coil is

$$\phi = (\vec{A}.\vec{B})n$$

$$= ABn\cos(\omega t + \theta_0)$$



where A = area of the coil (in m^2)

B = magnetic field (in tesla) n = number of turns

ω = angular frequency = $\frac{2\pi}{T} = 2\pi f$ (in rad s^{-1})

f = frequency (in hertz) θ_0 = initial phase angle

With the change of time $\cos(\omega t + \theta_0)$ changes consequently an emf V is induced. According to Faraday's law

$$V = \frac{d\phi}{dt}$$

$$= -\frac{d}{dt}[Abn\cos(\omega t + \theta_0)] = Abn\ \omega\sin(\omega t + \theta_0) \Rightarrow V = V_m \sin(\omega t + \theta_0)$$

Here V_m = voltage amplitude of sinusoidal voltage or the peak value of ac voltage

where V_m - ABnω

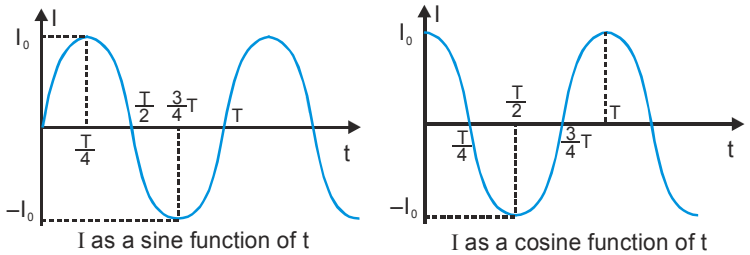
Alternating Current and Voltage

Voltage or current is said to be alternating if it is change continously in magnitude and perodically in direction with time. It can be represented by a sine curve or cosine curve

$I = I_0 \sin \omega t$ or $I = I_0 \cos \omega t$

where I = Instantaneous value of current at time t, I_0 = Amplitude or peak value

ω = Angular frequency $\omega = \frac{2\pi}{T} = 2\pi f$ T = time period f = frequency



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Amplitude of AC

The maximum value of current in either direction is called peak value or the amplitude of current. It is represented by I_0. Peak to peak value = $2I_0$

Periodic Time

The time taken by alternating current to complete one cycle of variation is called periodic time or time period of the current.

Frequency

The number of cycle completed by an alternating current in one second is called the frequency of the current.

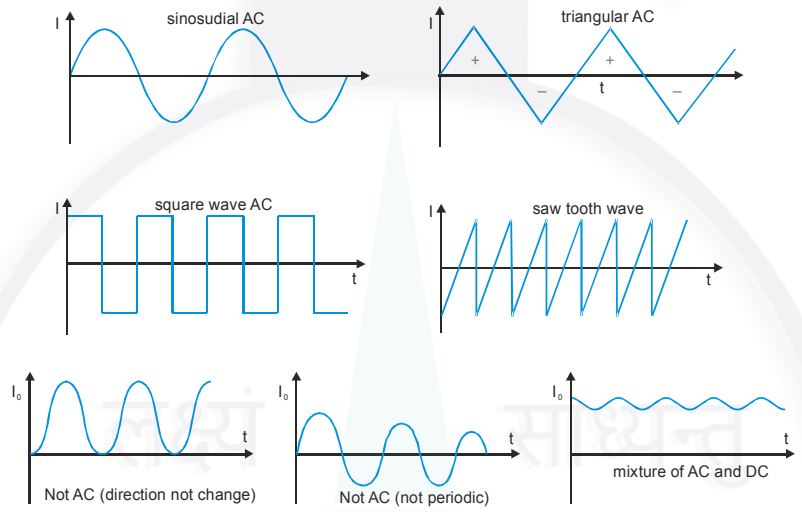
Unit : cycle/s ; (Hz)

In India : f = 50 Hz , supply voltage = 220 volt **In USA :** f = 60 Hz ,supply voltage = 110 volt

Condition required for Current/ Voltage to be Alternating

(a) Amplitude is constant **(b)** Alternate half cycle is positive and half negative

The alternating current continuously varies in magnitude and periodically reverses its direction.



Average Value or Mean Value

The mean value of A.C over any half cycle (either positive or negative) is that value of DC which would send same amount of charge through a circuit as is sent by the AC through same circuit in the same time.

$$\text{average value of current for half cycle } \langle I \rangle = \frac{\int_0^{T/2} I\,dt}{\int_0^{T/2} dt}$$

Average value of $I = I_0 \sin \omega t$ over the positive half cycle :

$$I_{av} = \frac{\int_0^{\frac{T}{2}} I_0 \sin \omega t\, dt}{\int_0^{\frac{T}{2}} dt} = \frac{2I_0}{\omega T}\left[-\cos \omega t\right]_0^{\frac{T}{2}} = \frac{2I_0}{\pi}$$

$\langle \sin\theta \rangle = \langle \sin 2\theta \rangle = 0$
$\langle \cos\theta \rangle = \langle \cos 2\theta \rangle = 0$
$\langle \sin\theta \cos\theta \rangle = 0$
$\langle \sin^2\theta \rangle = \langle \cos^2\theta \rangle = \frac{1}{2}$

- For symmetric AC, average value over full cycle = 0,

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Average value of sinusoidal AC

Full cycle	(+ve) half cycle	(–ve) half cycle
0	$\frac{2I_0}{\pi}$	$\frac{-2I_0}{\pi}$

As the average value of AC over a complete cycle is zero, it is always defined over a half cycle which must be either positive or negative

Maximum Value

(a) $I = a\sin\theta \Rightarrow I_{Max.} = a$

(b) $I = a + b\sin\theta \Rightarrow I_{Max.} = a + b$ (if a and b > 0)

(c) $I = a\sin\theta + b\cos\theta \Rightarrow I_{Max.} = \sqrt{a^2 + b^2}$

(d) $I = a\sin^2\theta \Rightarrow I_{Max.} = a$ (a > 0)

Root Mean square (rms) Value

It is value of DC which would produce same heat in given resistance in given time as is done by the alternating current when passed through the same resistance for the same time.

$$I_{rms} = \sqrt{\frac{\int_0^T I^2 dt}{\int_0^T dt}}$$ rms value = Virtual value = Apparent value

rms value of $I = I_0 \sin \omega t$:

$$I_{rms} = \sqrt{\frac{\int_0^T (I_0 \sin \omega t)^2 dt}{\int_0^T dt}} = \sqrt{\frac{I_0^2}{T}\int_0^T \sin^2 \omega t \, dt} = I_0\sqrt{\frac{1}{T}\int_0^T \left[\frac{1-\cos 2\omega t}{2}\right] dt} = I_0\sqrt{\frac{1}{T}\left[\frac{t}{2} - \frac{\sin 2\omega t}{2\times 2\omega}\right]_0^T} = \frac{I_0}{\sqrt{2}}$$

- If nothing is mentioned then values printed in a.c circuit on electrical appliances, any given or unknown values, reading of AC meters are assumed to be RMS.

Current	Average	Peak	RMS	Angular frequency
$I_1 = I_0 \sin \omega t$	0	I_0	$\frac{I_0}{\sqrt{2}}$	ω
$I_2 = I_0 \sin \omega t \cos \omega t = \frac{I_0}{2}\sin 2\omega t$	0	$\frac{I_0}{2}$	$\frac{I_0}{2\sqrt{2}}$	2ω
$I_3 = I_0 \sin \omega t + I_0 \cos \omega t$	0	$\sqrt{2}I_0$	I_0	ω

- For above varieties of current rms = $\frac{\text{Peak value}}{\sqrt{2}}$

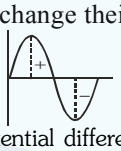
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(i) AC can't be used in
(a) Charging of battery or capacitor (as its average value = 0)
(b) Electrolysis and electroplating (Due to large inertia, ions can not follow frequency of A.C)

(ii) The rate of change of A.C. → Minimum, at that instant when they are near their peak values
→ Maximum, at that instant when they change their direction.

(iii) For alternating current $I_0 > I_{rms} > I_{av.}$

(iv) Average value over half cycle is zero if one quarter is positive and the other quarter is negative.

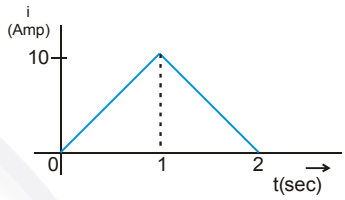


(v) Average value of symmetrical AC for a cycle is zero thats why average potential difference on any element in A.C circuit is zero.

(vi) The instrument based on heating effect of current are works on both A.C and D.C supply and also provides same heating for same value of A.C (rms) and D.C. that's why a bulb bright equally in D.C. and A.C. of same value.

(vii) If the frequency of AC is f then it becomes zero 2f times in one second and the direction of current changes 2f times in one second. Also it become maximum 2f times in one second.

Ex. Find the average value of current shown graphically, from t = 0 to t = 2 sec.



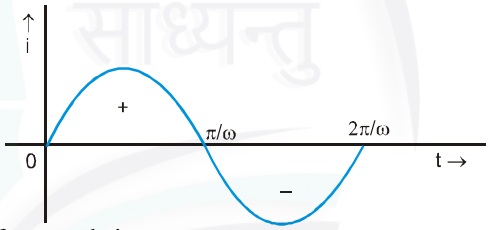
Sol. From the i – t graph, area from t = 0 to t = 2 sec

$$= \frac{1}{2} \times 2 \times 10 = 10 \text{ Amp. sec.}$$

$$\therefore \text{Average Current} = \frac{10}{2} = 5 \text{ Amp.}$$

Ex. Find the average value of current from t = 0 to $t = \frac{2\pi}{\omega}$ if the current varies as $i = I_m \sin \omega t$.

Sol. $$< i > = \frac{\int_0^{\frac{2\pi}{\omega}} I_m \sin \omega t dt}{\frac{2\pi}{\omega}} = \frac{\frac{I_m}{\omega}\left(1 - \cos \omega \frac{2\pi}{\omega}\right)}{\frac{2\pi}{\omega}} = 0$$



It can be seen graphically that the area of i – t graph of one cycle is zero.
$\therefore$ $< i >$ in one cycle = 0.

Ex. Show graphically that the average of sinusoidally varying current in half cycle may or may not be zero

Sol.

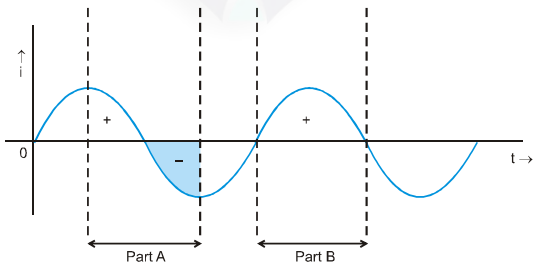


Figure shows two parts A and B, each half cycle. In part A we can see that the net area is zero
$\therefore$ $< i >$ in part A is zero.
In part B, area is positive hence in this part $< i > \neq 0$.

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Ex. Find the average value of current $i = I_m \sin \omega t$ from **(i)** $t = 0$ to $t = \frac{\pi}{\omega}$ **(ii)** $t = \frac{\pi}{2\omega}$ to $t = \frac{3\pi}{2\omega}$.

Sol. **(i)** $\langle i \rangle = \frac{\int_0^{\frac{\pi}{\omega}} I_m \sin \omega t dt}{\frac{\pi}{\omega}} = \frac{\frac{I_m}{\omega}\left(1 - \cos \omega \frac{\pi}{\omega}\right)}{\frac{\pi}{\omega}} = \frac{2I_m}{\pi}$ **(ii)** $\langle i \rangle = \frac{\int_{\frac{\pi}{2\omega}}^{\frac{3\pi}{2\omega}} I_m \sin \omega t dt}{\frac{\pi}{\omega}} = 0.$

Ex. Current in an A.C. circuit is given by $i = 2\sqrt{2}$ sin $(\pi t + \pi/4)$, then the average value of current during time $t = 0$ to $t = 1$ sec is:

Sol. $\langle i \rangle = \frac{\int_0^1 i \, dt}{1} = 2\sqrt{2} \int_0^1 \sin\left(\pi t + \frac{\pi}{4}\right) = \frac{4}{\pi}$ **Ans.**

Root Mean Square Value :

Root Mean Square Value of a function, from t_1 to t_2, is defined as $f_{rms} = \sqrt{\frac{\int_{t_1}^{t_2} f^2 dt}{t_2 - t_1}}$.

Ex. Find the rms value of current from $t = 0$ to $t = \frac{2\pi}{\omega}$ if the current varies as $i = I_m \sin \omega t$.

Sol. $i_{rms} = \sqrt{\frac{\int_0^{\frac{2\pi}{\omega}} I_m^2 \sin^2 \omega t dt}{\frac{2\pi}{\omega}}} = \sqrt{\frac{I_m^2}{2}} = \frac{I_m}{\sqrt{2}}$

Ex. Find the rms value of current $i = I_m \sin \omega t$ from **(i)** $t = 0$ to $t = \frac{\pi}{\omega}$ **(ii)** $t = \frac{\pi}{2\omega}$ to $t = \frac{3\pi}{2\omega}$.

Sol. **(i)** $i_{rms} = \sqrt{\frac{\int_0^{\frac{\pi}{\omega}} I_m^2 \sin^2 \omega t dt}{\frac{\pi}{\omega}}} = \sqrt{\frac{I_m^2}{2}} = \frac{I_m}{\sqrt{2}}$ **(ii)** $\langle i \rangle = \sqrt{\frac{\int_{\frac{\pi}{2\omega}}^{\frac{3\pi}{2\omega}} I_m^2 \sin^2 \omega t \, dt}{\frac{\pi}{\omega}}} = \sqrt{\frac{I_m^2}{2}} = \frac{I_m}{\sqrt{2}}$

Note:
- The r m s values for one cycle and half cycle (either positive half cycle or negative half cycle) is same.
- From the above two Ex.s note that for sinusoidal functions rms value (Also called effective value)

$= \frac{\text{peak value}}{\sqrt{2}}$ or $I_{rms} = \frac{I_m}{\sqrt{2}}$

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Ex. Find the effective value of current $i = 2 \sin 100\pi t + 2 \cos (100\pi t + 30°)$.

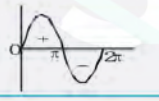
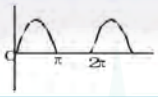
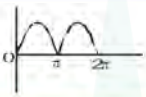
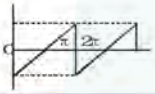
Sol. The equation can be written as $i = 2 \sin 100\pi t + 2 \sin (100\pi t + 120°)$

So phase difference $\phi = 120°$

$$I_m)_{res} = \sqrt{A_1^2 + A_2^2 + 2A_1A_2 \cos\phi}$$

$$= \sqrt{4+4+2\times2\times2\left(-\frac{1}{2}\right)} = 2, \text{ so effective value or rms value} = 2/\sqrt{2} = \sqrt{2}\ A$$

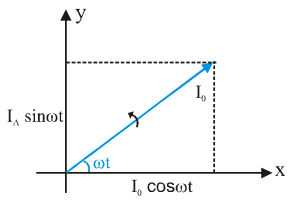
Some Important Wave Forms and their RMS and Average Value

Nature of wave form	Wave-form	RMS Value	Average or mean
Sinusoidal		$\frac{I_0}{\sqrt{2}} = 0.707\ I_0$	$\frac{2I_0}{\pi} = 0.637\ I_0$
Half wave rectifired		$\frac{I_0}{2} = 0.5\ I_0$	$\frac{I_0}{\pi} = 0.318\ I_0$
Full wave rectifired		$\frac{I_0}{\sqrt{2}} = 0.707\ I_0$	$\frac{2I_0}{\pi} = 0.637\ I$
Square or Rectangular		I_0	I_0
Saw Tooth wave		$\frac{I_0}{\sqrt{3}}$	$\frac{I_0}{2}$

Phasor Diagrams

Generally currents and voltages in ac circuits are represented in the form of phasors or anticlockwise rotating vectors. The length of arrow represents the peak value of the quantity and its projection on x and y axis gives its instantaneous value.

For example let $I = I_0 \sin\omega t$, then it will be represented as shown in the figure. Length of arrow is I_0 which represents the peak value of I. Its projection on y axis is $I_0 \sin\omega t$ which represents the instantaneous value. ωt is the phase angle which increases with time.



Note : If the equation of current were in sosine from as $I = I_0 \cos\omega t$ then projection on x axis will represent the instantaneous value.

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AC Circuits

Basic AC circuit elements are resistors, indicators and capacitor we will discuss the behaviour of each of them when connected in ac circuits.

AC Voltage Applied to a Resistor

A resistor connected to a source ε of ac voltage as shown in the circuit diagram. The symbol for an ac source on a circuit diagram is ⊖. For simplicity, we consider a source which produces sinusoidally varying potential difference across its terminals. Let this potential difference, also called ac voltage, be given by

$V = V_0 \sin\omega t$ ..... **(i)**

where V_0 is the amplitude of the sinusoidal voltage and ω is its angular frequency.



AC voltage applied to a resistor

The instantaneous potential drop across the resistor R is

$V_0 \sin\omega t = IR$

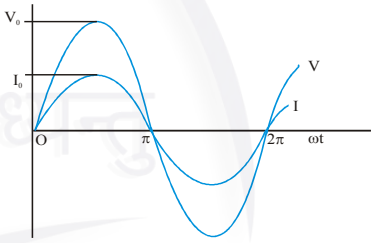
or $I = \frac{V_0}{R}\sin\omega t$

$I = I_0 \sin\omega t$ ..... **(ii)**

where I is the instantaneous current and the current amplitude I0 is given by

$I_0 = \frac{V_0}{R}$ ..... **(iii)**

Equation **(iii)** is just Ohm's law which for resistors work equally well for both ac and dc voltaghes. The voltage across a pure resistor and the current through it, given by equation **(i)** and **(ii)** are ploted as a function of time in figure. Note, in particular that both V and I reach zero, minimum and maximum values at the same time. Clearly, the voltage and current are in phase for a circuit containing pure resistance.



We see that,. like the applied voltage, the current varies sinusoidally and has corresponding positive and negative values during each cycle. Thus, the sum of the instantaneous current valuesover one complete cycle is zero, and the average current is zero. The fact that the average current is zero, however, does not mean that the average power is zero and that there is no dissipation of electrical energy. As you know, joule heating is given by I^2R and depends on I^2 (which is always positive whether I is positive or negative) and not on I. Thus there is Joule heating and dissipation of electrical energy when an ac current passes through a resistor.

The instantaneous power dissipated in the resistor is

$P = I^2R = I_0^2 R \sin^2\omega t$ ..... **(iv)**

The average value of Power P over a cycle is

$\bar{P} = \frac{1}{2} I_0^2 R = I_{rms}^2 R$ ..... **(v)**

Where the bar over a letter (here, P) denotes its average value.

To express ac power in the same fprm as dc power ($P=I^2R$), as special value of current is used. It is called, root mean square (rms) or effective current and is denoted by I_{rms}.

similarly, we define the rms voltage or effective voltage

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From equation (iii), we have

$$V_0 = I_0 R \qquad \text{..... (vi)}$$

or $$\frac{V_0}{\sqrt{2}} = \frac{I_0}{\sqrt{2}} R \qquad \text{..... (vii)}$$

or $$V_{rms} = I_{rms} R \qquad \text{..... (viii)}$$

In terms of rms values, the equation for power and relation between current and voltage in ac circuits are essentially the same as those for the dc case.

In fact, the I_{rms} or rms current is the equivalent dc current that would produce same average power loss as tghe alternating current. Equation (v) can also be written as

$$\vec{P} = V_{rms}^2 / = I_{rms}^2 R \qquad (\text{since } V_{rms} = I_{rms} R) \qquad \text{..... (ix)}$$

Ex. A bulb is rated 60 W at 220 V/30 Hz. Find the maximum value of instantaneous current through the filament ?

Sol. $V_{max} = 220\sqrt{2} = 311$ V

$$R = \frac{220^2}{P} = \frac{220\times220}{60} = \frac{2420}{2} = 806.67\Omega$$

$$I = \frac{V_{max}}{R} = \frac{311}{806.67} = 0.39A$$

Ex. A light bulb is rated at 200 W for a 220 V supply. Find

(a) The resistance of the bulb

(b) The peak voltage of the source; and

(c) The rms current through the bulb.

Sol. **(a)** We are given P = 100 W and V = 220 V. The resistance of the bulb is

$$R = \frac{V_{rms}^2}{P} = \frac{(220V)^2}{200W} = 242\Omega$$

(b) The peak voltage of the source is

$$V_m = \sqrt{2}V_{max} = 311V$$

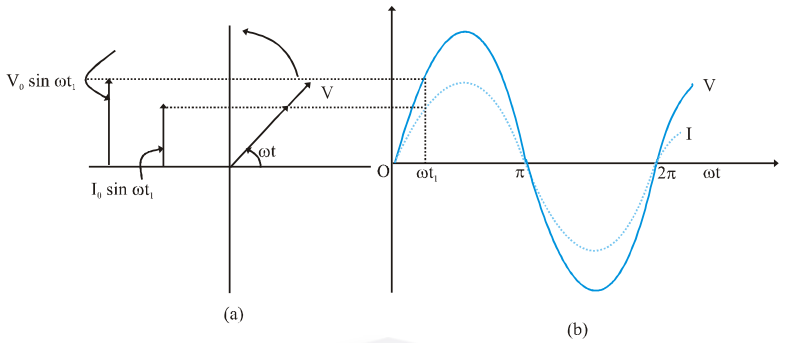
(c) Since, $P = I_{rms} V_{rms}$

$$I_{rms} = \frac{P}{V_{rms}} = \frac{200W}{220V} = 0.90A$$

Representation of AC Current and Voltage by Rotating Vectors - Phasors

In the previous section, we saw that the current through a resistor is in phase with the ac voltage. But this is not so in the case of an inductor, a capacitor or a combination. In order to show phase relationship betwen voltage and current in an ac circuit, we use the motion of PHASORS. The analysis of an ac circuit is faciliated by the use of a phasor diagram. a phasor is a vector which rotates about the origin with angular speed ω, as shown in figure. The vertical components of phasors V and I represent the sinusoidally varying quantities V and I. The magnetic of phasors V and I represent the amplitudes or the peak values V_0 and I_0 of these oscillating quantities. Figure (a) shows the voltage and their relationship at time t_1 i.e., corresponding to the circuit show in figure for the case of an ac source connected to a resistor. The projection of voltage and current phasors on vertical axis, i.e., $V_0 \sin \omega t$ and $I_0 \sin \omega t$, respectively represent the instaneous value of voltage and current at that instant. As they rotate with frequency ω, curves in figure (b) are generated which represent the sinusoidal variation of voltage and current with time.

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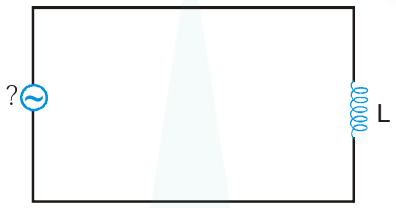


(a) A phasor diagram for the circuit in figure
(b) Graph of V and I versus ω

AC Voltage Applied to an Inductor :

An ac source connected to an inductor as shown in the circuit below. Usually, inductors have appreciable resistance in their windings but we shall assume that this is ideal inductor (having zero resistance). Thus, the circuit is a purely inductive ac circuit. Let the voltage across the source be $V = V_0 \sin \omega t$. Using the loop equation $\sum \varepsilon(t) = 0$, and since there is no resistor in the circuit.

$$V - L\frac{dI}{dt} = 0 \qquad \text{..... (x)}$$



An AC source connected to an inductor

where the second term is the self-induced emf in the inductor, and L is the self-inductance of the coil. Combining equation (i) and (x), we have

$$\frac{dI}{dt} = \frac{V}{L} = \frac{V_0}{L}\sin \omega t \qquad \text{..... (xi)}$$

$$dt = \frac{V_0}{L}\sin \omega t \ dt \quad \Rightarrow \quad I = -\frac{V_0}{\omega L}\cos(\omega t)$$

Using $-\cos(\omega t) = \sin\left(\omega t - \frac{\pi}{2}\right)$, we have

$$i = I_0 \sin\left(\omega t - \frac{\pi}{2}\right) \qquad \text{..... (xii)}$$

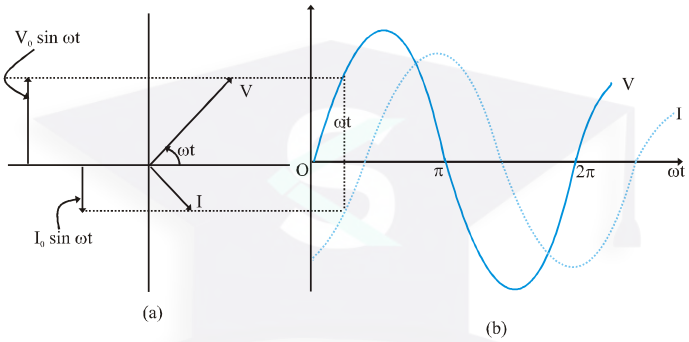
where $I = -\frac{V_0}{\omega L}$ is the amplitude of the current. The quantity ωL is analogous to the resistance and is called inductive reactance, denoted by X_L :

$$X_L = \omega L = 2\pi fL \qquad \text{..... (xiii)}$$

The dimension of inductive reactance is the same as that of resistance and SI unit is ohm(Ω). The inductive reactance limits the current in a pure inductive circuit in the same way as does the resistance in a pure resistive circuit. The inductive resistance is the directly proportional to the inductance frequency of the voltage source.

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A comparision of equation **(i)** and **(ii)** for the source voltage and the current in an inductor shows that the current lags the voltage by $\frac{\pi}{2}$ or one-quarter $\left(\frac{1}{4}\right)$ cycle. Figure a shows the voltage and the current phasors in the present case at instant t. The current phasor is 1 is $\frac{\pi}{2}$ behind the voltage phasor V. When rotated with frequency ω counter-clockwise, they generate the voltage and current given by equation **(1)** and **(xii)**, respectively and as shown in figure **(b)**.



(a) A phasor diagram for the circuit in figure
(b) Graph of V and I versus ωt

We see that current reaches its maximum value later than the voltage by one-fourth of a period $\left[\frac{T}{4} = \frac{\pi/2}{\omega}\right]$. You have seen that an inductor has reactance that limits current similar to resistance in a dc circuit. Does it also consume power like a resistance ? Let us try to find out.
The instantaneous power supplied to the inductor is

$$P_L = IV = I_m \sin\left(\omega t - \frac{\pi}{2}\right) V_0 \sin(\omega t) = -I_0 V_0 \cos(\omega t).\sin(\omega t) = -\frac{I_0 V_0}{2}\sin(2\omega t) \quad \text{..... (xiv)}$$

So, the average power over a complete cycle is zero
since the average of sin(2ωt) over a complete cycle is zero.

Thus, the average power supplied to an inductor over one complete cycle is zero.

Physically, this result means the follows, During the first quarter of each current cycle, the flux through the inductor builds up and sets uo a magnetic field and energy is stored in the inductor. In the next quarter of cycle, as the current decrease, the flux decreases and the stored energy is returned to the source. Thus, in each half cycle, the energy which is withdrawn from the source is returned to it without any dissipation of power.

Ex. A pure inductor of 50.0 mH is connected to a source of 220 V. Find the inductive resistance and rms current in the circuit if the frequency of the source is 50 Hz.

Sol. The inductive reactance.

$$X_L = 2\pi fL = 2 \times 3.14 \times 50 \times 50 \times 10^{-3}\,\Omega = 15.7\,\Omega$$

The rms current in the circuit is

$$I_{rms} - \frac{V_{rms}}{X_L} = \frac{220V}{15.7\Omega} = 14.01\text{A}$$

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AC Voltage Applied to A Capacitor

An ac source ε connected to a capacitor only, a purely capacitive ac circuit is as shown.



An AC source connected to a capacitor

When the capacitor is connected to an ac source, as in figure, it limits or regulates the current, but does not completely prevent the flow of charge. The capacitor is alternately charged and discharged as the current reverses each half cycle. Let 1(t) be the charge on the capacitor at any time t. The instantaneous voltage V(t) across the capacitor is

$$V(t)=\frac{q(t)}{C} \qquad \text{..... (xv)}$$

To find the current, we use the relation $I=\frac{dq}{dt}$

$$I=\frac{d}{dt}(V_0 C\sin\omega t)=\omega C V_0\cos(\omega t)$$

Using the relation, $\cos(\omega t)=\sin\left(\omega t+\frac{\pi}{2}\right)$, we have

$$I=I_0\sin\left(\omega t+\frac{\pi}{2}\right) \qquad \text{..... (xvi)}$$

where the amplitude of the oscillating current is

$$I_0=\frac{V_0}{(I/\omega C)}$$

Comparing it to $I_0=\frac{V_0}{R}$ for a purely resistive circuitmm we find that (I/ωC) plays the role of resistance.

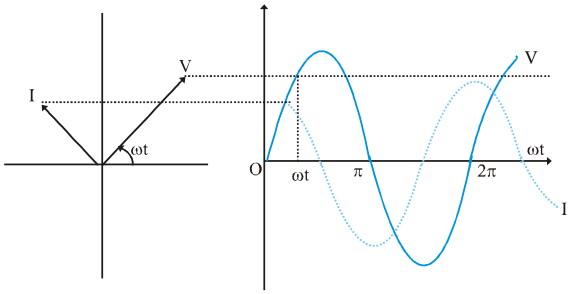
It is called capacitive reactance and is denoted by X_c,

$$X_c=1/\omega C=1/2\pi fC \qquad \text{..... (xvii)}$$

So that the amplitude of the current is

$$I_0=\frac{V_0}{X_c} \qquad \text{..... (xviii)}$$

The dimension of capacitive reactance is the same as that of resistance and its SI unit is Ohm (Ω). The capacitive reactance limits the amplitude of the current in a purely capacitive circuit in the same way as does the resistance in a purely resistive circuit. But it is inversely proportional to the frequency and the capacitance.



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AS comparision of equation (xvii) with the equation of source voltage equation (i) shows that the current in a capacitor leads the voltage by π/2. Figure shows the phasor diagram at an instant t. here the current phasor I is $\frac{\pi}{2}$ rad ahead of the voltage phasor V as they rotate counter clockwise. Figure shows the variation of voltage and current with time. We see that the current reaches its maximum value earlier than the voltage by one-fourth of a period.

The instantaneous power supplied to the capacitor is

$$P_c = IV = I_0 \cos(\omega t).\ V_0 \sin(\omega t)$$
$$= I_0\ V_0 \cos(\omega t) \sin(\omega t)$$
$$= \frac{I_0 V_0}{2}\sin(2\omega t) \qquad \text{..... (xiv)}$$

So, as in the case of an inductor, the average power

Since average of sin 2ωt over a complete cycle is zero. As discussed in the case of an inductor, the energy stored by a capacitor in each quarter period is returned to the source in the next quarter period.

Thus, we see that in the case of an inductor. The current lags the voltage by 90° and in the case of a capacitor, the current leads the voltage by 90°.

Ex. 30.0 μF capacitor is connected to a 220 V, 50 Hz source. Find the capacitive resistance and the current (rms and peak) in the circuit. If the frequency is doubled, what happens to the capacitive reactance and the current.

Sol. The capacitive reactance is

$$X_c = \frac{1}{2\pi fC} = 106\Omega$$

The rms current is

$$i_{rms} = \frac{V_{rms}}{X_c} = 2.08\text{A}$$

The peak current is

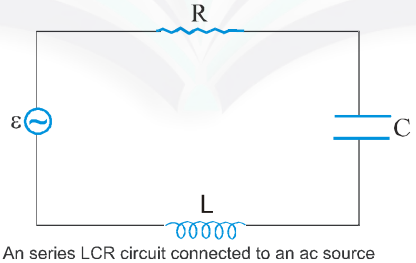
$$I_0 = \sqrt{2} I_{rms} = 2.96\text{A}$$

This current oscillates betwen 2.96A and –2.96A and is ahead of the voltage by 90°.

If the frequency is doubled, the capacitive reactance is halved and consequently, the current is doubled.

AC Voltage Applied to a Series LCR Circuit

Figure shows a series LCR circuit connected to an ac source ε. As usual, we take the voltage of the source to be $V = V_0 \sin\omega t$.



An series LCR circuit connected to an ac source

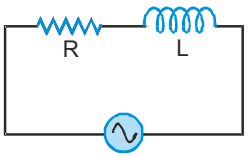
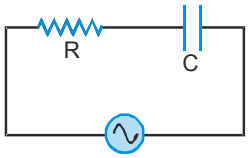
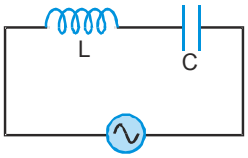
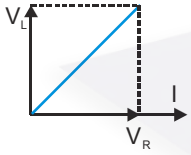
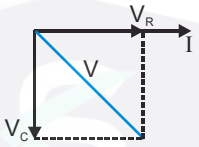
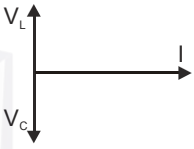
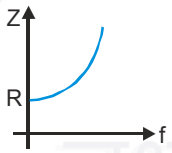
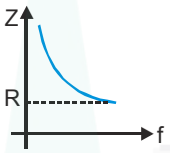
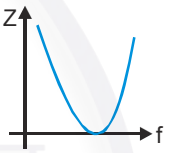
If q is the charge on the capacitor and I the current, at time t, we have, from Kirchhoff's loop rule :

$$L\frac{dI}{dt} + IR + \frac{q}{C} = V \qquad \text{..... (xx)}$$

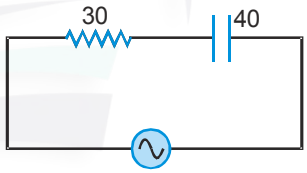
We want to determine the instantaneous current I and its phase relationship to the applied alternating voltage V. We shall use the technique of phasors so solve equation (xx) to obtain the time - dependence of I.

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Combination of Components (R-L or R-C or L-C)

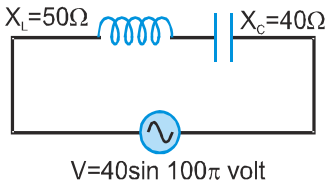
Term	R-L	R-C	L-C
Circuit	 I is same in R & L	 I is same in R & C	 I is same in L & C
Phasor diagram	 $V^2 = V_R^2 + V_L^2$	 $V^2 = V_R^2 + V_C^2$	 $V = V_L - V_C (V_L > V_C)$ $V = V_C - V_L (V_C > V_L)$
Phase difference in between V & I	V leads I ($\phi = 0$ to $\frac{\pi}{2}$) V leads I ($\phi = +\frac{\pi}{2}$, if $X_L > X_C$)	V lags I ($\phi = -\frac{\pi}{2}$ to 0) Impedance $Z = \sqrt{R^2 + X_L^2}$	V lags I ($\phi = -\frac{\pi}{2}$, if $X_C > X_L$) $Z = \sqrt{R^2 + (X_C)^2}$ $Z = \lvert X_L - X_C \rvert$
Variation of Z with f	as f↑,Z ↑ 	as f↑,Z↓ 	as f↑, Z first ↓ then↑ 
At very low f	$Z \simeq R$ ($X_L \to 0$)	$Z \simeq X_C$	$Z \simeq X_C$
At very high f	$Z \simeq X_L$	$Z \simeq R$ ($X_C \to 0$)	$Z \simeq X_L$

Ex. Calculate the impedance of the circuit shown in the figure.



Sol. $Z = \sqrt{R^2 + (X_c)^2} = \sqrt{(30)^2 + (40)^2} = \sqrt{2500} = 50\ \Omega$

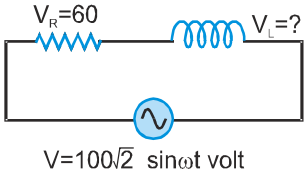
Ex. If $X_L = 50\ \Omega$ and $X_C = 40\ \Omega$ Calculate effective value of current in given circuit.



Sol. $Z = X_L - X_C = 10\ \Omega$

$I_0 = \frac{V_0}{Z} = \frac{40}{10} = 4\ A \quad \Rightarrow \quad I_{rms} = \frac{4}{\sqrt{2}} = 2\sqrt{2}\ A$

Ex. In given circuit calculate, voltage across inductor

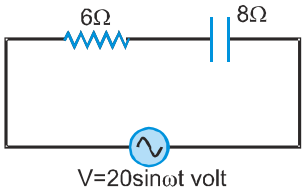


Sol. $\because\ V^2 = V_R^2 + V_L^2 \quad \therefore \quad V_L^2 = V^2 - V_R^2$

$V_L \sqrt{V^2 - V_R^2} = \sqrt{(100)^2 - (60)^2} = \sqrt{6400} = 80\ V$

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Ex. In given circuit find out **(i)** impedance of circuit **(ii)** current in circuit



Sol. **(i)** $Z = \sqrt{R^2 + X_C^2} = \sqrt{(6)^2 + (8)^2} = 10\,\Omega$

(ii) $V = IZ \Rightarrow I = \frac{V_0}{Z} = \frac{20}{10} = 2A$ So $I_{rms} = \frac{2}{\sqrt{2}} = \sqrt{2}\ A$

Ex. When 10V, DC is applied across a coil current through it is 2.5 A, if 10V, 50 Hz A.C. is applied current reduces to 2 A. Calculate reactance of the coil.

Sol. For 10 V D.C. $\because V = IR$ $\therefore$ Resistance of coil $R = \frac{10}{2.5} = 4\Omega$ For 10 V A.C. $\leftarrow V = IZ \Rightarrow Z = \frac{V}{I} = \frac{20}{10} = 5\Omega$

$\because Z = \sqrt{R^2 + X_L^2} = 5 \Rightarrow R^2 + X_L^2 = 25 \Rightarrow X_L^2 = 5^2 - 4^2 \Rightarrow X_L = 3\,\Omega$

Ex. When an alternating voltage of 220V is applied across a device X, a current of 0.5 A flows through the circuit and is in phase with the applied voltage. When the same voltage is applied across another device Y, the same current again flows through the circuit but it leads the applied voltage by $\pi/2$ radians.

(a) Name the devices X and Y.

(b) Calculate the current flowing in the circuit when same voltage is applied across the series combination of X and Y.

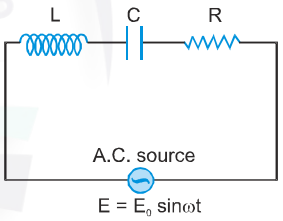
Sol. **(a)** X is resistor and Y is a capacitor

(b) Since the current in the two devices is the same (0.5A at 220 volt)

When R and C are in series across the same voltage then

$$R = X_C = \frac{220}{0.5} = 440\,\Omega \Rightarrow I_{rms} = \frac{V_{rms}}{\sqrt{R^2 + X_C^2}} = \frac{220}{\sqrt{(440)^2 + (440)^2}} = \frac{220}{440\sqrt{2}} = 0.35A$$

Inductance, Capacitance and Resistance in Series (L-C-R series circuit)



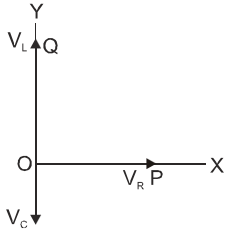
A circuit containing a series combination of an resistance R, a coil of inductance L and a capacitor of capacitance C, connected with a source of alternating e.m.f. of peak value of E_0, as shown in fig.

Phasor Diagram For Series L-C-R circuit

Let in series LCR circuit applied alternating emf is $E = E_0 \sin \omega t$.

As L,C and R are joined in series, therefore, current at any instant through the three elements has the same amplitude and phase.

However voltage across each element bears a different phase relationship with the current.



Let at any instant of time t the current in the circuit is I

Let at this time t the potential differences across L, C, and R

$V_L = I X_L$, $V_C = I X_C$ and $V_R = IR$

Now, V_R is in phase with current I but V_L leads I by 90°

While V_C legs behind I by 90°.

The vector OP represents V_R (which is in phase with I) the vector OQ represent VL (which leads I by 90°)

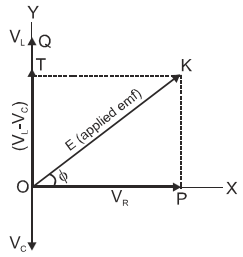
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and the vector OS represents V_C (which legs behind I by 90°)

V_L and V_C are opposite to each other.

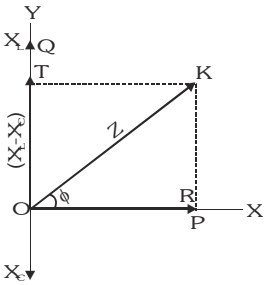
If $V_L > V_C$ (as shown in figure) the their resultant will be $(V_L - V_C)$ which is represented by OT.

Finally, the vector OK represents the resultant of V_R and $(V_L - V_C)$, that is, the resultant of all the three = applied e.m.f.



Thus $E = \sqrt{V_R^2 + (V_L - V_C)^2} = I\sqrt{R^2 + (X_L - X_C)^2} \Rightarrow I = \dfrac{E}{\sqrt{R^2 + (X_L - X_C)^2}}$

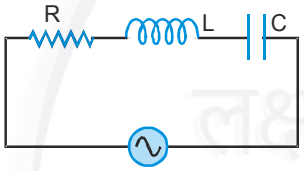
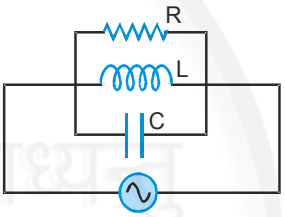
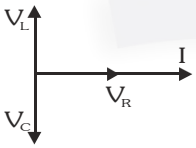
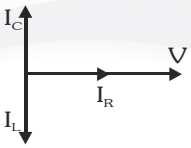
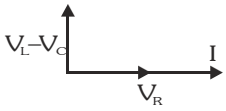
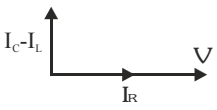
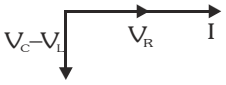
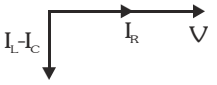
Impedance $Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + \left(\omega L - \dfrac{1}{\omega C}\right)^2}$



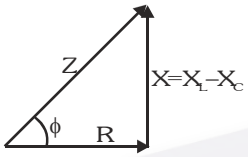
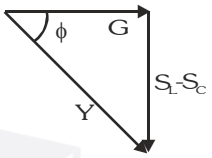
The phasor diagram also shown that in LCR circuit the applied e.m.f.

leads the current I by a phase angle ϕ $\tan\phi = \dfrac{X_L - X_C}{R}$

Series LCR and parallel LCR combination

	Series L-C-R circuit	Parallel L-C-R circuit
1.	**Circuit diagram**  I same for R, L & C	 V same for R,L and C V same for R, L & C
2.	**Phasor diagram** 	
(i)	If $V_L > V_C$ then 	(i) if $I_C > I_L$ then 
(ii)	If $V_C > V_L$ then 	(ii) if $I_L > I_C$ then 

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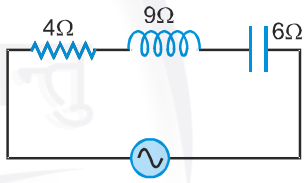
(iii) $V = \sqrt{V_R^2 + (V_L - V_C)^2}$ Impedance $Z = \sqrt{R^2 + (X_L - X_C)^2}$ $\tan\phi = \frac{X_L - X_C}{R} = \frac{V_L - V_C}{V_R}$ **(iv)** Impedance triangle 	**(iii)** $I = \sqrt{I_R^2 + (I_L - I_C)^2}$ Admittance $Y = \sqrt{G^2 + (S_L - S_C)^2}$ $\tan\phi = \frac{S_L - S_C}{G} = \frac{I_L - I_C}{I_R}$ **(iv)** Admittance triangle 

(i)	**Series**	**Parallel**
(a)	if $X_L > X_C$ then V leads I,ϕ (positive) circuit nature inductive	if $S_L > S_C$ ($X_L < X_C$ then V leads I,ϕ (positive) circuit nature inductive
(b)	if $X_C > X_L$ then V lags I,ϕ (negative) circuit nature capacitive	if $S_C > S_L$ ($X_C < X_L$) then V lags I, ϕ (negative) circuit nature capacitive

(ii) In A.C. circuit voltage for L or C may be greater than source voltage or current but it happens only when circuit contains L and C both and on R it never greater than source voltage or current.

(iii) In parallel A.C.circuit phase difference between I_L and I_C is π

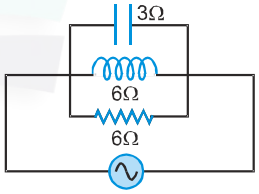
Ex. Find out the impedance of given circuit.



Sol. $Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{4^2 + (9-6)^2} = \sqrt{4^2 + 3^2} = \sqrt{25} = 5\Omega$

($\because X_L > X_C \therefore$ Inductive)

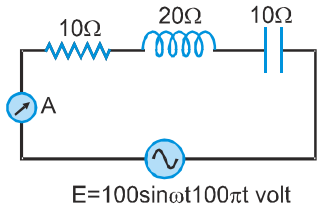
Ex. Find out impedance of given circuit.



Sol. $Y^2 = G^2 + (S_L - S_C)^2 \frac{1}{36} + \left[\frac{1}{6} - \frac{1}{3}\right]^2$

$Y = \frac{\sqrt{2}}{6}\Omega \quad \Rightarrow \quad Z = \frac{6}{\sqrt{2}}\ \Omega$ (capacitive, because $X_L > X_C$)

Ex. Find out reading of A C ammeter and also calculate the potential difference across, resistance and capacitor.



Sol. $Z = \sqrt{R^2 + (X_L - X_C)^2} = 10\sqrt{2}\ \Omega \quad \Rightarrow \quad I_0 = \frac{V_0}{Z} = \frac{100}{10\sqrt{2}} = \frac{10}{\sqrt{2}}A$

$\because$ ammeter reads RMS value, so its reading $= \frac{10}{\sqrt{2}\sqrt{2}} = 5A$

So $V_R = 5 \times 10 = 50$ V and $V_C = 5 \times 10 = 50$ V

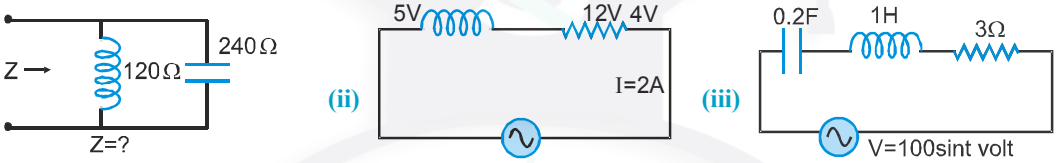
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Ex. In LCR circuit with an AC source R = 300 Ω , C = 20 μF, L = 1.0 H, E_{rms} = 50V and f = 50/π Hz. Find RMS current in the circuit.

Sol. $$I_{rms} = \frac{E_{rms}}{Z} = \frac{E_{rms}}{\sqrt{R^2 + \left[\omega L - \frac{1}{\omega C}\right]^2}} = \frac{50}{\sqrt{300^2 + \left[2\pi \times \frac{50}{\pi} \times 1 - \frac{1}{20 \times 10^{-6} \times 2\pi \times \frac{50}{\pi}}\right]^2}}$$

$$\Rightarrow \quad I_{rms} = \frac{50}{\sqrt{(300)^2 + \left[100 - \frac{10^3}{2}\right]^2}} = \frac{50}{100\sqrt{9+16}} = \frac{1}{10} = 0.1A$$

Ex. Calculate impedance of the given circuit :



Sol. **(i)** It is parallel circuit so Y is evaluated

$$Y = S_L - S_C = \frac{1}{120} - \frac{1}{240} = +\frac{1}{240} \quad \Rightarrow \quad Z = 240\ \Omega \text{ (inductive)}$$

(ii) $V_s^2 = 5^2 + 12^2 = 169 \quad \Rightarrow \quad V_s = 13$ volt therefore $Z = \frac{V_s}{I} = \frac{13}{2} = 6.5\Omega$

(iii) $R = 3\Omega$, $X_L = \omega L = 1$ as $(\omega = 1)$

$X_C = \frac{1}{\omega C} = \frac{1}{(0.2).1} = 5\Omega$ so $Z^2 = R^2 + (X_L - X_C)^2 = 3^2 + (1-5)^2 = 25 \Rightarrow Z = 5\Omega$

Resonance

A circuit is said to be resonant when the natural frequency of circuit is equal to frequency of the applied voltage. For resonance both L and C must be present in circuit.

There are two types of resonance : **(i)** Series Resonance **(ii)** Parallel Resonance

Series Resonance

(a) At Resonance

(i) $X_L = X_C$ **(ii)** $V_L = V_C$ **(iii)** $\phi = 0$ (V and I in same phase)

(iv) $Z_{min} = R$ (impedance minimum) **(v)** $I_{max} = \frac{V}{R}$ (current maximum)

(b) Resonance frequency

$$\because \quad X_L = X_C \Rightarrow \omega_r L = \frac{1}{\omega_r C} \Rightarrow \omega_r^2 = \frac{1}{LC} \Rightarrow \omega_r = \frac{1}{\sqrt{LC}} \Rightarrow f_r = \frac{1}{2\pi\sqrt{LC}}$$

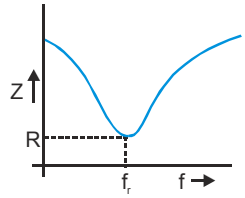
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(c) Variation of Z with f

(i) If $f < f_r$ then $X_L < X_C$ circuit nature capacitive, ϕ (negative)

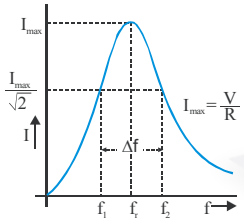
(ii) At $f = f_r$ then $X_L = X_C$ circuit nature, Resistive, ϕ = zero

(iii) If $f > f_r$ then $X_L > X_C$ circuit nature is inductive, ϕ (positive)



Variation of I with f as f increase, Z first decreases then increase

(d)



as f increase, I first increase then decreases

At resonance impedance of the series resonant circuit is minimum so it is called 'acceptor circuit' as it most readily accepts that current out of many currents whose frequency is equal to its natural frequency. In radio or TV tuning we receive the desired station by making the frequency of the circuit equal to that of the desired station.

Half power frequencies

The frequencies at which, power become half of its maximum value called half power frequencies

Band width $= \Delta f = f_2 - f_1$

Quality factor Q : Q-factor of AC circuit basically gives an idea about stored energy & lost energy.

$$Q = 2\pi \frac{\text{maximum energy stored per cycle}}{\text{maximum energy loss per cycle}}$$

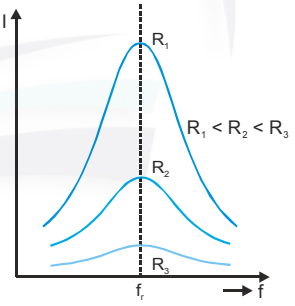
(i) It represents the sharpness of resonance. **(ii)** It is unit less and dimension less quantity

(iii) $Q = \frac{(X_L)_r}{R} = \frac{(X_C)_r}{R} = \frac{2\pi f_r L}{R} = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{f_r}{\Delta f} = \frac{f_r}{\text{band width}}$

Magnification

At resonance V_L or $V_C = QE$ (where E = supplied voltage)

So at resonance Magnification factor = Q-factor



Sharpness

Sharpness ∝ Quality factor ∝ Magnification factor

R decrease ⇒ Q increases ⇒ Sharpness increases

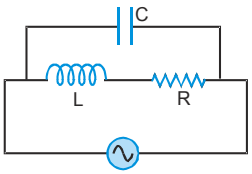
Parallel Resonance

(a) At resonance

(i) $S_L = S_C$ **(ii)** $I_L = I_C$ **(iii)** $\phi = 0$

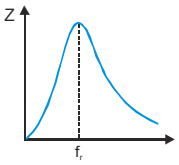
(iv) $Z_{max} = R$ (impedance maximum)

(v) $I_{min} = \frac{V}{R}$ (current minimum)



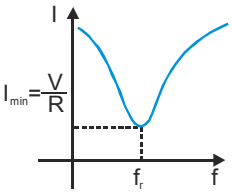
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(b) **Resonant frequency** $f_r = \dfrac{1}{2\pi\sqrt{LC}}$

(c) 

Variation of Z with f as f increases , Z first increases then decreases

- If $f < f_r$ then $S_L > S_C$, ϕ (positive), circuit nature is inductive
- If $f > f_r$ then $S_C > S_L$, ϕ (negative), circuit nature capacitive.



(d) **Variation of I with f** as f increases , I first decreases then increases

Note : For this circuit $f_r = \dfrac{1}{2\pi}\sqrt{\dfrac{1}{LC}-\dfrac{R^2}{L^2}} \Rightarrow Z_{max} = \dfrac{L}{RC}$ For resonance $\dfrac{1}{LC} > \dfrac{R^2}{L^2}$

(i) Series resonance circuit gives voltage amplificaltion while parallel resonance circuit gives current amplification.

(ii) At resonance current does not depend on L and C, it depends only on R and V.

(iii) At half power frequencies : net reactance = net resistance.

(iv) As R increases ,bandwidth increases

(v) To obtain resonance in a circuit following parameter can be altered :

(i) L **(ii)** C **(iii)** frequency of source.

(vi) Two series LCR circuit of same resonance frequency f are joined in series then resonance frequency of series combination is also f

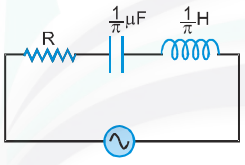
(vii) The series resonance circuit called acceptor whereas parallel resonance circuit called rejector circuit.

(viii) Unit of $\sqrt{LC}$ is second

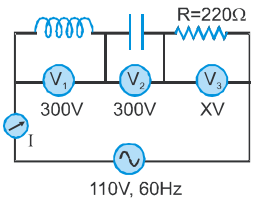
Ex. For what frequency the voltage across the resistance R will be maximum.

Sol. It happens at resonance

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{\frac{1}{\pi}\times 10^{-6}\times\frac{1}{\pi}}} = 500 \text{ Hz}$$



Ex. A capacitor, a resistor and a 40 mH inductor are connected in series to an AC source of frequency 60Hz, calculate the capacitance of the capacitor, if the current is in phase with the voltage. Also calculate the value of X and I.



Sol. At resonance

$$\omega L = \frac{1}{\omega C},\ C = \frac{1}{\omega^2 L} = \frac{1}{4\pi^2 f^2 L} = \frac{1}{4\pi^2\times(60)^2\times 40\times 10^{-3}} = 176\,\mu F$$

$$V = V_R \Rightarrow X = 110\,V \quad \text{and} \quad I = \frac{V}{R} = \frac{110}{220} = 0.5\,A$$

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Ex. A coil, a capacitor and an A.C. source of rms voltage 24 V are connected in series, By varying the frequency of the source, a maximum rms current 6 A is observed, If this coil is connected to a bettery of emf 12 V, and internal resistance 4Ω , then calculate the current through the coil.

Sol. At resonance current is maximum. $I = \frac{V}{R} \Rightarrow$ Resistance of coil $R = \frac{V}{I} = \frac{24}{6} = 4\,\Omega$

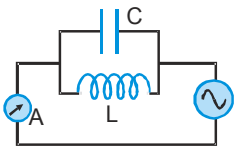
When coil is connected to battery, suppose I current flow through it then $I = \frac{E}{R+r} = \frac{12}{4+4} = 1.5\,A$

Ex. Radio receiver receives a message at 300m band, If the available inductance is 1 mH, then calculate required capacitance

Sol. Radio receives EM waves. (velocity of EM waves $c = 3 \times 10^8$ m/s)

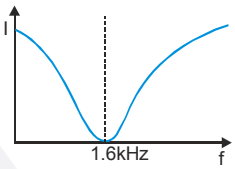
$\therefore \quad c = f\lambda \Rightarrow f = \frac{3\times10^8}{300} = 10^6$ Hz Now $f = \frac{1}{2\pi\sqrt{LC}} = 1 \times 10^6 \Rightarrow C = \frac{1}{4\pi^2 L \times 10^{12}} = 25$ pF

Ex. In a L–C circuit parallel combination of inductance of 0.01 H and a capacitor of 1 μF is connected to a variable frequency alternating current source as shown in figure. Draw a rough sketch of the current variation as the frequency is changed from 1kHz to 3kHz.



Sol. L and C are connected in parallel to the AC source,

so resonance frequency $f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{0.01\times10^{-6}}} = \frac{10^4}{2\pi} \simeq 1.6$kHz



In case of parallel resonance, current in L–C circuit at resonance is zero, so the I-f curve will be as shown in figure.

Power in AC Circuit

The average power dissipation in LCR ac circuit

Let $V = V_0 \sin\omega t$ and $I = I_0 \sin(\omega t - \phi)$

Instantaneous power $P = (V_0 \sin\omega t)(I_0 \sin(\omega t - \phi) = V_0 I_0 \sin\omega t (\sin\omega t\cos\phi - \sin\phi\cos\omega t)$

Average power $\langle P \rangle = \frac{1}{T}\int_0^T (V_0 I_0 \sin^2 \omega t \cos\phi - V_0 I_0 \sin\omega t \cos\omega t \sin\phi)dt$

$$= V_0 I_0 \left[\frac{1}{T}\int_0^T \sin^2\omega t \cos\phi dt - \frac{1}{T}\int_0^T \sin\omega t \cos\omega t \sin\phi dt\right] = V_0 I_0 \left[\frac{1}{2}\cos\phi - 0 \times \sin\phi\right]$$

$$\Rightarrow \quad \langle P \rangle = \frac{V_0 I_0 \cos\phi}{2} = V_{rms} I_{rm,s} \cos\phi$$

Instantaneous power	Average power/actual power/ dissipated power/power loss	Virtual power/ apparent Power/rms Power	Peak power
$P = VI$	$P = V_{rms} I_{rms} \cos\phi$	$P = V_{rms} I_{rms}$	$P = V_0 I_0$

(i) $I_{rms}\cos\phi$ is known as active part of current or wattfull current, workfull current. It is in phase with voltage.

(ii) $I_{rms}\sin\phi$ is known as inactive part of current, wattless current, workless current. It is in quadrature (90°) with voltage.

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Power Factor :

Average power $\bar{P} = E_{rms}\, I_{rms} \cos\phi = r\,m\,s\ power \times \cos\phi$

Power factor $(\cos\phi) = \dfrac{Average\ power}{r\,m\,s\ Power}$ and $\cos\phi = \dfrac{R}{Z}$

Power factor : **(i)** is leading if I leads V **(ii)** is lagging if I lags V

(i) $P_{av} \le P_{rms}$.

(ii) Power factor varies from 0 to 1

(iii)

Pure/Ideal power	ϕ	V	Power factor = $\cos\phi$	Average
R	0	V, I same Phase	1 (maximum)	$V_{rms}.\ I_{rms}$
L	$+\frac{\pi}{2}$	V leads I	0	0
C	$-\frac{\pi}{2}$	V lags I	0	0
Choke coil	$+\frac{\pi}{2}$	V leads I	0	0

(iv) At resonance power factor is maximum ($\phi = 0$ so $\cos\phi = 1$) and $P_{av} = V_{rms}\, I_{rms}$

Ex. A voltage of 10 V and frequency 10^3 Hz is applied to $\frac{1}{\pi}$ μF capacitor in series with a resistor of 500Ω. Find the power factor of the circuit and the power dissipated.

Sol. $\because \quad X_C = \dfrac{1}{2\pi f C} = \dfrac{1}{2\pi \times 10^3 \times \frac{10^{-6}}{\pi}} = 500\Omega \quad \therefore \quad Z = \sqrt{R^2 + X_C^2} = \sqrt{(500)^2 + (500)^2} = 500\sqrt{2}\,\Omega$

Power factor $\cos\phi = \dfrac{R}{Z} = \dfrac{500}{500\sqrt{2}} = \dfrac{1}{\sqrt{2}}$, Power dissipated $= V_{rms}\, I_{rms} \cos\phi = \dfrac{V_{rms}^2}{Z}\cos\phi = \dfrac{(10)^2}{500\sqrt{2}} \times \dfrac{1}{\sqrt{2}} = \dfrac{1}{10}$ W

Ex. If V = 100 sin 100 t volt and I = 100 sin $(100\,t + \frac{\pi}{3})$ mA for an A.C. circuit then find out

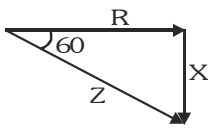
(a) phase difference between V and I **(b)** total impedance, reactance, resistance

(c) power factor and power dissipated **(d)** components contains by circuits

Sol. **(a)** Phase difference $\phi = -\dfrac{\pi}{3}$ (I leads V)

(b) Total impedance $Z = \dfrac{V_0}{I_0} = \dfrac{100}{100 \times 10^{-3}} = 1k\Omega$ Now resistance $R = Z\cos 60° = 1000 \times \dfrac{1}{2} = 500\Omega$

reactance $X = Z\sin 60° = 1000 \times \dfrac{\sqrt{3}}{2} = \dfrac{500}{\sqrt{3}}\Omega$



(c) $\phi = -60° \Rightarrow$ Power factor = $\cos\phi = \cos(-60°) = 0.5$ (leading)

Power dissipated $P = V_{rms}\, I_{rms} \cos\phi = \dfrac{100}{\sqrt{2}} \times \dfrac{0.1}{\sqrt{2}} \times \dfrac{1}{2} = 2.5$ W

(d) Circuit must contains R as $\phi \ne \dfrac{\pi}{2}$ and as ϕ is negative so C must be their, (L may exist but $X_C > X_L$)

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Ex. If power factor of a R-L series circuit is $\frac{1}{2}$ when applied voltage is V = 100 sin 100πt volt and resistance of circuit is 200Ω then calculate the inductance of the circuit.

Sol. $\cos\phi = \frac{R}{Z} \Rightarrow \frac{1}{2} = \frac{R}{Z} \Rightarrow Z = 2R \Rightarrow \sqrt{R^2 + X_L^2} = 2R \Rightarrow X_L = \sqrt{3}\ R$

$\omega L = \sqrt{3}\ R \Rightarrow L = \frac{\sqrt{3}R}{\omega} = \frac{\sqrt{3} \times 200}{100\pi} = \frac{2\sqrt{3}}{\pi} H$

Ex. A circuit consisting of an inductance and a resistance joined to a 200 volt supply (A.C.). It draws a current of 10 ampere. If the power used in the circuit is 1500 watt. Calculate the wattless current.

Sol. Apparent power = 200 × 10 = 2000 W

$\therefore$ Power factor $\cos\phi = \frac{\text{True power}}{\text{Apparent power}} = \frac{1500}{2000} = \frac{3}{4}$

Wattless current = $I_{rms} \sin\phi = 10\sqrt{1 - \left(\frac{3}{4}\right)^2} = \frac{10\sqrt{7}}{4} A$

Ex. A coil has a power factor of 0.866 at 60 Hz. What will be power factor at 180 Hz.

Sol. Given that $\cos\phi = 0.866$, $\omega = 2\pi f = 2\pi \times 60 = 120\pi$ rad/s, $\omega' = 2\pi f' = 2\pi \times 180 = 360\pi$ rad/s

Now, $\cos\phi = R/Z \Rightarrow R = Z\cos\phi = 0.866\ Z$

But $Z = \sqrt{R^2 + (\omega L)^2} \Rightarrow \omega L = \sqrt{Z^2 - R^2} = \sqrt{Z^2 - (0.866\ Z)^2} = 0.5\ Z \therefore L = \frac{0.5Z}{\omega} = \frac{0.5Z}{120\pi}$

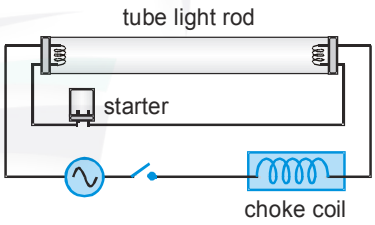
When the frequency is changed to $\omega' = 2\pi \times 180 = 3 \times 120\pi = 300$ rad/s, then inductive reactance $\omega' L = 3\ \omega L = 3 \times 0.5\ Z = 1.5$

$\therefore$ New impedance $Z' = \sqrt{[R'+(\omega' L)^2]} = \sqrt{(0.866\ Z)^2 + (1.5\ Z)^2} = Z\sqrt{[(0.866)^2 + (1.5)^2]} = 1.732Z$

$\therefore$ New power factor $= \frac{R}{Z'} = \frac{0.866\ Z}{1.732\ Z} = 0.5$

Choke Coil

In a direct current circuit, current is reduced with the help of a resistance. Hence there is a loss of electrical energy $I^2 R$ per sec in the form of heat in the resistance. But in an AC circuit the current can be reduced by choke coil which involves very small amount of loss of energy. Choke coil is a copper coil wound over a soft iron laminated core. This coil is put in series with the circuit in which current is to be reduced. It also known as ballast.



Circuit with a choke coil is a series L-R circuit. If resistance of choke coil = r (very small)

The current in the circuit $I = \frac{E}{Z}$ with $Z = \sqrt{(R + r)^2 + (\omega L)^2}$ So due to large inductance L of the coil, the current in the circuit is decreased appreciably. However, due to small resistance of the coil r,

The power loss in the choke $P_{av} = V_{rms}\ I_{rms} \cos\phi \to 0$ $\because$ $\cos\phi = \frac{r}{Z} = \frac{r}{\sqrt{r^2 + \omega^2 L^2}} \approx \frac{r}{\omega L} \to 0$

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(i) Choke coil is a high inductance and negligible resistance coil.
(ii) Choke coil is used to control current in A.C. circuit at negligible power loss
(iii) Choke coil used only in A.C. and not in D.C. circuit
(iv) Choke coil is based on the principle of wattless current.
(v) Iron cored choke coil is used generally at low frequency and air cored at high frequency.
(vi) Resistance of ideal choke coil is zero

Ex. A choke coil and a resistance are connected in series in an a.c circuit and a potential of 130 volt is applied to the circuit. If the potential across the resistance is 50 V. What would be the potential difference across the choke coil.

Sol. $V = \sqrt{V_R^2 + V_L^2} \Rightarrow V_L = \sqrt{V^2 - V_R^2} = \sqrt{(130)^2 - (50)^2} = 120\,V$

Ex. An electric lamp which runs at 80V DC consumes 10 A current. The lamp is connected to 100 V – 50 Hz ac source compute the inductance of the choke required.

Sol. Resistance of lamp $R = \frac{V}{I} = \frac{80}{10} = 8\Omega$

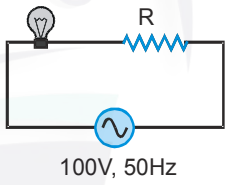
Let Z be the impedance which would maintain a current of 10 A through the Lamp when it is run on 100 Volt a.c. then. $Z = \frac{V}{I} = \frac{100}{10} = 10\ \Omega$ but $Z = \sqrt{R^2 + (\omega L)^2}$

$\Rightarrow (\omega L)^2 = Z^2 - R^2 = (10)^2 - (8)^2 = 36 \Rightarrow \omega L = 6 \Rightarrow L = \frac{6}{\omega} = \frac{6}{2\pi \times 50} = 0.02H$

Ex. Calculate the resistance or inductance required to operate a lamp (60V, 10W) from a source of (100 V, 50 Hz)

Sol. **(a)** Maximum voltage across lamp = 60V

$\because V_{Lamp} + V_R = 100 \quad \therefore V_R = 40V$

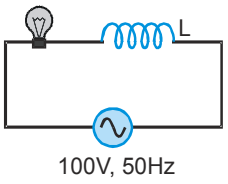


Now current througth Lamp is $= \frac{\text{Wattage}}{\text{voltage}} = \frac{10}{60} = \frac{1}{6}A$

But $V_R = IR \Rightarrow 40 = \frac{1}{6}(R) \Rightarrow R = 240\ \Omega$

(b) Now in this case $(V_{Lamp})^2 + (V_L)^2 = (V)^2$

$(60)^2 + (V_L)^2 = (100)^2 \Rightarrow V_L = 80\ V$

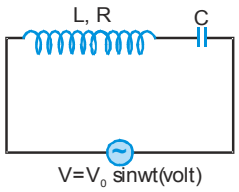


Also $V_L = IX_L = \frac{1}{6}X_L$ so $X_L = 80 \times 6 = 480\ \Omega = L(2\pi f) \Rightarrow L = 1.5\ H$

A capacitor of suitable capacitance replace a choke coil in an AC circuit, the average power consumed in a capacitor is also zero. Hence, like a choke coil, a capacitor can reduce current in AC circuit without power dissipation. Cost of capacitor is much more than the cost of inductance of same reactance that's why choke coil is used.

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Ex. A choke coil of resistance R and inductance L is connected in series with a capacitor C and complete combination is connected to a.c. voltage, Circuit resonates when angular frequency of supply is $\omega = \omega_0$.



(a) Find out relation betwen ω_0, L and C

(b) What is phase difference between V and I at resonance, is it changes when resistance of choke coil is zero.

Sol. **(a)** At resonance condition $X_L = X_C \Rightarrow \omega_0 L = \dfrac{1}{\omega_0 C} \Rightarrow \omega_0 = \dfrac{1}{\sqrt{LC}}$

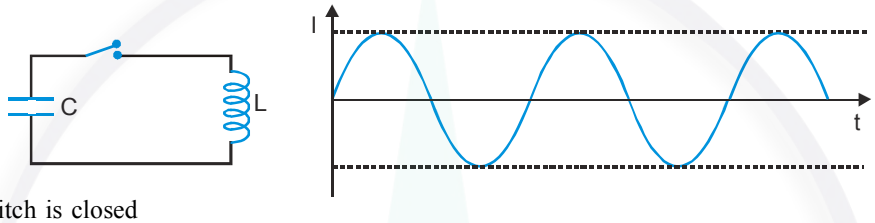
(b) $\because \cos\phi = \dfrac{R}{Z} = \dfrac{R}{R} = 1 \quad \therefore \phi = 0°$ No, It is always zero.

LC Oscillation

The oscillation of energy between capacitor (electric field energy) and inductor (magnetic field energy) is called LC Oscillation.

Undamped Oscillation

When the circuit has no resistance, the energy taken once from the source and given to capacitor keeps on oscillating between C and L then the oscillation produced will be of constant amplitude. These are called undamped oscillation.



After switch is closed

$$\frac{Q}{C} + L\frac{di}{dt} = 0 \Rightarrow \frac{Q}{C} + L\frac{d^2Q}{dt^2} = 0 \Rightarrow \frac{d^2Q}{dt^2} + \frac{1}{LC}Q = 0$$

By comparing with standard equation of free oscillation $\left[\dfrac{d^2x}{dt^2} + \omega^2 x = 0\right]$

$$\omega^2 = \frac{1}{LC} \quad \text{Frequency of oscillation } f = \frac{1}{2\pi\sqrt{LC}}$$

Charge varies sinusoidally with time $q = q_m \cos \omega t$

current also varies periodically with t $\quad I = \dfrac{dq}{dt} = q_m \omega \cos\left(\omega t + \dfrac{\pi}{2}\right)$

If initial charge on capacitor is q_m then electrical energy strored in capacitor is $U_E = \dfrac{1}{2}\dfrac{q_m^2}{C}$

At t = 0 switch is closed, capacitor is starts to discharge.

As the capacitor is fully discharged, the total electrical energy is stored in the inductor in the form of magnetic energy.

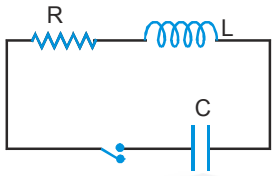
$$U_B = \frac{1}{2}LI_m^2 \qquad \text{where } I_m = \text{max. current}$$

$$(U_{max})_{EPE} = (U_{max})_{MPE} \Rightarrow \frac{1}{2}\frac{q_m^2}{C} = \frac{1}{2}LI_m^2$$

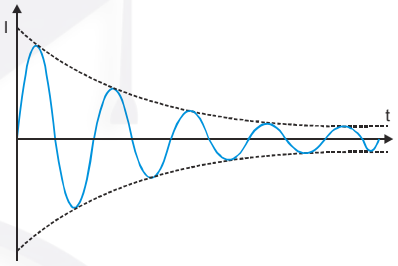
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Damped Oscillation

Practically, a circuit can not be entirely resistanceless, so some part of energy is lost in resistance and amplitude of oscillation goes on decreasing. These are called damped oscillation.



Angular frequency of oscillation $\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$



frequency of oscillation $f = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$

oscillation to be real if $\frac{1}{LC} - \frac{R^2}{4L^2} > 0$

Hence for oscilation to be real $\frac{1}{LC} > \frac{R^2}{4L^2}$

(i) In damped oscillation amplitude of oscillation decreases exponentially with time.

(ii) At $t = \frac{T}{4}, \frac{3T}{4}, \frac{5T}{4}$..... energy stored is completely magnetic.

(iii) At $t = \frac{T}{8}, \frac{3T}{8}, \frac{5T}{8}$..... energy is shared equally between L and C

(iv) Phase difference between charge and current is $\frac{\pi}{2}$ [when charge is maximumum, current minimum / when charge is minimum, current maximum]

Ex. An LC circuit contains a 20mH inductor and a 50μF capacitor with an initial charge of 10mC. The resistance of the circuit is negligible. Let the instant the circuit is closed to be t = 0.

(a) What is the total energy stored initially.

(b) What is the natural frequency of the circuit.

(c) At what time is the energy stored is completely magnetic.

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(d) At what times is the total energy shared equally between inductor and the capacitor.

Sol. **(a)** $U_E = \frac{1}{2}\frac{q^2}{C} = \frac{1}{2} \times \frac{(10 \times 10^{-3})^2}{50 \times 10^{-6}} = 1.0J$

(b) $\omega = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{20 \times 10^{-3} \times 50 \times 10^{-6}}} = 10^3$ rad/sec $\Rightarrow$ f = 159 Hz

(c) $\because \quad q = q_0 \cos \omega t$

Energy stored is completely magnetic (i.e. electrical energy is zero, q = 0)

at $t = \frac{T}{4}, \frac{3T}{4}, \frac{5T}{4} \ldots\ldots\ldots$ where $T = \frac{1}{f} = 6.3$ ms

(d) Energy is shared equally between L and C when charge on capacitor become $\frac{q_0}{\sqrt{2}}$

So, at $t = \frac{T}{8}, \frac{3T}{8}, \frac{5T}{8} \ldots\ldots$ energy is shared equally between L and C

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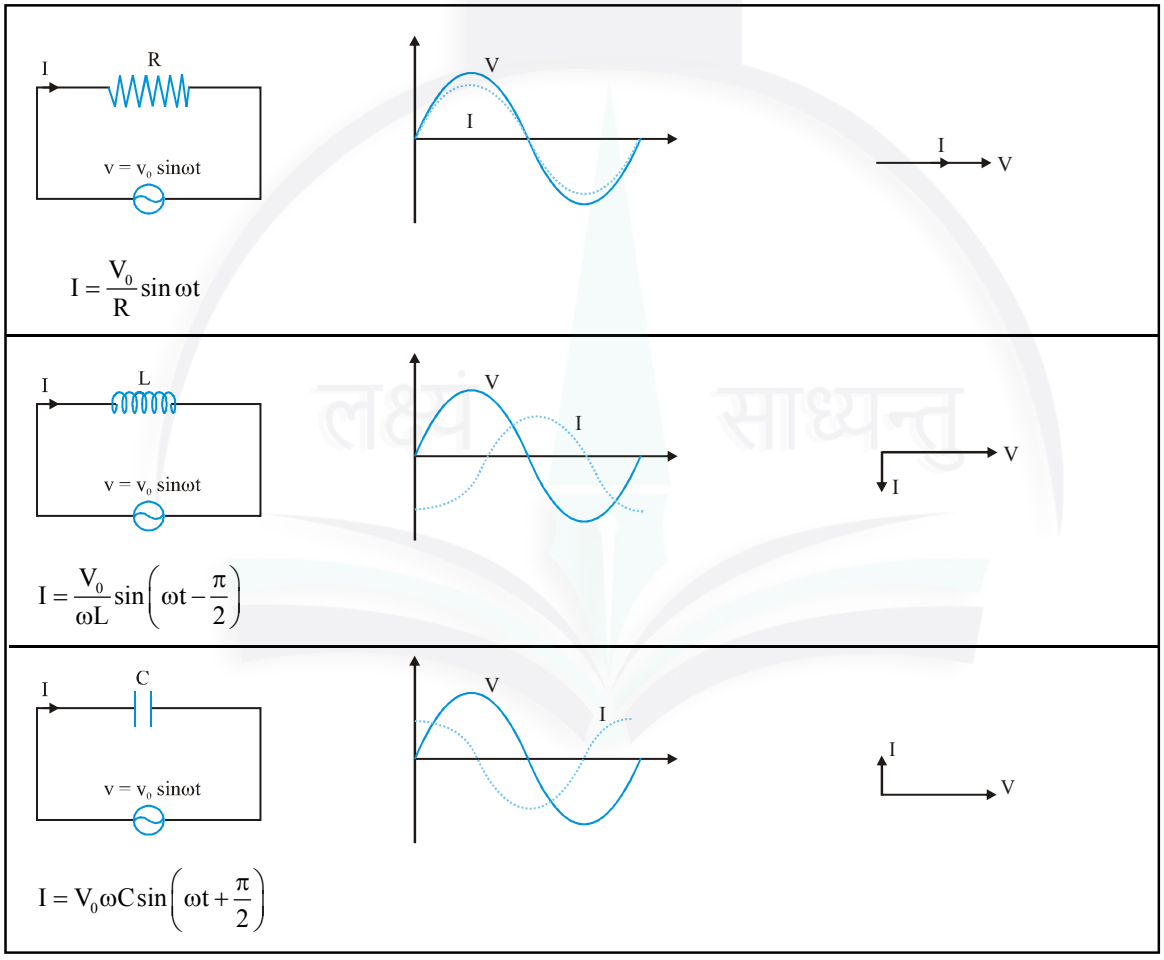
tip&formulas

1. Average value $I_{av} = \dfrac{\int_0^T Idt}{\int_0^T dt} = \dfrac{1}{T}\int_0^T Idt$ **RMS value** $I_{rms} = \sqrt{\dfrac{\int_0^T I^2 dt}{\int_0^T dt}}$

For sinusoidal voltage $V = V_0 \sin \omega t$: $V_{av} = \dfrac{2V_0}{\pi}$ & $V_{rms} = \dfrac{V_0}{\sqrt{2}}$

For sinusoidal current $I = I_0 \sin(\omega t + \phi)$: $I_{av} = \dfrac{2I_0}{\pi}$ & $I_{rms} = \dfrac{I_0}{\sqrt{2}}$

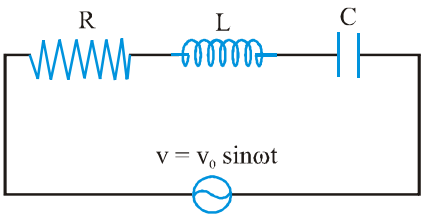
2. AC Circuits



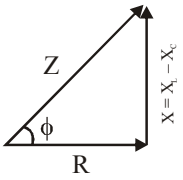
3. Impendance : $Z = \sqrt{R^2 + X^2}$ where X = reactance

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4. Series LCR Circuit



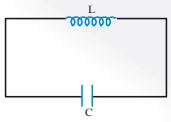
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$;



$$V = \sqrt{V_R^2 + (V_L - V_C)^2}$$

5. Power Factor $= \cos\phi = R/Z$ At resonance : $X_L = X_C \Rightarrow Z = R, V = V_R$

6. LC Oscillation



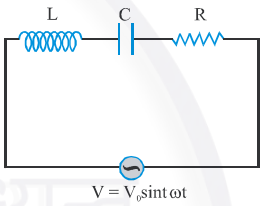
$q = q_0 \sin(\omega t + \theta)$, $I = I_0 \cos(\omega t + \theta)$ $\boxed{I_0 = q_0\omega}$

$$\text{Energy} = \frac{1}{2}LI^2 + \frac{q^2}{2C} = \frac{q_0^2}{2C} = \frac{1}{2}LI_0^2 = \text{constant}$$

Comparison with SHM $q \to x, I \to v, L \to m, C \to \frac{1}{K}$

7. Comparison of Damped Mechanical & Electrical Systems

(a) Series LCR circuit :



$$\frac{d^2q}{dt^2} + \frac{R}{L}\frac{dq}{dt} + \frac{1}{LC}q = \frac{V_0}{L}\cos\omega t$$

compare with mechanical damped system equation

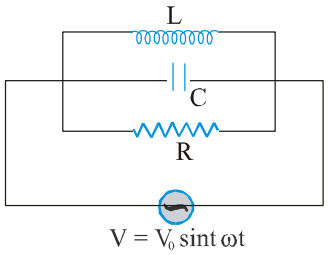
$$\frac{d^2x}{dt^2} + \frac{b}{m}\frac{dx}{dt} + \frac{k}{m}x = \frac{F_0}{m}\cos\omega t$$

where b = damping coefficient.

Mechanical system	Electrical system (series RLC)
Displacement (x)	Charge (q)
Driving force (F)	Driving voltage (V)
Kinetic energy $\left(\frac{1}{2}mv^2\right)$	Electromagnetic energy of moving charge $\frac{1}{2}L\left(\frac{dq}{dt}\right)^2 = \frac{1}{2}LI^2$
Potential energy $\frac{1}{2}kx^2$	Energy of static charge $\frac{q^2}{2C}$
mass (m)	(1/C)
Power P = Fv	Power P = VI
Damping (b)	Resistance (R)

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(b) **Parallel LCR circuit :** In this case



$$I = I_L + I_C + I_R = \frac{\phi}{L} + \frac{d}{dt}C\left(\frac{d\phi}{dt}\right) + \frac{1}{R}\frac{d\phi}{dt} \Rightarrow \frac{d^2\phi}{dt^2} + \frac{1}{RC}\frac{d\phi}{dt^2} + \frac{1}{LC}\phi = \frac{V_0}{ZC}\sin\omega t$$

Displacement (x)	$\Leftrightarrow$	Flux linkage (ϕ)
Velocity $\left(\frac{dx}{dt}\right)$	$\Leftrightarrow$	Voltage $\left(\frac{d\phi}{dt}\right)$
Mass (m)	$\Leftrightarrow$	Capacitance (C)
Spring constant (k)	$\Leftrightarrow$	Reciprocal Industance (1/L)
Damping coefficient (b)	$\Leftrightarrow$	Reciprocal resistance (1/R)
Driving force (F)	$\Leftrightarrow$	Current (i)

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SOLVED EXAMPLE

Ex. 1 The peak voltage in a 220 V AC source is
(A) 220 V **(B)** about 160 V
(C) about 310 V **(D)** 440 V

Sol. $V_0 = \sqrt{2}\ V_{rms} = \sqrt{2} \times 220 \simeq 330$ V
Ans is **(C)**

Ex. 2 An AC source is rated 220 V, 50 Hz. The average voltage is calculated in a time interval of 0.01 s. It
(A) must be zero **(B)** may be zero
(C) is never zero **(D)** is $(220/\sqrt{2})$V

Sol. May be zero
Ans. is **(B)**

Ex. 3 Find the effective value of current i = 2 + 4 cos 100 πt.

Sol. $I_{rms} = \left[\int_0^T \frac{(2+4\cos 100\pi t)^2\, dt}{T}\right]^{1/2} = 2\sqrt{3}$

Ex. 4 The peak value of an alternating current is 5 A and its frequency is 60 Hz. Find its rms value. How long will the current
take to reach the peak value starting from zero?

Sol. $I_{rms} = \frac{I_0}{\sqrt{2}} = \frac{5}{\sqrt{2}}$ A, $\quad t = \frac{T}{4} = \frac{1}{240}$ s

Ex. 5 An alternating current having peak value 14 A is used to heat a metal wire. To produce the same heating effect,
a constant current i can be used where i is
(A) 14 A **(B)** about 20 A
(C) 7 A **(D)** about 10 A

Sol. $I_{RMS} = \frac{I_0}{\sqrt{2}} = \frac{14}{\sqrt{2}} \simeq 10$ Ans. is **(D)**

Ex. 6 Find the average power concumed in the circuit if a voltage $v_s = 200\sqrt{2}$ sin ωt is applied to an AC circuit and
the current in the circuit is found to be i = 2 sin (ωt + π/4) .

Sol. $P = V_{RMS} I_{RMS} \cos\phi = \frac{200\sqrt{2}}{\sqrt{2}} \times \frac{2}{\sqrt{2}} \times \cos\frac{\pi}{4} = 200$ W

Ex. 7 A capacitor acts as an infinite resistance for
(A) DC **(B)** AC
(C) DC as well as AC **(D)** neither AC nor DC

Sol. $x_C = \frac{1}{\omega c}$ for DC ω = 0. so, $x_C = \infty$
Ans. is **(A)**

Ex. 8 A 10 μF capacitor is connected with an ac source $E = 200\sqrt{2}$ sin (100 t) V through an ac ammeter (it reads rms value).
What will be the reading of the ammeter?

Sol. $I_0 = \frac{V_0}{x_C} = \frac{200\sqrt{2}}{1/\omega C}$; $I_{RMS} = \frac{I_0}{\sqrt{2}} = 200$ mA

Ex. 9 Find the reactance of a capacitor (C = 200 μF) when it is connected to **(A)** 10 Hz AC source, **(B)** a 50 Hz AC source
and **(C)** a 500 Hz AC source.

Sol. **(A)** $x_C = \frac{1}{\omega C} = \frac{1}{2\pi fC} \simeq 80\ \Omega$ for f = 10 Hz AC source,
(B) $x_C = \frac{1}{\omega C} = \frac{1}{2\pi fC} \simeq 16\ \Omega$ for f = 50 Hz and
(C) $x_C = \frac{1}{\omega C} = \frac{1}{2\pi fC} \simeq 1.6\ \Omega$ for f = 500 Hz.

Ex. 10 An inductor (L = 200 mH) is connected to an AC source of peak current. What is the intantaneous voltage of the
source when the current is at its peak value?

Sol. Because phase difference between volatage and current is π/2 for pure inductor.
So, Ans. is zero

Ex. 11 An AC source producing emf $E = E_0[\cos(100\ \pi\ s^{-1})t + \cos(500\ \pi\ s^{-1})t]$ is connected in series with a capacitor and a resistor. The current in the circuit is found to be $i = i_1 \cos[(100\ \pi\ s^{-1})t + \varphi_1] + i_2 \cos[(500\ \pi\ s^{-1})t + \varphi_1]$
(A) $i_1 > i_2$ **(B)** $i_1 = i_2$
(C) $i_1 < i_2$
(D) the information is insufficient to find the relation between i_1 and i_2

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Sol. Impedence z is given by $z = \sqrt{\left(\frac{1}{\omega C}\right)^2 + R^2}$

For higher ω, z will be lower so current will be higher

Ans is **(C)**

Ex. 12 An alternating voltage of 220 volt r.m.s. at a frequency of 40 cycles/sec is supplied to a circuit containing a pure inductance of 0.01 H and a pure resistance of 6 ohms in series. Calculate (i) the current, (ii) potential difference across the resistance, (iii) potential difference across the inductance, (iv) the time lag, (v) power factor.

Sol. **(i)** $z = \sqrt{(\omega L)^2 + R^2}$

$= \sqrt{(2\pi \times 40 \times 0.01^2)^2 + 6^2} = \sqrt{(42.4)}$

$I_{rms} = \frac{220}{z} = 33.83$ amp.

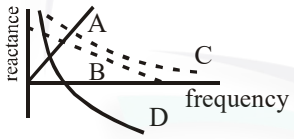
(ii) $V_{rms} = I_{rms} \times R = 202.98$ volts

(iii) $\omega L \times I_{rms} = 96.83$ volts

(iv) $t = T\frac{\phi}{2\pi} = 0.01579$ sec

(v) $\cos\phi = \frac{R}{Z} = 0.92$

Ex. 13 Which of the following plots may represnet the reactance of a series LC combination ?



Sol. D

Ex. 14 A series AC circuit has resistance of 4 Ω and a reactance of 3 Ω. the impedance of the circuit is

(A) 5 Ω

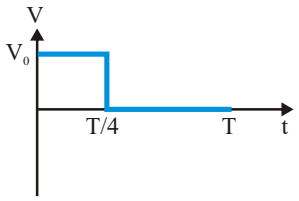
(B) 7 Ω

(C) 12/7 Ω

(D) 7/12 Ω

Sol. $Z = \sqrt{4^2 + 3^2} = 5\ \Omega$ Ans. is **(A)**

Ex.15 A periodic voltage V varies with time t as shown in the figure. T is the time period. The r.m.s. value of the voltage is:-



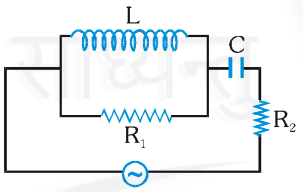
(A) $\frac{V_0}{8}$ **(B)** $\frac{V_0}{2}$

(C) V_0 **(D)** $\frac{V_0}{4}$

Sol. Root mean square value <V>

$$= \sqrt{\frac{\int_0^{T/4} V_0^2 dt}{\int_0^T dt}} = \sqrt{\frac{V_0^2\left(\frac{T}{4}\right)}{T}} == \sqrt{\frac{V_0^2\left(\frac{T}{4}\right)}{T}} = \sqrt{\frac{V_0^2}{4}} = \frac{V_0}{2}$$

Ex.16 For the given circuit



(A) The phase difference between I_L & I_{R_1} is 0°

(B) The phase difference between V_C & V_{R_2} is 90°

(C) The phase difference between I_L & I_{R_1} is 180°

(D) The phase difference between V_C & V_{R_2} is 180°

Sol. The phase difference between V_C and V_{R_2} is $\pi/2$ rad or 90°

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Ex.17 The potential difference V and current I flowing through the AC circuit is given by $V = 5\cos(\omega t - \pi/6)$ volt and $I = 10\sin\omega t$ ampere. The average power dissipated in the circuit is

(A) $\frac{25\sqrt{3}}{2}$ W **(B)** 12.5 W

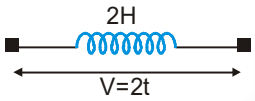
(C) 25 W **(D)** 50 W

Sol. $V = 5\cos(\omega t - \pi/6)$; $i = 10\sin\omega t = 10\cos(\omega t - \pi/2)$

$$\phi = \frac{\pi}{2} - \frac{\pi}{6} = \frac{\pi}{3};$$

$$P = \frac{VI}{2}\cos\phi = \frac{5\times10}{2}\times\frac{1}{2} = 12.5W$$

Ex.18 A time varying voltage V = 2t volt is applied across an ideal inductor of inductance L = 2H as shown in figure. Then select incorrect statement



(A) current versus time graph is a parabola

(B) energy stored in magnetic field at t = 2 s is 4J

(C) potential energy at time t = 1 s in magnetic field is increasing at a rate of 1 J/s

(D) energy stored in magnetic field is zero all the time

Sol. $V = 2t \Rightarrow L\frac{di}{dt} = 2t \Rightarrow 2\times\frac{di}{dt} = 2t \Rightarrow \frac{di}{dt}$

$\Rightarrow i = \frac{t^2}{2} \Rightarrow i - t$ graph parabola

$U = \frac{1}{2}Li^2 = \frac{1}{2}\times2\times4 = 4J$ and

$\frac{dU}{dt} = Li\frac{di}{dt} = 2\times\frac{t^2}{2}\times t = t^3 = 1$ J/s

Ex.19 The radius of a coil decreases steadily at the rate of 10^{-2} m/s. A constant and uniform magnetic field of induction 10^{-3} Wb/m^2 acts perpendicular to the plane of the coil. The radius of the coil when the induced e.m.f. in the coil is 1μV, is :-

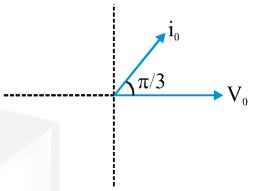
(A) $\frac{2}{\pi}$ cm **(B)** $\frac{3}{\pi}$ cm

(C) $\frac{4}{\pi}$ cm **(D)** $\frac{5}{\pi}$ cm

Sol. $e = \frac{d\phi}{dt} = \frac{d}{dt}(\pi r^2 B) = 2\pi rB\frac{dr}{dt}$

$$\Rightarrow r = \frac{e}{\left(2\pi B\frac{dr}{dt}\right)} \Rightarrow r = \frac{10^{-6}}{2\pi\times10^{-3}\times10^{-2}} = \frac{5}{\pi}\text{cm}$$

Ex.20 For an LCR series circuit, phasors of current i and applied voltage $V = V_0\sin\omega t$ are shown in diagram at t =0. Which of the following is/are correct?



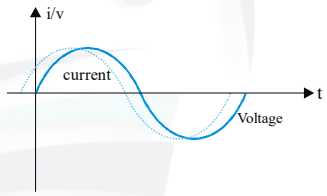
(A) At $t = \frac{\pi}{2\omega}$, instantaneous power supplied by source is negative.

(B) From $0 < t < \frac{2\pi}{3\omega}$, average power supplied by source is positive.

(C) At $t = \frac{5\pi}{6\omega}$, instantaneous power supplied by source is negative.

(D) If ω is increased slightly, angle between the two phasors decreases.

Sol. The graph shows V & I as function of time.



Current leads the voltage by π/3

Power is positive if V & I are of same sign.

Power is negative if V & I are of opposite sign

If $\omega\uparrow \Rightarrow \frac{1}{\omega C}\downarrow$ thus angle decreases.

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Exercise # 1 SINGLE OBJECTIVE NEET LEVEL

1. The power is transmitted from a power house on high voltage ac because
(A) Electric current travels faster at higher *volts*
(B) It is more economical due to less power wastage
(C) It is difficult to generate power at low voltage
(D) Chances of stealing transmission lines are minimized

2. The potential difference V and the current i flowing through an instrument in an ac circuit of frequency f are given by $V = 5\cos\omega t$ *volts* and $I = 2\sin\omega t$ *amperes* (where $\omega = 2\pi f$). The power dissipated in the instrument is
(A) Zero **(B)** 10 W
(C) 5 W **(D)** 2.5 W

3. In an ac circuit, V and I are given by
$V = 100\sin(100\,t)$ *volts*, $I = 100\sin\left(100\,t + \frac{\pi}{3}\right)mA$.
The power dissipated in circuit is
(A) 10^4 *watt* **(B)** 10 *watt*
(C) 2.5 *watt* **(D)** 5 *watt*

4. Alternating current can not be measured by dc ammeter because
(A) ac cannot pass through dc ammeter
(B) Average value of complete cycle is zero
(C) ac is virtual
(D) ac changes its direction

5. The resistance of a coil for dc is in ohms. In ac, the resistance
(A) Will remain same **(B)** Will increase
(C) Will decrease **(D)** Will be zero

6. If instantaneous current is given by $i = 4\cos(\omega t + \phi)$ *amperes*, then the *r.m.s.* value of current is
(A) 4 amperes **(B)** $2\sqrt{2}$ amperes
(C) $4\sqrt{2}$ amperes **(D)** Zero amperes

7. In an ac circuit, peak value of voltage is 423 *volts*. Its effective voltage is
(A) 400 volts **(B)** 323 volts
(C) 300 volts **(D)** 340 volts

8. In an ac circuit $I = 100\sin 200\pi t$. The time required for the current to achieve its peak value will be
(A) $\frac{1}{100}$ *sec* **(B)** $\frac{1}{200}$ *sec*
(C) $\frac{1}{300}$ *sec* **(D)** $\frac{1}{400}$ *sec*

9. The peak value of an Alternating current is 6 *amp*, then *r.m.s.* value of current will be
(A) $3\,A$ **(B)** $3\sqrt{3}\,A$
(C) $3\sqrt{2}\,A$ **(D)** $2\sqrt{3}\,A$

10. A generator produces a voltage that is given by $V = 240\sin 120\,t$, where t is in seconds. The frequency and *r.m.s.* voltage are
(A) 60 *Hz* and 240 V **(B)** 19 *Hz* and 120 V
(C) 19 *Hz* and 170 V **(D)** 754 *Hz* and 70 V

11. If E_0 represents the peak value of the voltage in an ac circuit, the *r.m.s.* value of the voltage will be
(A) $\frac{E_0}{\pi}$ **(B)** $\frac{E_0}{2}$
(C) $\frac{E_0}{\sqrt{\pi}}$ **(D)** $\frac{E_0}{\sqrt{2}}$

12. The peak value of 220 *volts* of ac mains is
(A) 155.6 *volts* **(B)** 220.0 *volts*
(C) 311.0 *volts* **(D)** 440 *volts*

13. A sinusoidal ac current flows through a resistor of resistance R. If the peak current is I_p, then the power dissipated is
(A) $I_p^2 R\cos\theta$ **(B)** $\frac{1}{2}I_p^2 R$
(C) $\frac{4}{\pi}I_p^2 R$ **(D)** $\frac{1}{\pi}I_p^2 R$

14. A 40 Ω electric heater is connected to a 200 V, 50 Hz mains supply. The peak value of electric current flowing in the circuit is approximately
(A) 2.5 A **(B)** 5.0 A
(C) 7 A **(D)** 10 A

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15. The frequency of ac mains in India is

(A) 30 *c/s* or *Hz* **(B)** 50 *c/s* or *Hz*

(C) 60 *c/s* or *Hz* **(D)** 120 *c/s* or *Hz*

16. The *r.m.s.* value of an ac of 50 *Hz* is 10 *amp*. The time taken by the alternating current in reaching from zero to maximum value and the peak value of current will be

(A) 2×10^{-2} *sec* and 14.14 *amp*

(B) 1×10^{-2} *sec* and 7.07 *amp*

(C) 5×10^{-3} *sec* and 7.07 *amp*

(D) 5×10^{-3} *sec* and 14.14 *amp*

17. The root mean square value of the alternating current is equal to

(A) Twice the peak value

(B) Half the peak value

(C) $\frac{1}{\sqrt{2}}$ times the peak value

(D) Equal to the peak value

18. The peak value of an alternating e.m.f. E is given by $E = E_0 \cos \omega t$ is 10 *volts* and its frequency is 50 *Hz*. At time $t = \frac{1}{600}$ *sec* , the instantaneous e.m.f. is

(A) 10 *V* **(B)** $5\sqrt{3}$ *V*

(C) 5 *V* **(D)** 1 *V*

19. If a current I given by $I_0 \sin\left(\omega t - \frac{\pi}{2}\right)$ flows in an ac circuit across which an ac potential of $E = E_0 \sin \omega t$ has been applied, then the power consumption P in the circuit will be

(A) $P = \frac{E_0 I_0}{\sqrt{2}}$ **(B)** $P = \sqrt{2} E_0 I_0$

(C) $P = \frac{E_0 I_0}{2}$ **(D)** $P = 0$

20. In an ac circuit, the instantaneous values of e.m.f. and current are e = 200 sin 314 t *volt* and $i = \sin\left(314\, t + \frac{\pi}{3}\right)$ *ampere*. The average power consumed in *watt* is

(A) 200 **(B)** 100

(C) 50 **(D)** 25

21. An ac generator produced an output voltage $E = 170 \sin 377\, t$ *volts* , where t is in seconds. The frequency of ac voltage is

(A) 50 *Hz* **(B)** 110 *Hz*

(C) 60 *Hz* **(D)** 230 *Hz*

22. In general in an alternating current circuit

(A) The average value of current is zero

(B) The average value of square of the current is zero

(C) Average power dissipation is zero

(D) The phase difference between voltage and current is zero

23. An alternating current is given by the equation $i = i_1 \cos \omega t + i_2 \sin \omega t$. The *r.m.s.* current is given by

(A) $\frac{1}{\sqrt{2}}(i_1 + i_2)$ **(B)** $\frac{1}{\sqrt{2}}(i_i + i_2)^2$

(C) $\frac{1}{\sqrt{2}}(i_1^2 + i_2^2)^{1/2}$ **(D)** $\frac{1}{2}(i_1^2 + i_2^2)^{1/2}$

24. In an ac circuit, the current is given by $i = 5 \sin\left(100\, t - \frac{\pi}{2}\right)$ and the ac potential is $V = 200 \sin(100)$ *volt*. Then the power consumption is

(A) 20 *watts* **(B)** 40 *watts*

(C) 1000 *watts* **(D)** 0 *watt*

25. An electric lamp is connected to 220 *V*, 50 *Hz* supply. Then the peak value of voltage is

(A) 210 V **(B)** 211 *V*

(C) 311 V **(D)** 320 *V*

26. Choke coil works on the principle of

(A) Transient current **(B)** Self induction

(C) Mutual induction **(D)** Wattless current

27. A choke coil has

(A) High inductance and low resistance

(B) Low inductance and high resistance

(C) High inductance and high resistance

(D) Low inductance and low resistance

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28. Choke coil is used to control

(A) ac **(B)** dc

(C) Both ac and dc **(D)** Neither ac nor dc

29. Current in the circuit is wattless, if

(A) Inductance in the circuit is zero

(B) Resistance in the circuit is zero

(C) Current is alternating

(D) Resistance and inductance both are zero

30. The phase angle between e.m.f. and current in *LCR* series ac circuit is

(A) 0 to $\pi/2$ **(B)** $\pi/4$

(C) $\pi/2$ **(D)** π

31. A choke coil is preferred to a rheostat in ac circuit as

(A) It consumes almost zero power

(B) It increases current

(C) It increases power

(D) It increases voltage

32. An alternating e.m.f. is applied to purely capacitive circuit. The phase relation between e.m.f. and current flowing in the circuit is **or** In a circuit containing capacitance only

(A) e.m.f. is ahead of current by $\pi/2$

(B) Current is ahead of e.m.f. by $\pi/2$

(C) Current lags behind e.m.f. by π

(D) Current is ahead of e.m.f. by π

33. An ac source is connected to a resistive circuits. Which of the following is true

(A) Current leads the voltage and both are in same phase

(B) Current lags behind the voltage and both are in same phase

(C) Current and voltage are in same phase

(D) Any of the above may be true depending upon the value of resistance

34. The average power dissipated in a pure inductor of inductance *L* when an ac current is passing through it, is

(A) $\frac{1}{2}LI^2$ **(B)** $\frac{1}{4}LI^2$

(C) $2\,Li^2$ **(D)** Zero

(Inductance of the coil *L* and current *I*)

35. An alternating current of frequency 'f' is flowing in a circuit containing a resistance *R* and a choke *L* in series. The impedance of this circuit is

(A) $R+2\pi fL$ **(B)** $\sqrt{R^2+4\pi^2f^2L^2}$

(C) $\sqrt{R^2+L^2}$ **(D)** $\sqrt{R^2+2\pi fL}$

36. A resonant ac circuit contains a capacitor of capacitance $10^{-6}\,F$ and an inductor of $10^{-4}\,H$. The frequency of electrical oscillations will be

(A) $10^5\,Hz$ **(B)** $10\,Hz$

(C) $\frac{10^5}{2\pi}\,Hz$ **(D)** $\frac{10}{2\pi}\,Hz$

37. Power delivered by the source of the circuit becomes maximum, when

(A) $\omega L=\omega C$ **(B)** $\omega L=\frac{1}{\omega C}$

(C) $\omega L=-\left(\frac{1}{\omega C}\right)^2$ **(D)** $\omega L=\sqrt{\omega C}$

38. An alternating voltage is connected in series with a resistance *R* and an inductance *L* If the potential drop across the resistance is 200 *V* and across the inductance is 150 *V*, then the applied voltage is

(A) 350 *V* **(B)** 250 *V*

(C) 500 *V* **(D)** 300 *V*

39. An inductive circuit contains resistance of 10 Ω and an inductance of 20 *H*. If an ac voltage of 120 *V* and frequency 60 *Hz* is applied to this circuit, the current would be nearly

(A) 0.32 *amp* **(B)** 0.016 *amp*

(C) 0.48 *amp* **(D)** 0.80 *amp*

40. Same current is flowing in two alternating circuits. The first circuit contains only inductance and the other contains only a capacitor. If the frequency of the e.m.f. of ac is increased, the effect on the value of the current will be

(A) Increases in the first circuit and decreases in the other

(B) Increases in both the circuits

(C) Decreases in both the circuits

(D) Decreases in the first circuit and increases in the other

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41. A capacitor is a perfect insulator for

(A) Alternating currents **(B)** Direct currents

(C) Both ac and dc **(D)** None of these

42. In a circuit containing an inductance of zero resistance, the e.m.f. of the applied ac voltage leads the current by

(A) 90^o **(B)** 45^o

(C) 30^o **(D)** 0^o

43. In a pure inductive circuit or In an ac circuit containing inductance only, the current

(A) Leads the e.m.f. by 90^o

(B) Lags behind the e.m.f. by 90^o

(C) Sometimes leads and sometime lags behind the e.m.f.

(D) Is in phase with the e.m.f.

44. A 20 *volts* ac is applied to a circuit consisting of a resistance and a coil with negligible resistance. If the voltage across the resistance is 12 *V*, the voltage across the coil is

(A) 16 *volts* **(B)** 10 *volts*

(C) 8 *volts* **(D)** 6 *volts*

45. A resistance of 300 Ω and an inductance of $\frac{1}{\pi}$ henry are connected in series to a ac voltage of 20 *volts* and 200 *Hz* frequency. The phase angle between the voltage and current is

(A) $\tan^{-1}\frac{4}{3}$ **(B)** $\tan^{-1}\frac{3}{4}$

(C) $\tan^{-1}\frac{3}{2}$ **(D)** $\tan^{-1}\frac{2}{5}$

46. The power factor of *LCR* circuit at resonance is

(A) 0.707 **(B)** 1

(C) Zero **(D)** 0.5

47. An inductance of 1 *mH* a condenser of 10 μF and a resistance of 50 Ω are connected in series. The reactances of inductor and condensers are same. The reactance of either of them will be

(A) 100 Ω **(B)** 30 Ω

(C) 3.2 Ω **(D)** 10 Ω

48. The natural frequency of a *L*-*C* circuit is equal to

(A) $\frac{1}{2\pi}\sqrt{LC}$ **(B)** $\frac{1}{2\pi\sqrt{LC}}$

(C) $\frac{1}{2\pi}\sqrt{\frac{L}{C}}$ **(D)** $\frac{1}{2\pi}\sqrt{\frac{C}{L}}$

49. An alternating voltage $E = 200\sqrt{2}\sin(100\,t)$ is connected to a 1 *microfarad* capacitor through an ac ammeter. The reading of the ammeter shall be

(A) 10 *mA* **(B)** 20 *mA*

(C) 40 *mA* **(D)** 80 *mA*

50. An ac circuit consists of an inductor of inductance 0.5 *H* and a capacitor of capacitance 8 μF in series. The current in the circuit is maximum when the angular frequency of ac source is

(A) 500 *rad/sec* **(B)** 2×10^5 *rad/sec*

(C) 4000 *rad/sec* **(D)** 5000 *rad/sec*

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Exercise # 2 SINGLE OBJECTIVE AIIMS LEVEL

1. The peak value of an alternating e.m.f given by $E = E_0 \cos \omega t$, is 10 volt and frequency is 50 Hz. At time t = (1/600) sec, the instantaneous value of e.m.f is :

(A) 10 volt **(B)** $5\sqrt{3}$ volt

(C) 5 volt **(D)** 1 volt

2. r.m.s. value of current $i = 3 + 4 \sin(\omega t + \pi/3)$ is:

(A) 5 A **(B)** $\sqrt{17}$ A

(C) $\frac{5}{\sqrt{2}}$ A **(D)** $\frac{7}{\sqrt{2}}$ A

3. The voltage of an AC source varies with time according to the equation, $V = 100 \sin 100\pi t \cos 100\pi t$. Where t is in second and V is in volt. Then

(A) the peak voltage of the source is 100 volt

(B) the peak voltage of the source is $(100/\sqrt{2})$ volt

(C) the peak voltage of the source is 50 volt

(D) the frequency of the source is 50 Hz

4. An AC voltage is given by :

$$E = E_0 \sin \frac{2\pi t}{T}$$

Then the mean value of voltage calculated over time interval of T/2 seconds :

(A) is always zero **(B)** is never zero

(C) is $(2E_0/\pi)$ always **(D)** may be zero

5. An alternating voltage is given by : $e = e_1 \sin \omega t + e_2 \cos \omega t$. Then the root mean square value of voltage is given by :

(A) $\sqrt{e_1^2 + e_2^2}$ **(B)** $\sqrt{e_1 e_2}$

(C) $\sqrt{\frac{e_1 e_2}{2}}$ **(D)** $\sqrt{\frac{e_1^2 + e_2^2}{2}}$

6. Energy dissipates in LCR circuit in :

(A) L only **(B)** C only

(C) R only **(D)** all of these

7. The average power delivered to a series AC circuit is given by (symbols have their usual meaning) :

(A) $E_{rms} I_{rms}$ **(B)** $E_{rms} I_{rms} \cos\phi$

(C) $E_{rms} I_{rms} \sin\phi$ **(D)** zero

8. An AC voltage of $V = 220\sqrt{2} \sin\left(100\pi t + \frac{\pi}{2}\right)$ is applied across a DC voltmeter, its reading will be:

(A) $220\sqrt{2}$ V **(B)** $\sqrt{2}$ V

(C) 220 V **(D)** zero

9. The potential difference V across and the current I flowing through an instrument in an AC circuit are given by:

$V = 5 \cos \omega t$ volt

$I = 2 \sin \omega t$ Amp.

The power dissipated in the instrument is :

(A) zero **(B)** 5 watt

(C) 10 watt **(D)** 2.5 watt

10. What is the rms value of an alternating current which when passed through a resistor produces heat, which is thrice that produced by a D.C. current of 2 ampere in the same resistor in the same time interval?

(A) 6 ampere **(B)** 2 ampere

(C) $2\sqrt{3}$ ampere **(D)** 0.65 ampere

11. A direct current of 2 A and an alternating current having a maximum value of 2 A flow through two identical resistances. The ratio of heat produced in the two resistances in the same time interval will be:

(A) 1 : 1 **(B)** 1 : 2

(C) 2 : 1 **(D)** 4 : 1

12. A sinusoidal AC current flows through a resistor of resistance R. If the peak current is I_p, then average power dissipated is :

(A) $I_p^2 R \cos\theta$ **(B)** $\frac{1}{2} I_p^2 R$

(C) $\frac{4}{\pi} I_p^2 R$ **(D)** $\frac{1}{\pi^2} I_p^2 R$

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13. The impedance of a series circuit consists of 3 ohm resistance and 4 ohm reactance. The power factor of the circuit is :

(A) 0.4 **(B)** 0.6

(C) 0.8 **(D)** 1.0

14. A resistor and a capacitor are connected to an AC supply of 200 volt, 50 Hz in series. The current in the circuit is 2 ampere. If the power consumed in the circuit is 100 watt, then the resistance in the circuit is:

(A) 100 Ω **(B)** 25 Ω

(C) $\sqrt{125\times75}$ Ω **(D)** 400 Ω

15. An electric bulb and a capacitor are connected in series with an AC source. On increasing the frequency of the source, the brightness of the bulb :

(A) increase

(B) decreases

(C) remains unchanged

(D) sometimes increases and sometimes decreases

16. A coil of inductance 5.0 mH and negligible resistance is connected to an alternating voltage V = 10 sin (100t). The peak current in the circuit will be :

(A) 2 amp **(B)** 1 amp

(C) 10 amp **(D)** 20 amp

17. By what percentage the impedance in an AC series circuit should be increased so that the power factor changes from (1/2) to (1/4) (when R is constant) ?

(A) 200% **(B)** 100%

(C) 50% **(D)** 400%

18. A 0.21-H inductor and a 88-Ω resistor are connected in series to a 220-V, 50-Hz AC source. The current in the circuit and the phase angle between the current and the source voltage are respectively.

(Use π = 22/7)

(A) 2 A, $\tan^{-1}3/4$ **(B)** 14.4 A, $\tan^{-1}7/8$

(C) 14.4 A, $\tan^{-1}8/7$ **(D)** 3.28 A, $\tan^{-1}2/11$

19. If the frequency of the source e.m.f. in an AC circuit is n, the power varies with a frequency :

(A) n **(B)** 2 n

(C) n/2 **(D)** zero

20. A 100 volt AC source of angular frequency 500 rad/s is connected to a LCR circuit with L = 0.8 H, C = 5 μF and R = 10 Ω, all connected in series. The potential difference across the resistance is

(A) $\frac{100}{\sqrt{2}}$ volt **(B)** 100 volt

(C) 50 volt **(D)** $50\sqrt{3}$

21. An LCR series circuit with 100 Ω resistance is connected to an AC source of 200 V and angular frequency 300 radians per second. When only the capacitance is removed, the current lags the voltage by 60°. When only the inductance is removed, the current leads the voltage by 60°. Then the current and power dissipated in LCR circuit are respectively

(A) 1A, 200 watt. **(B)** 1A, 400 watt.

(C) 2A, 200 watt. **(D)** 2A, 400 watt.

22. In an L-R series circuit ($L = \frac{175}{11}$ mH and R = 12Ω), a variable emf source ($V = V_0 \sin \omega t$) of $V_{rms} = 130\sqrt{2}$ V and frequency 50 Hz is applied. The current amplitude in the circuit and phase of current with respect to voltage are respectively (Use π = 22/7)

(A) 14.14A, 30° **(B)** $10\sqrt{2}$ A, $\tan^{-1}\frac{5}{12}$

(C) 10 A, $\tan^{-1}\frac{5}{12}$ **(D)** 20 A, $\tan^{-1}\frac{5}{12}$

23. A pure resistive circuit element X when connected to an AC supply of peak voltage 200 V gives a peak current of 5 A which is in phase with the voltage. A second circuit element Y, when connected to the same AC supply also gives the same value of peak current but the current lags behind by 90°. If the series combination of X and Y is connected to the same supply, what will be the rms value of current ?

(A) $\frac{10}{\sqrt{2}}$ amp **(B)** $\frac{5}{\sqrt{2}}$ amp

(C) $\frac{5}{2}$ amp **(D)** 5 amp

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24. In an AC circuit the potential differences across an inductor and resistor joined in series are respectively 16 V and 20 V. The total potential difference across the circuit is

(A) 20 V **(B)** 25.6 V

(C) 31.9 V **(D)** 53.5 V

25. In an AC circuit, a resistance of R ohm is connected in series with an inductance L. If phase angle between voltage and current be 45°, the value of inductive reactance will be.

(A) R/4 **(B)** R/2

(C) R

(D) cannot be found with the given data

26. An AC voltage source V = $200\sqrt{2}$ sin 100 t is connected across a circuit containing an AC ammeter (it reads rms value) and capacitor of capacity 1 μF. The reading of ammeter is :

(A) 10 mA **(B)** 20 mA

(C) 40 mA **(D)** 80 mA

27. If in a series LCR AC circuit, the rms voltage across L, C and R are V_1, V_2 and V_3 respectively, then the voltage of the source is always :

(A) equal to $V_1 + V_2 + V_3$

(B) equal to $V_1 - V_2 + V_3$

(C) more than $V_1 + V_2 + V_3$

(D) none of these is true

28. When 100 V DC is applied across a solenoid, a steady current of 1 A flows in it. When 100 V AC is applied across the same solenoid, the current drops to 0.5 A. If the frequency of the AC source is $150\sqrt{3}/\pi$ Hz, the impedance and inductance of the solenoid are :

(A) 200 Ω and 1/3 H

(B) 100 Ω and 1/16 H

(C) 200 Ω and 1.0 H

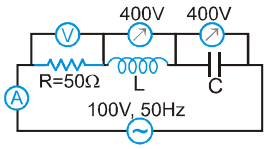
(D) 1100 Ω and 3/117 H

29. The value of power factor cosϕ in series LCR circuit at resonance is :

(A) zero **(B)** 1

(C) 1/2 **(D)** 1/2 ohm

30. In the series LCR circuit as shown in figure, the voltmeter and ammeter readings are :



(A) V = 100 volt, I = 2 amp

(B) V = 100 volt, I = 5 amp

(C) V = 1000 volt, I = 2 amp

(D) V = 300 volt, I = 1 amp

31. A resistor R, an inductor L and a capacitor C are connected in series to an oscillator of frequency υ. If the resonant frequency is υ_r, then the current lags behind voltage, when :

(A) $\upsilon = 0$ **(B)** $\upsilon < \upsilon_r$

(C) $\upsilon = \upsilon_r$ **(D)** $\upsilon > \upsilon_r$

32. A series LCR circuit containing a resistance of 120 ohm has angular resonance frequency 4×10^3 rad s^{-1}. At resonance, the voltage across resistance and inductance are 60V and 40 V respectively. The values of L and C are respectively

(A) 20 mH, 25/8 μF **(B)** 2mH, 1/35 μF

(C) 20 mH, 1/40 μF **(D)** 2mH, 25/8 nF

33. In an LCR circuit, the capacitance is made one-fourth, when in resonance. Then what should be the change in inductance, so that the circuit remains in resonance ?

(A) 4 times **(B)** 1/4 times

(C) 8 times **(D)** 2 times

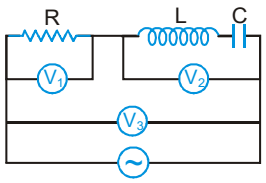
34. A power transformer (step up) with an 1 : 8 turn ratio has 60 Hz, 120 V across the primary; the load in the secondary is 10^4 Ω. The current in the secondary is

(A) 96 A **(B)** 0.96 A

(C) 9.6 A **(D)** 96 mA

35. A resistor R, an inductor L, a capacitor C and voltmeters V_1, V_2 and V_3 are connected to an oscillator in the circuit as shown in the adjoining diagram. When the frequency of the oscillator is increased, upto resonance frequency, the voltmeter reading (at resonance frequency) is zero in the case of :

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(A) voltmeter V_1
(B) voltmeter V_2
(C) voltmeter V_3
(D) all the three voltmeters

36. In a step-up transformer the voltage in the primary is 220 V and the current is 5A. The secondary voltage is found to be 22000 V. The current in the secondary (neglect losses) is

(A) 5 A **(B)** 50 A
(C) 500 A **(D)** 0.05 A

37. A transformer is used to light a 140 watt, 24 volt lamp from 240 V AC mains. The current in the main cable is 0.7 amp. The efficiency of the transformer is :

(A) 48% **(B)** 63.8%
(C) 83.3% **(D)** 90%

38. A capacitor is a perfect insulator for :

(A) constant direct current
(B) alternating current
(C) direct as well as alternating current
(D) variable direct current

39. The core of a transformer is laminated to reduce

(A) eddy current loss **(B)** hysteresis loss
(C) copper loss **(D)** magnetic loss

40. A choke coil is preferred to a rheostat in AC circuit as :

(A) it consumes almost zero power
(B) it increases current
(C) it increases power
(D) it increases voltage

41. A choke coil sould have :

(A) high inductance and high resistance
(B) low inductance and low resistance
(C) high inductance and low resistance
(D) low inductance and high resistance

42. With increase in frequency of an AC supply, the capacitive reactance :

(A) varies inversely with frequency
(B) varies directly with frequency
(C) varies directly as square of frequency
(D) remains constant

43. With increase in frequency of an AC supply, the inductive reactance :

(A) decreases
(B) increases directly proportional to frequency
(C) increases as square of frequency
(D) decreases inversely with frequency

44. In an a.c. circuit consisting of resistance R and inductance L, the voltage across R is 60 volt and that across L is 80 volt. The total voltage across the combination is

(A) 140 V **(B)** 20 V
(C) 100 V **(D)** 70 V

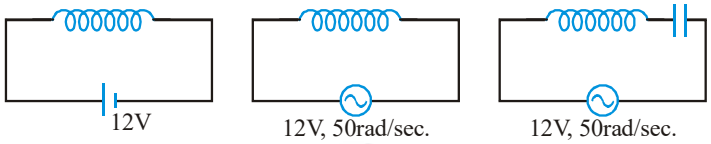
45. An AC ammeter is used to measure current in a circuit. When a given direct constant current passes through the circuit, the AC ammeter reads 3 ampere. When an alternating current passes through the circuit, the AC ammeter reads 4 ampere. Then the reading of this ammeter if DC and AC flow through the circuit simultaneously, is :

(A) 3 A **(B)** 4 A
(C) 7 A **(D)** 5 A

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Exercise # 3 PART - 1 MATRIX MATCH COLUMN

1. A steady current 4 A flows in an inductor coil when connected to a 12 V dc source as shown in figure 1. If the same coil is connected to an ac source of 12 V, 50 rad/s, a current of 2.4 A flows in the circuit as shown in figure 2. Now after these observations, a capacitor of capacitance $\frac{1}{50}$F is connected in series with the coil as shown in figure 3 with the same AC source :



(Figure 1) (Figure 2) (Figure 3)

Column-I	Column-II (in S.I units)
(A) The inductance of the coil (nearly)	**(P)** 24
(B) The resistance of the coil	**(Q)** 3
(C) Average power (nearly)	**(R)** 0.08
(D) Total reactance	

2. Match the Physical quantities given in column-I with the parameters they depend on as given in column-II.

Column I	Column II
(A) Inductance of a coil	**(P)** Depends on resistivity
(B) Capacitance	**(Q)** Depends on shape
(C) Impedance of a coil	**(R)** Depends on medium inserted
(D) Reactance of a capacitor	**(S)** Depends on external AC voltage source

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Exercise # 3 PART - 2 ASSERTION & REASONING

These questions contains, Statement I (assertion) and Statement II (reason).

(A) If both assertion and reason are true and the reason is the correct explanation of the assertion.

(B) If both assertion and reason are true but reason is not the correct explanation of the assertion.

(C) If assertion is true but reason is false.

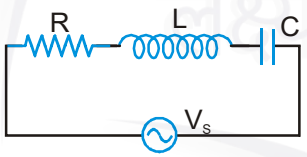
(D) If assertion is false but reason is true.

(E) If the assertion and reason both are false.

1. **Assertion :** An inductor is connected to an ac source. When the magnitude of current decreases in the circuit, energy is absorbed by the ac source.

Reason : When current through an inductor decreases, the energy stored in inductor decreases.

2. **Assertion :** In a series R,L,C circuit if V_R, V_L, and V_C denote rms voltage across R, L and C repectively and V_S is the rms voltage across the source, then $V_S = V_R + V_L + V_C$.



Reason : In AC circuits, kirchoff voltage law is correct at every instant of time.

3. **Assertion :** The electrostatic energy stored in capacitor plus magnetic energy stored in inductor will always be zero in a series LCR circuit driven by ac voltage source under condition of resonance.

Reason : The complete voltage of ac source appears across the resistor in a series LCR circuit driven by ac voltage source under condition of resonance.

4. **Assertion :** Average power consumed in an ac circuit is equal to average power consumed by resistors in the circuit.

Reason : Average power consumed by capacitor and inductor in an ac circuit is zero.

5. **Assertion :** In series LCR circuit resonance can take place.

Reason : Resonance takes place if inductance and capacitive reactances are equal and opposite.

6. **Assertion :** The alternating current lags behind the e.m.f. by a phase angle of $\pi/2$, when ac flows through an inductor.

Reason : The inductive reactance increases as the frequency of ac source decreases.

7. **Assertion :** Capacitor serves as a block for dc and offers an easy path to ac.

Reason : Capacitive reactance is inversely proportional to frequency.

8. **Assertion :** When capacitive reactance is smaller than the inductive reactance in LCR current, e.m.f. leads the current .

Reason : The phase angle is the angle between the alternating e.m.f. and alternating current of the circuit.

9. **Assertion :** Chock coil is preferred over a resistor to adjust current in an ac circuit.

Reason : Power factor for inductance is zero.

10. **Assertion :** If the frequency of alternating current in an ac circuit consisting of an inductance coil is increased then current gets decreased.

Reason : The current is inversely proportional to frequency of alternating current.

11. **Assertion :** A bulb connected in series with a solenoid is connected to ac source. If a soft iron core is introduced in the solenoid, the bulb will glow brighter.

Reason : On introducing soft iron core in the solenoid, the inductance increases.

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12. **Assertion :** An alternating current does not show any magnetic effect.
Reason : Alternating current varies with time.

13. **Assertion :** The dc and ac both can be measured by a hot wire instrument.
Reason : The hot wire instrument is based on the principle of magnetic effect of current.

14. **Assertion :** ac is more dangerous than dc
Reason : Frequency of ac is dangerous for human body.

15. **Assertion :** Average value of ac over a complete cycle is always zero.
Reason : Average value of ac is always defined over half cycle.

16. **Assertion :** The division are equally marked on the scale of ac ammeter.
Reason : Heat produced is directly proportional to the current.

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Exercise # 4 PART - 1 PREVIOUS YEAR (NEET/AIPMT)

1. A wire of resistance R is connected in series with an inductor of reactance ωL. Then quality factor of RL circuit is

(A) $\frac{R}{\omega L}$ **(B)** $\frac{\omega L}{R}$

(C) $\frac{R}{\sqrt{R^2+\omega^2L^2}}$ **(D)** $\frac{\omega L}{\sqrt{R^2+\omega^2L^2}}$

2. The reactance of a capacitor of capacitance C is X. If both the frequency and capacitance be doubled, then new reactance will be

(A) X **(B)** 2X

(C) 4 X **(D)** $\frac{X}{4}$

3. What is the cause of "Green house effect"?

(A) Infrared rays **(B)** Ultraviolet rays

(C) X-rays **(D)** Radio-waves

4. For a series L C R circuit, the power loss at resonance is

(A) $\frac{V^2}{\omega L-\frac{1}{\omega C}}$ **(B)** $i^2 C\omega$

(C) $i^2 R$ **(D)** $\frac{V^2}{\omega C}$

5. In a circuit, L, C and R are connected in series with an alternating voltage source of frequency f. the current leads the voltage by 45°. The value of C is

(A) $\frac{1}{2\pi f(2\pi fL+R)}$ **(B)** $\frac{1}{\pi f(2\pi fL+R)}$

(C) $\frac{1}{2\pi f(2\pi fL-R)}$ **(D)** $\frac{1}{\pi f(2\pi fL-R)}$

6. The core of a transformer is laminated because

(A) energy losses due to eddy currents may be minimised

(B) the weight of the transformer may be reduced

(C) rusting of the core may be prevented

(D) ratio of voltage in primary and secondary may be increased

7. A coil of inductive reactance 31 Ω has a resistance of 8Ω. It is placed in series with a condenser of capacitative reactance 25 Ω.The combination is connected to an AC source of 110 V. The power factor of the circuit is

(A) 0.56 **(B)** 0.64

(C) 0.80 **(D)** 0.33

8. What is the value of inductance L for which the current is maximum in a series LCR circuit with $C = 10\ \mu F$ and $\omega = 1000\ s^{-1}$?

(A) 100 mH

(B) 1 mH

(C) Cannot be calculated unless R is known

(D) 10 mH

9. The primary and secondary coils of a transformer have 50 and 1500 turns respectively. If the magnetic flux ϕ linkedwith the primary coil is given by $\phi = \phi_0 + 4t$, where ϕ is in weber, t is time in second and ϕ_0 is a constant, the outpur voltage across the secondary coil is

(A) 90 V **(B)** 120 V

(C) 220 V **(D)** 30 V

10. A transformer is used to light a 100 W and 110 V lamp from a 220 V mains. If the main current is 0.5 A, the efficiency of the transformer is approximately

(A) 30% **(B)** 50%

(C) 90% **(D)** 10%

11. The velocity of electromagnetic radiation in a medium of permittivity ε_0 and permeability μ_0 is given by

(A) $\sqrt{\frac{\varepsilon_0}{\mu_0}}$ **(B)** $\sqrt{\mu_0\varepsilon_0}$

(C) $\frac{1}{\sqrt{\mu_0\varepsilon_0}}$ **(D)** $\sqrt{\frac{\mu_0}{\varepsilon_0}}$

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12. In an AC circuit the emf (V) and the current (i) at any instant are given respectively by

$V = V_0 \sin \omega t,\ i = i_0 \sin(\omega t - \phi)$

The average power in the circuit over one cycle of AC is

(A) $\frac{V_0 i_0}{2}$ **(B)** $\frac{V_0 i_0}{2}\sin\phi$

(C) $\frac{V_0 i_0}{2}\cos\phi$ **(D)** $V_0 i_0$

13. Power dissipated in an L-C-R series circuit connected to an AC source of emf ε is

(A) $\frac{\varepsilon^2 R}{\left[R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2\right]}$ **(B)** $\frac{\varepsilon^2\sqrt{R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2}}{R}$

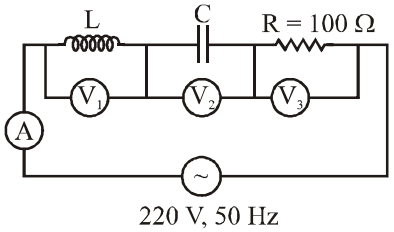
(C) $\frac{\varepsilon^2\left[R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2\right]}{R}$ **(D)** $\frac{\varepsilon^2 R}{\sqrt{R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2}}$

14. A 220 V input is supplied to a transformer. The output circuit draws a current of 2.0 A at 440 V. If the efficiency of the transformer is 80%, the current drawn by the primary windings of the transformer is

(A) 3.6 A **(B)** 2.8 A

(C) 2.5 A **(D)** 5.0 A

15. In the given circuit, the reading of voltmeter V_1 and V_2 are 300 V each. The reading to the voltmetmeter V_3 and ammeter A are respectively



(A) 150 V, 2.2 A **(B)** 220 V, 2.2 A

(C) 220 V, 2.0 A **(D)** 100 V, 2.0 A

16. An AC voltage is applied to a resistance R and an inductor L in series. If R and the inductive reactance are both equal to 3 Ω, the phase difference between the applied voltage and the current in the circuit is

(A) π/4 **(B)** π/2

(C) zero **(D)** π/6

17. In an AC circuit an alternating voltage $e = 200\sqrt{2}\sin 100\ t$ volt is connected to a capacitor of capacity 1 μF. The rms value of the current in the circuit is

(A) 100 mA **(B)** 200 mA

(C) 20 mA **(D)** 10 mA

18. In an electrical circuit, R, L, C and an AC voltage source are all connected in series. When L is removed from the circuit, the phase difference between the voltage and the current in the circuit is π/3. If instead, C is removed from the circuit, the phase difference is again π/3. The power factor of the circuit is

(A) 1/2 **(B)** $1/\sqrt{2}$

(C) 1 **(D)** $\sqrt{3}/2$

19. A coil of self-inductance L is connected in series with a bulb B and an AC source. Brightness of the bulb decreases when

(A) frequency of the AC source is decreased

(B) number of turns in the coil is reduced

(C) a capacitance of reactance $X_C = X_L$ is included in the same circuit

(D) an iron rod is inserted in the coil

20. A transformer having efficiency of 90% is working on 200 V and 3 kW power supply. If the current in the secondary coil is 6 A, the voltage across the secondary coil and the current in the primary coil respectively are

(A) 300 V, 15 A **(B)** 450 V, 15 A

(C) 450 V, 13.5 A **(D)** 600 V, 15 A

21. A series R-C circuit is connected to an alternating voltage source. Consider two situation :

1. When capacitor is air filled.
2. When capacitor is mica filled.

Current through resistor is i and voltage across capacitor is V then

(A) $V_a < V_b$ **(B)** $V_a > V_b$

(C) $i_a > i_b$ **(D)** $V_a = V_b$

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22. A resistance 'R' draws power 'P when connected to an AC source. If an inductance is now placed in series with the resistacne, such that the impedance of the circuit becomes 'Z' the power drawn will be

(A) $P\left(\frac{R}{Z}\right)^2$ **(B)** $P\sqrt{\frac{R}{Z}}$

(C) $P\left(\frac{R}{Z}\right)$ **(D)** P

23. A 100 Ω resistance and a capacitor of 100 Ω reactance are connected in series across a 220 V source. When the capacitor is 50% charged, the peak value of the displacement current is

(A) 2.2 A **(B)** 11 A

(C) 4.4 A **(D)** $11\sqrt{2}$A

24. The potential differences across the resistance, capacitance and inductance are 80 V, 40 V and 100 V respectively in an L-C-R circuit. The power factor of this circuit is

(A) 0.4 **(B)** 0.5

(C) 0.8 **(D)** 1.0

25. Which of the following combinations should be selected for better tuning of an L-C-R circuit used for communication?

(A) R - 20Ω, L - 1.5 H, C = 35 μF

(B) R - 25Ω, L - 2.5 H, C = 45 μF

(C) R - 15Ω, L - 3.5 H, C = 30 μF

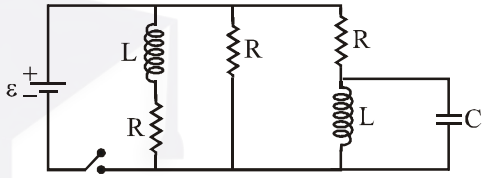
(D) R - 25Ω, L - 1.5 H, C = 45 μF

26. An inductor 20 mH, a capacitor 50 μF and a resistor 40 Ω are connected in series across a source of emf V = 10 sin 340 t. The power loss in AC circuit is

(A) 0.67 W **(B)** 0.76 W

(C) 0.89 W **(D)** 0.51 W

27. Figure shows a circuit that contains three indentical resistors with resistance R = 9.0 Ω each, two identical inductors with inductance L = 2.0 mH each, and an ideal battery with emf ε = 18 V. The current i through the battery just after the switch closed is



(A) 2 mA **(B)** 4 A

(C) 2 A **(D)** 0 A

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Exercise # 4 PART - 2 PREVIOUS YEAR (AIIMS)

1. Turn ratio in a step-up transformer is 1 : 2. If a Lechlanche cell of 1.5 V is connected across the input, what is the voltage across the output ?

(A) 1.5 V **(B)** 0.0 V
(C) 3 V **(D)** 0.75 V.

2. In a series LCR circuit the voltage across resistance, capacitance and inductance is 10 V each. If the capacitance is short circuited, the voltage across the inductance will be

(A) $\frac{10}{\sqrt{2}}$ V **(B)** 10 V
(C) $10\sqrt{2}$ V **(D)** 20 V

3. The self-induced e.m.f. in closing a d.c. current circuit is e_c, in breaking it is e_b and the e.m.f. of the source is e_0, then

(A) $e_c > e_0 > e_b$ **(B)** $e_c < e_0 < e_b$
(C) $e_c < e_b < e_0$ **(D)** $e_c = e_b < e_0$

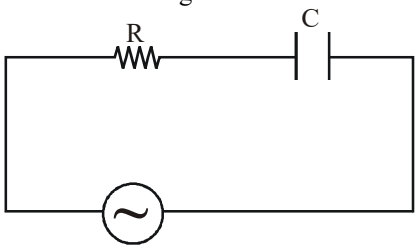
4. A capacitor of capacitance 2 μF is connected in the tank circuit of an oscillator oscillating with a frequency of 1 kHz. If the current flowing in the circuit is 2 mA, the voltage across the capacitor will be

(A) 0.16 V **(B)** 0.32 V
(C) 79.5 V **(D)** 159 V

5. In an ideal parallel LC circuit, the capacitor is charged by connecting it to a d.c. source which is then disconnected. The current in the circuit

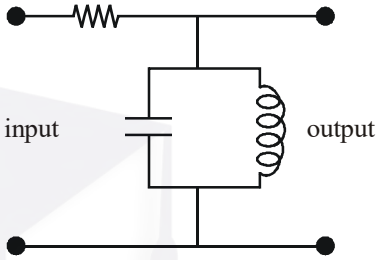
(A) becomes zero instantaneously
(B) grows monotonically
(C) decays monotonically
(D) oscillates instantaneously.

6. A 50 Hz a.c. source of 20 volts is connected across R and C as shown in figure. The voltage across R is 12 volt. The voltage across C is



(A) 8 V
(B) 16 V
(C) 10 V
(D) not possible to determine unless values of R and Care given.

7. The circuit shown below acts as



(A) tuned filter **(B)** low pass filter
(C) high pass filter **(D)** rectifier.

8. With the decrease of current in the primary coil from 2 amperes to zero value in 0.01 s the emf generated in the secondary coil is 1000 volts. The mutual inductance of the two coils is

(A) 1.25 H **(B)** 2.50 H
(C) 5.00 H **(D)** 10.00 H

9. In an AC circuit the potential differences across an inductance and resistance joined in series are respectively 16 V and 20 V. The total potential difference of the source is

(A) 20.0 V **(B)** 25.6 V
(C) 31.9 V **(D)** 53.5 V

10. If frequency of R-L circuit is *f* then impedance will be

(A) $\sqrt{R^2 + (2\pi fL)^2}$ **(B)** $R^2 + (2\pi f^2)^2$
(C) $\sqrt{(R^2 + L\pi f^2)}$ **(D)** $R^2 + (2\pi f)^2$

11. When 100 V d.c. is applied across a coil, a current of 1 A flows through it. When 100 V a.c. of 50 Hz is applied to the same coil only 0.5 A flows. The inductance of the coil is

(A) 0.55 H **(B)** 5.5 mH
(C) 0.55 mH **(D)** 55 mH

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12. Alternating current cannot be measured by D.C. ammeter because

(A) A.C. cannot pass through D.C. ammeter

(B) A.C. changes direction

(C) average value of current for complete cycle is zero

(D) D.C. ammeter will get damaged.

13. The core of any transformer is laminated so as to

(A) reduce the energy loss due to eddy currents

(B) make it light weight

(C) make it robust & strong

(D) increase the secondary voltage.

14. What is the mechanical equivalent of spring constant k in LC oscillating circuit ?]

(A) $\frac{1}{L}$ (B) $\frac{1}{C}$

(C) $\frac{L}{C}$ (D) $\frac{1}{LC}$

15. In series LCR circuit, the phase difference between applied voltage and current is

(A) positive when $X_L > X_C$

(B) positive when $X_C > X_L$

(C) 90°

(D) 0 °

16. In an AC circuit, voltage $V = V_0 \sin\omega t$ and inductor L is connected across the circuit. Then the instantaneous power will be

(A) $\frac{V_0^2}{2\omega L}\sin\omega t$ (B) $\frac{-V_0^2}{2\omega L}\sin\omega t$

(C) $\frac{-V_0^2}{2\omega L}\sin 2\omega t$ (D) $\frac{V_0^2}{\omega L}\sin 2\omega t$

17. In a given series LCR circuit $R = 4\ \Omega$, $X_L = 5\ \Omega$ and $X_C = 8\ \Omega$, the current

(A) leads the voltage by $\tan^{-1}(3/4)$

(B) leads the voltage by $\tan^{-1}(5/8)$

(C) lags the voltage by $\tan^{-1}(3/4)$

(D) lags the voltage by $\tan^{-1}(5/8)$

18. Which of the following parameter in the series LCR circuit is analogous to driving force F(t) in mechanics ?

(A) $\frac{V_0}{L}$ (B) Inductance L

(C) Capacitance C (D) Voltage V_0

19. Find the voltage drop across a capacitor connected with a resistance and a battery of 60 V in series after a long time.

(A) 0 V (B) 60 V

(C) 30 V (D) 38 V

20. In an oscillating system, a restoring force is a must. In an LC circuit, restoring force is provide by

(A) capacitor (B) inductance

(C) resistance (D) both (A) and (B)

21. The most suitable metal for making electromagnets and transformer cores is

(A) steel (B) iron

(C) copper (D) aluminium

22. An inductive circuit contains a resistance of 10 W and an inductance of 2 H. If an AC voltage of 120 V and frequency 60 Hz is applied to this circuit, the current would be nearly

(A) 0.72 A (B) 0.16 A

(C) 0.48 A (D) 0.80 A

23. A 5 μF capacitor is charged by being connected to a 3 V battery. The battery is then disconnected. If the resistance of the dielectric material between the capacitor plates is 10^9 W, what is the charge remaining on the capacitor 1 h after it has been disconnected ?

(A) 1.5×10^{-5} C (B) 7.4×10^{-6} C

(C) 5.4×10^{-6} C (D) 8.4×10^{-5} C

24. A coil of inductance 8 μH is connected to a capacitor of capacitance 0.02 μF. To what wavelength is this circuit tuned ?

(A) 7.54×10^3 m (B) 4.12×10^2 m

(C) 15.90×10^3 m (D) 7.54×10^2 m

25. A series resonant LCR circuit has a quality factor (Q-factor) 0.4. If R = 2 kΩ, C = 0.1 mF, then the value of inductance is

(A) 0.1 H (B) 0.064 H

(C) 2 H (D) 5 H

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ASSERTION AND REASON

26. **Assertion :** The quantity L/R possesses dimension of time.

Reason : To reduce the rate of increase of current through a solenoid, we should increase the time constant (L/R).

27. **Assertion :** We use a thick wire in the secondary of a step down transformer to reduce the production heat.

Reason : When the plane of the armature is parallel to the line of force of magnetic field, the magnitude of induced e.m.f. is maximum.

28. **Assertion :** Faraday's laws are consequences of conservation of energy.

Reason : In a purely resistive A.C. circuit, the current lags behind the e.m.f. in phase.

29. **Assertion :** No power loss associated with pure capacitor in ac circuit.

Reason : No current is flowing in this circuit

30. **Assertion :** The alternating current lags behind the e.m.f. by a phase angle of $\pi/2$, when AC flows through an inductor.

Reason : The inductive reactance increases as the frequency of AC source decreases.

31. **Assertion :** Inductance coils are usually made of thick copper wire.

Reason : Induced current is more in wire having less resistance.

32. **Assertion :** Transformers are used only in alternating current source not in direct current.

Reason : Only a.c. can be stepped up or down by means of transformers.

33. **Assertion :** At resonance, LCR series circuit have a minimum current.

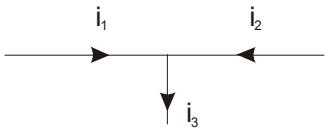
Reason : At resonance, in LCR series circuit, the current and e.m.f are not in phase with each other.

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MOCK TEST

STRAIGHT OBJECTIVE TYPE

1. If $i_1 = 3 \sin \omega t$ and $i_2 = 4 \cos \omega t$, then i_3 is



(A) $5 \sin(\omega t + 53^\circ)$ **(B)** $5 \sin(\omega t + 37^\circ)$ **(C)** $5 \sin(\omega t + 45^\circ)$ **(D)** $5 \cos(\omega t + 53^\circ)$

2. An alternating EMF of angular frequency $\omega \left(= \frac{1}{\sqrt{LC}}\right)$ is applied to a series LCR circuit. For this frequency of the applied EMF,

(A) The circuit is at 'resonance' and its impedance is made up only of a reactive part

(B) The current in the circuit is in phase with the applied EMF and the voltage across R equals this applied EMF

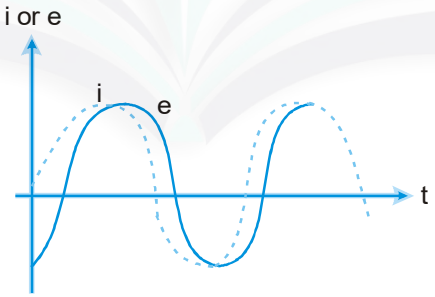
(C) The sum of the potential differences across the inductance and capacitance equals the applied EMF which is 180° ahead of phase of the current in the circuit

(D) Impedance of the circuit is less than R

3. An LCR series circuit with 100 Ω resistance is connected to an AC source of 200 V and angular frequency 300 radians per second. When only the capacitance is removed, the current lags the voltage by 60°. When only the inductance is removed, the current leads the voltage by 60°. Then the current and power dissipated in LCR circuit are respectively

(A) 1A, 200 watt. **(B)** 1A, 400 watt. **(C)** 2A, 200 watt. **(D)** 2A, 400 watt.

4. When an AC source of emf $E = E_0 \sin(100\, t)$ is connected across a circuit, the phase difference between the emf E and the current i in the circuit is observed to be $\frac{\pi}{4}$, as shown in the diagram. If the circuit consists possibly only of R-C or R-L or L-C series, find the relationship between the two elements.



(A) $R = 1k\Omega, C = 10\ \mu F$ **(B)** $R = 1k\Omega, C = 1\ \mu F$

(C) $R = 1k\Omega, L = 10\ H$ **(D)** $R = 1k\Omega, L = 1H$

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5. A bulb is rated at 100 V,100 W , it can be treated as a resistor. Find out the inductance of an inductor (called choke coil) that should be connected in series with the bulb to operate the bulb at its rated power with the help of an ac source of 200 V and 50 Hz.

(A) $\frac{\pi}{\sqrt{3}}$ H **(B)** 100 H **(C)** $\frac{\sqrt{2}}{\pi}$ H **(D)** $\frac{\sqrt{3}}{\pi}$ H

6. An ac source of angular frequency ω is fed across a resistor R and a capacitor C in series. The current registered is I. If now the frequency of source is changed to ω/3 (but maintaining the same voltage), the current in the circuit is found to be halved. Then the ratio of reactance to resistance at the original frequency ω is :

(A) $\sqrt{3/5}$ **(B)** $\sqrt{5/3}$ **(C)** $\sqrt{2/3}$ **(D)** $\sqrt{3/2}$

7. In an AC circuit the potential differences across an inductance and resistance joined in series are respectively 16 V and 20 V. The total potential difference across the circuit is

(A) 20 V **(B)** 25.6 V **(C)** 31.9 V **(D)** 53.5 V

8. Current in an ac circuit is given by i = 3 sin ωt + 4 cos ωt then :

(A) rms value of current is 5 A.

(B) mean value of this current in one half period will be $6/\pi$.

(C) if voltage applied is $V = V_m \sin \omega t$ then the circuit must be containing resistance and capacitance.

(D) if voltage applied is $V = V_m \sin \omega t$, the circuit may contain resistance and inductance.

9. A current source sends a current $i = i_0 \cos(\omega t)$. When connected across an unknown load gives a voltage output of, $v = v_0 \sin(\omega t + \pi/4)$ across that load. Then voltage across the current source may be brought in phase with the current through it by:

(A) connecting an inductor in series with the load

(B) connecting a capacitor in series with the load

(C) connecting an inductor in parallel with the load

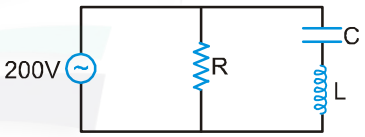
(D) connecting a capacitor in parallel with the load.



10. In the circuit diagram shown, $X_C = 100\ \Omega$, $X_L = 200\ \Omega$ & $R = 100\ \Omega$. The effective current through the source is:

(A) 2 A **(B)** $2\sqrt{2}$ A

(C) 0.5 A **(D)** $\sqrt{0.4}$ A



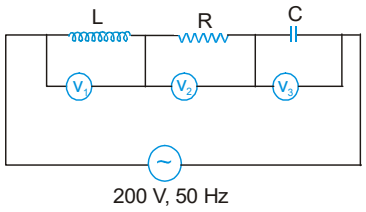
11. If the readings of v_1 and v_3 are 100 volt each then reading of v_2 is :

(A) 0 volt

(B) 100 volt

(C) 200 volt

(D) cannot be determined by given information.



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12. For a LCR series circuit with an A.C. source of angular frequency ω.

(A) circuit will be capacitive if $\omega > \frac{1}{\sqrt{LC}}$

(B) circuit will be inductive if $\omega = \frac{1}{\sqrt{LC}}$

(C) power factor of circuit will by unity if capacitive reactance equals inductive reactance

(D) current will be leading voltage if $\omega > \frac{1}{\sqrt{LC}}$

13. The value of current in two series L C R circuits at resonance is same when connected across a sinusoidal voltage source. Then:

(A) both circuits must be having same value of capacitance and inductor

(B) in both circuits ratio of L and C will be same

(C) for both the circuits X_L/X_C must be same at that frequency

(D) both circuits must have same impedance at all frequencies.

14. In series L C R circuit voltage drop across resistance is 8 volt, across inductor is 6 volt and across capacitor is 12 volt. Then:

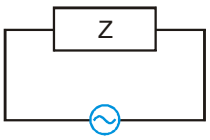
(A) voltage of the source will be leading current in the circuit

(B) voltage drop across each element will be less than the applied voltage

(C) power factor of circuit will be 4/3

(D) none of these

15. In a black box of unknown elements (L, C or R or any other combination) an AC voltage $E = E_0 \sin(\omega t + \phi)$ is applied and current in the circuit was found to be $i = i_0 \sin(\omega t + \phi + \pi/4)$. Then the unknown elements in the box may be :



(A) only capacitor

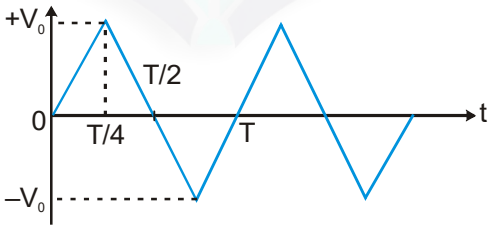
(B) inductor and resistor both

(C) either capacitor, resistor and inductor **or** only capacitor and resistor

(D) only resistor

16. The voltage time (V - t) graph for triangular wave having peak value. V_0 is as shown in figure.

The rms value of V in time interval from t = 0 to $\frac{T}{4}$ is :



(A) $\frac{V_0}{\sqrt{3}}$ **(B)** $\frac{V_0}{2}$ **(C)** $\frac{V_0}{\sqrt{2}}$ **(D)** None of these

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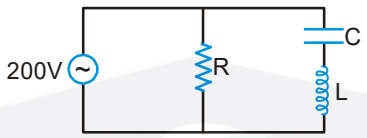
17. In the above questions the average value of voltage (v) in one time period will be :

(A) $\frac{V_0}{\sqrt{3}}$ **(B)** $\frac{V_0}{2}$ **(C)** $\frac{V_0}{\sqrt{2}}$ **(D)** zero

18. A series AC circuit has resistance of 4 Ω and a reactance of 3 Ω. The impedance(Z) of the circuit is

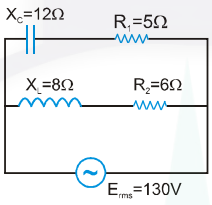
(A) 5 Ω **(B)** 7 Ω **(C)** 12/7 Ω **(D)** 7/12 Ω

19. In the circuit diagram shown, $X_C = 100\ \Omega$, $X_L = 200\ \Omega$ and $R = 100\ \Omega$. The effective current through the source is:



(A) 2 A **(B)** $2\sqrt{2}$ A **(C)** 0.5 A **(D)** $\sqrt{0.4}$ A

20. What is the amount of power delivered by the ac source in the circuit shown (in watts).



(A) 500 watt **(B)** 1014 watt **(C)** 1514 watt **(D)** 2013 watt

21. The secondary coil of an ideal step down transformer is delivering 500 watt power at 12.5 A current. If the ratio of turns in the primary to the secondary is 5 : 1, then the current flowing in the primary coil will be :

(A) 62.5 A **(B)** 2.5 A **(C)** 6 A **(D)** 0.4 A

22. A bulb and a capacitor are in series with an ac source. On increasing frequency how will glow of the bulb change

(A) The glow decreases **(B)** The glow increases

(C) The glow remain the same **(D)** The bulb quenches

23. The r.m.s. current in an ac circuit is 2 A. If the wattless current be $\sqrt{3}$A , what is the power factor

(A) $\frac{1}{\sqrt{3}}$ **(B)** $\frac{1}{\sqrt{2}}$ **(C)** $\frac{1}{2}$ **(D)** $\frac{1}{3}$

24. $\frac{2.5}{\pi}\mu F$ capacitor and 3000-ohm resistance are joined in series to an ac source of 200 volt and $50 sec^{-1}$ frequency. The power factor of the circuit and the power dissipated in it will respectively

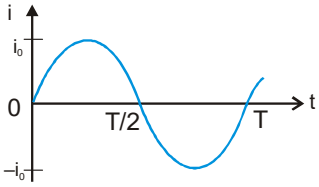
(A) 0.6, 0.06 W **(B)** 0.06, 0.6 W **(C)** 0.6, 4.8 W **(D)** 4.8, 0.6 W

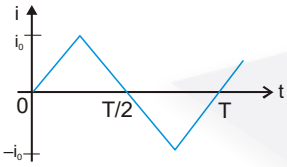
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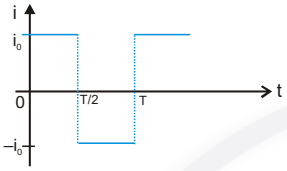
MATRIX - MATCH TYPE

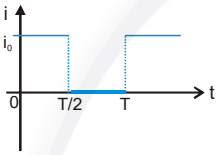
25. In Column I, variation of current i with time t is given in figures. In column II root mean square current i_{rms}, and average current is given. Match the column I with corresponding quantities given in Column II

Column I

(A) 

(B) 

(C) 

(D) 

Column II

(P) $i_{rms} = \frac{i_0}{\sqrt{3}}$

(Q) Average current for positive half cycle is i_0

(R) Average current for positive half cycle is $\frac{i_0}{2}$

(S) Full cycle average current is zero.

(T) Root mean square value of current for positive half cycle is i_0

26. Four different circuit components are given in each situation of column-I and all the components are connected across an AC source of same angular frequency $\omega = 200$rad/sec. The information of phase difference between the current and source voltage in each situation of column-I is given in column-II. Match the circuit components in column-I with corresponding results in column-II.

Column - I

(A) 

(B) 

(C) 

(D) 

Column - II

(P) the magnitude of required phase difference is $\frac{\pi}{2}$.

(Q) the magnitude of required phase difference is $\frac{\pi}{4}$.

(R) the current leads in phase to source voltage.

(S) the magnitude of required phase difference is zero.

(T) the current lags in phase to source voltage.

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ASSERTION AND REASON TYPE

These questions contains, Statement 1 (assertion) and Statement II (reason).

(A) Statement-1 is True, Statement-2 is True; Statement-2 **is** a correct explanation for Statement-1

(B) Statement-1 is True, Statement-2 is True; Statement-2 **is NOT** a correct explanation for Statement-1

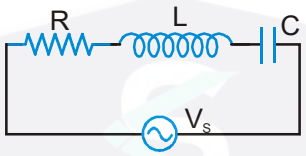
(C) Statement-1 is True, Statement-2 is False

(D) Statement-1 is False, Statement-2 is True.

27. **Assertion :** The D.C. and A.C. both can be measured by a hot wire instrument.

Reason : The hot wire instrument is based on the principle of magnetic effect of current.

28. **Assertion :** In a series R,L,C circuit if V_R, V_L, and V_C denote rms voltage across R, L and C respectively and V_S is the rms voltage across the source, then $V_S = V_R + V_L + V_C$.



Reason : In AC circuits, kirchoff voltage law is correct at every instant of time.

29. **Assertion :** The electrostatic energy stored in capacitor plus magnetic energy stored in inductor will always be zero in a series LCR circuit driven by ac voltage source under condition of resonance.

Reason : The complete voltage of ac source appears across the resistor in a series LCR circuit driven by ac voltage source under condition of resonance.

30. **Assertion :** An inductor is connected to an ac source. When the magnitude of current decreases in the circuit, energy is absorbed by the ac source.

Reason : When current through an inductor decreases, the energy stored in inductor decreases.

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ANSWER KEY

EXERCISE - 1

1. B **2.** A **3.** C **4.** B **5.** B **6.** B **7.** C **8.** D **9.** C **10.** C **11.** D **12.** C **13.** B
14. C **15.** B **16.** D **17.** C **18.** B **19.** D **20.** C **21.** C **22.** A **23.** C **24.** D **25.** C **26.** B
27. A **28.** A **29.** B **30.** A **31.** A **32.** B **33.** C **34.** D **35.** B **36.** C **37.** B **38.** B **39.** B
40. D **41.** B **42.** A **43.** B **44.** A **45.** A **46.** B **47.** D **48.** B **49.** B **50.** A

EXERCISE - 2

1. B **2.** B **3.** C **4.** D **5.** D **6.** C **7.** B **8.** D **9.** A **10.** C **11.** C **12.** B **13.** B
14. B **15.** A **16.** D **17.** B **18.** A **19.** B **20.** B **21.** D **22.** D **23.** C **24.** B **25.** C **26.** B
27. D **28.** A **29.** B **30.** A **31.** D **32.** A **33.** A **34.** D **35.** B **36.** D **37.** C **38.** A **39.** A
40. A **41.** C **42.** A **43.** B **44.** C **45.** D

EXERCISE - 3 : PART # 1

1. A → R ; B → Q; C →P; D → Q **2.** A → Q,R ; B → Q,R ; C → P,Q,R,S ; D → Q,R, S

PART # 2

1. A **2.** D **3.** D **4.** A **5.** A **6.** C **7.** A **8.** B **9.** A **10.** A **11.** E **12.** B **13.** C
14. A **15.** B **16.** D

EXERCISE - 4 : PART # 1

1. B **2.** D **3.** A **4.** C **5.** C **6.** A **7.** C **8.** A **9.** B **10.** C **11.** C **12.** C **13.** A
14. D **15.** B **16.** A **17.** C **18.** C **19.** D **20.** B **21.** B **22.** A **23.** A **24.** C **25.** C **26.** D
27. B

PART # 2

1. B **2.** A **3.** C **4.** A **5.** D **6.** B **7.** A **8.** C **9.** B **10.** A **11.** A **12.** C **13.** A
14. B **15.** A **16.** C **17.** A **18.** A **19.** B **20.** B **21.** B **22.** B **23.** B **24.** D **25.** B **26.** B
27. B **28.** C **29.** C **30.** C **31.** A **32.** A **33.** D

MOCK TEST

1. A **2.** B **3.** D **4.** A **5.** D **6** A **7.** B **8.** C **9.** A **10.** B **11.** C **12.** C **13.** C
14. D **15.** C **16.** A **17.** D **18.** A **19.** B **20.** C **21.** B **22.** B **23.** C **24.** C
25. A → S ; B → P, R, S ; C → Q, S, T ; D → Q, T **26.** A → Q,R ; B → P,T ; C → P,R ; D → Q, T
27. C **28.** D **29.** D **30.** A

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HINTS & SOLUTIONS

EXERCISE - 1
NEET LEVEL

1. (B) Power loss $\propto \frac{1}{(\text{Voltage})^2}$

2. (A) $V = 5\cos\omega t = 5\sin\left(\omega t + \frac{\pi}{2}\right)$ and $i = 2\sin\omega t$

Power $= V_{r.m.s.} \times i_{r.m.s.} \times \cos\phi = 0$

(Since $\phi = \frac{\pi}{2}$, therefore $\cos\phi = \cos\frac{\pi}{2} = 0$)

3. (C) $P = V_{r.m.s.} \times i_{r.m.s.} \times \cos\phi = \frac{100}{\sqrt{2}} \times \frac{100\times10^{-3}}{\sqrt{2}} \times \cos\frac{\pi}{3}$

$= \frac{10^4 \times 10^{-3}}{2} \times \frac{1}{2} = \frac{10}{4} = 2.5\ watt$

4. (B) In *dc* ammeter, a coil is free to rotate in the magnetic field of a fixed magnet. If an alternating current is passed through such a coil, the torque will reverse it's direction each time the current changes direction and the average value of the torque will be zero.

5. (B) The coil having inductance L besides the resistance R. Hence for ac it's effective resistance $\sqrt{R^2 + X_L^2}$ will be larger than it's resistance R for dc.

6. (B) $i_{r.m.s.} = \frac{i_o}{\sqrt{2}} = \frac{4}{\sqrt{2}} = 2\sqrt{2}\ ampere$

7. (C) Effective voltage $V_{r.m.s.} = \frac{V_o}{\sqrt{2}} = \frac{423}{\sqrt{2}} = 300\ V$

8. (D) The current takes $\frac{T}{4}\ sec$ to reach the peak value.

In the given question $\frac{2\pi}{T} = 200\pi \Rightarrow T = \frac{1}{100} sec$

$\therefore$ Time to reach the peak value $= \frac{1}{400} sec$

9. (C) $i_{r.m.s} = \frac{6}{\sqrt{2}} = 3\sqrt{2}\ A$

10. (C) $\nu = \frac{\omega}{2\pi} = \frac{120\times7}{2\times22} = 19\ Hz$

$V_{r.m.s.} = \frac{240}{\sqrt{2}} = 120\sqrt{2} \approx 170\ V$

11. (D)

12. (C) Peak value $= 220\sqrt{2} = 311\ V$

13. (B) Power $= I^2R = \left(\frac{I_p}{\sqrt{2}}\right)^2 R = \frac{I_p^2 R}{2}$

14. (C) $i_{r.m.s.} = \frac{V_{r.m.s.}}{R} = \frac{200}{40} = 5\ A$

$\Rightarrow i_0 = i_{r.m.s.}\sqrt{2} = 7.07\ A$

15. (B)

16. (D) Time taken by the current to reach the maximum value $t = \frac{T}{4} = \frac{1}{4\nu} = \frac{1}{4\times50} = 5\times10^{-3} sec$ and

$i_o = i_{rms}\sqrt{2} = 10\sqrt{2} = 14.14\ amp$

17. (C)

18. (B) $E = E_0\cos\omega t = E_0\cos\frac{2\pi t}{T}$

$= 10\cos\frac{2\pi\times50\times1}{600} = 10\cos\frac{\pi}{6} = 5\sqrt{3}\ volt.$

19. (D) Phase angle $\phi = 90^o$, so power $P = Vi\cos\phi = 0$

20. (C) $V_{rms} = \frac{200}{\sqrt{2}}$, $i_{rms} = \frac{1}{\sqrt{2}}$

$\therefore P = V_{rms}\, i_{rms}\cos\phi = \frac{200}{\sqrt{2}}\frac{1}{\sqrt{2}}\cos\frac{\pi}{3} = 50\ watt$

21. (C) $2\pi\nu = 377 \Rightarrow \nu = 60.03\ Hz$

22. (A)

23. (C) $i_{rms} = \sqrt{\frac{i_1^2 + i_2^2}{2}} = \frac{1}{\sqrt{2}}(i_1^2 + i_2^2)^{1/2}$

24. (D) $P = Vi\cos\phi$

Phase difference $\phi = \frac{\pi}{2} \Rightarrow P = zero$

25. (C) $V_0 = V_{rms} \times \sqrt{2} = 220\times\sqrt{2} = 310$

26. (B) **27. (A)**

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28. (A) The choke coil can be used only in ac circuits, not in *dc* circuits, because for dc ($\omega = 0$) the inductive reactance $X_L = \omega L$ of the coil is zero, only the resistance of the coil remains effective which too is almost zero.

29. (B) Because power $= i^2R$, if $R = 0$, then $P = 0$.

30. (A)

31. (A) A choke coil contains high inductance but negligible resistance, due to which power loss becomes appreciably small.

32. (B) For purely capacitive circuit $e = e_0 \sin \omega t$

$i = i_o \sin\left(\omega t + \frac{\pi}{2}\right)$ *i.e.* current is ahead of emf by $\frac{\pi}{2}$

33. (C) **34. (D)**

35. (B) $Z = \sqrt{R^2 + X_L^2}$, $X_L = \omega L$ and $\omega = 2\pi f$

$\therefore Z = \sqrt{R^2 + 4\pi^2 f^2 L^2}$

36. (C) $\nu = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{10^{-6} \times 10^{-4}}} = \frac{10^5}{2\pi} Hz$

37. (B)

38. (B) The applied voltage is given by $V = \sqrt{V_R^2 + V_L^2}$

$V = \sqrt{(200)^2 + (150)^2} = 250$ *volt*

39. (B) $i = \frac{V}{\sqrt{R^2 + \omega^2 L^2}} = \frac{120}{\sqrt{100 + 4\pi^2 \times 60^2 \times 20^2}}$

$= 0.016\, A$

40. (D) For the first circuit $i = \frac{V}{Z} = \frac{V}{\sqrt{R^2 + \omega^2 L^2}}$

$\therefore$ Increase in ω will cause a decrease in i.

For the second circuit $i = \frac{V}{\sqrt{R^2 + \frac{1}{\omega^2 C^2}}}$

Increase in ω will cause an increase in i.

41. (B) $X_C = \frac{1}{\omega C} = \frac{1}{2\pi \nu C}$; For dc $\nu = 0$, $\therefore X_C = \infty$

42. (A) In a pure inductor (zero resistance), voltage leads the current by 90° i.e. $\pi/2$.

43. (B)

44. (A) The voltage across a *L–R* combination is given by

$V^2 = V_R^2 + V_L^2$

$V_L = \sqrt{V^2 - V_R^2} = \sqrt{400 - 144} = \sqrt{256} = 16$ volt.

45. (A) Phase angle $\tan\varphi = \frac{\omega L}{R} = \frac{2\pi \times 200}{300} \times \frac{1}{\pi} = \frac{4}{3}$

$\therefore \varphi = \tan^{-1}\frac{4}{3}$

46. (B) At resonance, *LCR* circuit behaves as purely resistive circuit, for purely resistive circuit power factor = 1

47. (D) Given $\omega L = \frac{1}{\omega C} \Rightarrow \omega^2 = \frac{1}{LC}$

or $\omega = \frac{1}{\sqrt{10^{-3} \times 10 \times 10^{-6}}} = \frac{1}{\sqrt{10^{-8}}} = 10^4$

$X_L = \omega L = 10^4 \times 10^{-3} = 10\Omega$

48. (B)

49. (B) Reading of ammeter $= i_{rms} = \frac{V_{rms}}{X_C} = \frac{V_0 \omega C}{\sqrt{2}}$

$= \frac{200\sqrt{2} \times 100 \times (1 \times 10^{-6})}{\sqrt{2}} = 2 \times 10^{-2}\,A = 20\,mA$

50. (A) Current will be maximum at the condition of resonance. So resonant frequency

$\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{0.5 \times 8 \times 10^{-6}}} = 500\ rad/s$

EXERCISE - 2
AIIMS LEVEL

1. (B)

2. (B) $I_{rms} = \left[\frac{\int_0^T i^2\, dt}{T}\right]^{\frac{1}{2}}$

$= \left[\int_0^T \frac{[3 + 4\sin(\omega t + \pi/3)]^2}{T} dt\right]^{1/2} = \sqrt{17}$.

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3. **(C)** $V = 100 \sin 100\pi t \cos 100\pi t$

$V = 50 \sin 200\pi t$

here $V_O = 50$

& $\omega = 200\pi$

$f = 100$ Hz

4. **(D)** If net area of E – t curve is zero for given interval then average value will be zero.

5. **(D)** **6.** **(C)** **7.** **(B)** **8.** **(D)**

9. **(A)** $P_{av} = v_{rms} I_{rms} \cos\phi$

Here $\phi = 90°$ So $P_{av} = 0$

10. **(C)** **11.** **(C)**

12. **(B)** $\langle P \rangle = I^2_{rms} R = \left(\frac{I_P}{\sqrt{2}}\right)^2 R = \frac{I_P^2 R}{2}$

13. **(B)**

14. **(B)** $I^2R = 100$

$$R = \frac{100}{I^2} = \frac{100}{(2)^2} = 25.$$

15. **(A)**

16. **(D)** $I_O = \frac{V_0}{\omega L} = \frac{10}{100 \times 5 \times 10^{-3}}$

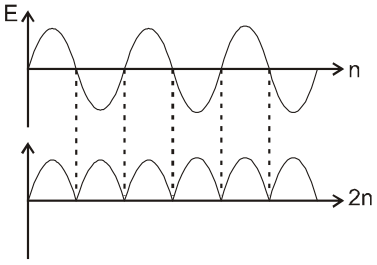
17. **(B)** $\cos\phi = \frac{R}{z}$

$$\% \text{ change} = \frac{z' - z}{z} \times 100 = 100\%.$$

18. **(A)** $I_{rms} = \frac{V_{rms}}{Z} = \frac{V_{rms}}{\sqrt{R^2 + (\omega L)^2}} = 2A$

$$\tan\phi = \frac{\omega L}{R} = \frac{66}{88} = \frac{3}{4}.$$

19. **(B)**



20. **(B)** $I_{rms} = \frac{V_{rms}}{Z} = \frac{100}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$

P.d. across resistance = $R\, I_{rms}$ = 100 volt.

21. **(D)** **22.** **(D)**

23. **(C)** $R = \frac{V_0}{I_0} = \frac{200}{5} = 40\,\Omega$ (For circuit x)

$X_L = \frac{V_0}{I_0} = 40\,\Omega$ (For circuit y)

If x & y are in series

$$I = \frac{200}{40 \times \sqrt{2}} = \frac{5}{\sqrt{2}} \text{ Amp.}$$

$$\Rightarrow I_{rms} = \frac{I_0}{\sqrt{2}} = \frac{5}{2} \text{ amp.}$$

24. **(B)**

25. **(C)** $\tan\phi = \tan 45° = \frac{\omega L}{R}$

$X_L = \omega L = R.$

26. **(B)** $I = \frac{200\sqrt{2}}{(X_C) \times \sqrt{2}} = 200 \times \omega C = 20$ mA.

27. **(D)** Voltage of source is always less than $(V_1 + V_2 + V_3)$, $V_{net} = \sqrt{V_1^2 + V_2^2 + V_3^2}$

28. **(A)** **29.** **(B)** **30.** **(A)**

31. **(D)** Current lags behind voltage.

If $X_L > X_C \Rightarrow 2\pi\nu L > \frac{1}{2\pi\nu C} \Rightarrow \nu > \frac{1}{2\pi\sqrt{LC}}$

But as $\nu_r = \frac{1}{2\pi\sqrt{LC}}$

therefore, $\nu > \nu_r$

32. **(A)** $I_{rms} = \frac{60}{120} = \frac{1}{2}$ Amp.

$V_L = I_{rms} \times (\omega L)$

$40 = \frac{1}{2} \times (40 \times 10^3) \times L$

$L = 20$ mH

At resonance $V_C = I_{rms}\left(\frac{1}{\omega c}\right) = V_L$

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$$C = \frac{1}{2} \times \frac{1}{4\times10^3} \times \frac{1}{40} \Rightarrow C = \frac{25}{8}\ \mu F.$$

33. (A)

34. (D) $\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{8}{1} \Rightarrow V_2 = 8 \times 120 = 960$ volt

$$I = \frac{960}{10^4} = 96\ mA.$$

35. (B)

36. (D) $I_1 E_1 = I_2 E_2$

$$I_2 = \frac{I_1 E_1}{E_2} = \frac{5\times220}{22000} = .05\ A$$

37. (C) **38.** (A) **39.** (A) **40.** (A) **41.** (C) **42.** (A)
43. (B) **44.** (C) **45.** (D)

EXERCISE - 3
P-1 (Matrix Match)

1. **A → R ; B → Q; C → P; D → Q**

2. **A → Q,R ; B → Q,R ; C → P,Q,R,S ; D → Q,R, S**

(A) Inductance of a coil depends on its shape and magnetic properties of its core (medium inserted)

(B) Capacitance of capacitor depends on its shape and dielectric properties of medium inserted.

(C) Impedance of coil $\sqrt{R^2+\omega^2L^2}$ depends on resis tivity (due to R), shape (for L), magnetic properties of core inserted and also depends on angular fre quency ω of external voltage source.

(D) Reactance of capacitor = $\frac{1}{\omega C}$ depends on shape (for C), nature of dielectric medium (for C) and exter nal voltage source (due to ω).

EXERCISE - 3
P-2 (Assertion & Reason)

1. **(A)**

2. **(D)** Statement 1 is false because the given relation is true if all voltages are instantaneous.

3. **(D)**

4. **(A)** Statement-1 is True, Statement-2 is True; Statement-2 is a correct explanation for Statement-1

5. **(A)** At resonant frequency, $X_L = X_C$ $\therefore$ Z = R (minimum) there for current in the circuit is maximum.

6. **(C)** When ac flows through an inductor current lags behind the emf., by phase of π/2, inductive reactance, $X_L = \omega L = \pi.2f.L$, so when frequency increases correspondingly inductive reactance also increases.

7. **(A)** The capacitive reactance of capacitor is given by

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi fC}$$

So this is infinite for dc (f = 0) and has a very small value for ac. Therefore a capacitor blocks dc.

8. **(B)** The phase angle for the LCR circuit is given by

$$\tan\varphi = \frac{X_L - X_C}{R} = \frac{\omega L - 1/\omega C}{R}$$

Where X_L, X_C are inductive reactance and capacitive reactance respectively when $X_L > X_C$, then tan ϕ is positive i.e. ϕ is positive (between 0 and π/2). Hence emf leads the current.

9. **(A)** If resistor is used in controlling ac supply, electrical energy will be wasted in the form of heat energy across the resistance wire. However, ac supply can be controlled with choke without any wastage of energy. This is because, power factor (cos ϕ) for resistance is unity and is zero for an inductance. [P = EI cos ϕ].

10. **(A)** When frequency of alternating current is increased, the effective resistance of the inductive coil increases. Current ($X_L = \omega L = 2\pi fL$) in the circuit containing inductor is given by $I = \frac{V}{X_L} = \frac{V}{2\pi fL}$. As inductive resistance of the inductor increases, current in the circuit decreases.

11. **(E)** On introducing soft iron core, the bulb will glow dimmer. This is because on introducing soft iron core in the solenoid, its inductance L increases, the inductive reactance, $X_L = \omega L$ increases and hence the current through the bulb decreases.

12. **(B)** Like direct current, an alternating current also produces magnetic field. But the magnitude and direction of the field goes on changing continuously with time.

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13. (C) Both ac and dc produce heat, which is proportional to square of the current. The reversal of direction of current in ac is immaterial so far as production of heat is concerned.

14. (A) The effect of ac on the body depends largely on the frequency. Low frequency currents of 50 to 60 Hz (cycles/sec), which are commonly used, are usually more dangerous than high frequency currents and are 3 to 5 times more dangerous than dc of same voltage and amperage (current). The usual frequency of 50 cps (or 60 cps) is extremely dangerous as it corresponds to the fibrillation frequency of the myocardium. This results in ventricular fibrillation and instant death.

15. (B) The mean average value of alternating current (or emf) during a half, cycle is given by $I_m = 0.636 I_0$ (or $E_m = 0.636 E_0$)) During the next half cycle, the mean value of ac will be equal in magnitude but opposite in direction. For this reason the average value of ac over a complete cycle is always zero. So the average value is always defined over a half cycle of ac.

16. (D) An ac ammeter is constructed on the basics of heating effect of the electric current. Since heat produced varies as square of current $(H = I^2R)$. Therefore the division marked on the scale of ac ammeter are not equally spaced.

EXERCISE - 4

P-1 (NEET/AIPMT)

1. (B) We define the quality factor of the circuit as follows

Quality factor, Q

$$= 2\pi \times \frac{\text{total energy stored in the circuit}}{\text{loss in energy in each cycle}}$$

But the total energy stored in circuit = Li_{rms}^2

and the energy loss per second = $i_{rms}^2 R$

So, loss in energy per cycle $= \frac{i_{rms}^2 R}{f}$

Hence, quality factor, $Q = 2\pi \times \frac{Li_{rms}^2}{i_{rms}^2 R / f}$

$$= \frac{2\pi fL}{R} = \frac{\omega L}{R}$$

2. (D) If a capacitor of capacitance C is connected with an AC signal, then reactance of that circuit is purely capacitive.

The capacitive reactance is

$$X = \frac{1}{\omega C} = \frac{1}{2\pi fC} \qquad (\omega = 2\pi f)$$

or $X \propto \frac{1}{fC}$

Considering two different situation of frequency and capacitance, we have

$$\frac{X'}{X} = \frac{fC}{f'C'} = \frac{f \times C}{2f \times 2C} \qquad [\because f' = 2f \text{ and } C' = 2C]$$

or $\frac{X'}{X} = \frac{1}{4}$ or $X' = \frac{X}{4}$

3. (A) The green house is a room made of glass which is constructed to grow plants in open space. The glass transmits the infrared radiations of short wavelength and the visible light, but it absorbs the inifrared radiations of long wavelength. During the day time, the light and the infrared radiations of short wavelength enter inside the green house through the roof and the walls and they are absorbed by the plants.

At night, plants emit the infrared radiations through the glass walls and roof. As a result, green house remains warm. This is called green house effect.

4. (C) In series LCR circuit at resonance,

capacitive reactance (X_C)

= inductive reactance (X_L)

i.e. $\frac{1}{\omega C} = \omega L$

Total impedance of the circuit

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$= \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

i.e. $Z = R$

So, power factor, $\cos\phi = \frac{R}{Z} = \frac{R}{R} = 1$

Thus, power loss at resonance is given by

$$P = V_{rms}\, i_{rms} \cos\phi \qquad [\cos\phi = 1]$$

$$= V_{rms}\, i_{rms} \times 1$$

$$= (i_{rms}\, R)\, i_{rms}$$

$$= (i_{rms})^2 R = i^2 R$$

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5. **(C)** Phase difference between current and voltage in LCR series circuit is given by

$$\tan\phi = \frac{\omega L - \frac{1}{\omega C}}{R} \qquad \left[\begin{array}{l}\omega L = \text{inductive reactance} \\ \frac{1}{\omega C} = \text{capacitive reactance}\end{array}\right]$$

ϕ being the angle by which the current leads the voltage.

Given,

$\phi = 45°$

$$\therefore \quad \tan 45° = \frac{\omega L - \frac{1}{\omega C}}{R}$$

$$\Rightarrow \quad 1 = \frac{\omega L - \frac{1}{\omega C}}{R}$$

$$\Rightarrow \quad R = \omega L - \frac{1}{\omega C}$$

$$\Rightarrow \quad \omega C = \frac{1}{(\omega L - R)}$$

$$\Rightarrow \quad C = \frac{1}{\omega(\omega L - R)}$$

$$= \frac{1}{2\pi f(2\pi f L - R)}$$

6. **(A)** When magnetic flux linked with a coil changes, induced emf is produced in it and the induced current flows through the wire forming the coil. In 1895, Focault experimentally found that these induced currents are set up in the conductor in the form of closed loops. These currents look like eddies or whirlpools and likewise are known as eddy currents. They are also known as Focault's current. These currents oppose the cause of their origin, therefore, due to eddy currents, a great amount of energy is wasted in form of heat energy. If core of transformer is laminated, then their effect can be minimised.

7. **(C)** Power factor of AC circuit is given by

$$\cos\phi = \frac{R}{Z} \qquad \text{...(i)}$$

where, R is resistance and Z is the impedance of the circuit and is given by

$$Z = \sqrt{R^2 + (X_L - X_C^2)} \qquad \text{...(ii)}$$

X_L = inductive reactance

X_C = capacitive reactance

Eqs. (i) and (ii) meet to give,

$$\cos\phi = \frac{R}{\sqrt{R^2 + (X_L - X_C)^2}} \qquad \text{...(iii)}$$

Given, $R = 8\,\Omega, X_L = 31\,\Omega, X_C = 25\,\Omega$

$$\therefore \quad \cos\phi = \frac{8}{\sqrt{(8)^2 + (31-25)^2}} = \frac{8}{\sqrt{64+36}}$$

Hence, $\cos\phi = 080$

8. **(A)** Current in LCR series circuit.

$$i = \frac{V}{\sqrt{R^2 + (X_L - (X_C)2}}$$

where, V is rms value of voltage R is resistance, X_L is inductive reactance and X_C is capacitive reactance.

For current to be maximum, denominator should be minimum which can be done, i.e. during the resonance of series LCR circuit.

$$X_L = X_C \quad \text{i.e. } \omega L = \frac{1}{\omega C} \quad \text{or}$$

$$L = \frac{1}{\omega^2 C} \qquad \text{...(i)}$$

Given, $\omega = 1000\ s^{-1}, C = 10\ \mu F = 10 \times 10^{-6}\ F$

Hence, $L = \frac{1}{(1000)^2 \times 10 \times 10^{-6}}$

$= 0.1\ H = 100\ mH$

9. **(B)** The magnetic flux linked with the primary coil is given by

$\phi = \phi_0 + 4t$

So, voltage across primary

$$V_p = \frac{d\phi}{dt} = \frac{d}{dt}(\phi_0 + 4t)$$

$= 4\ V$ (as ϕ_0 = constant)

Also, we have

$N_p = 50$ and $N_s = 1500$

As we know that voltage across primary and secondary coil is directly proportional to the no. of turns in primary and secondary coil respectively.

$$\text{So, } \frac{V_s}{V_p} = \frac{Ns}{N_p} \quad \text{and } V_s = V_p \frac{N_s}{N_p}$$

$$= 4\left(\frac{1500}{50}\right) = 120V$$

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Note :

As in case of given transformer, voltage in secondary is increased, hence it is a step-up transformer.

10. (C) The efficiency of transformer

$$= \frac{\text{Energy obtained from the secondary coil}}{\text{Energy given to the primary coil}}$$

or $\eta = \dfrac{\text{Output power}}{\text{Input power}}$

or $\eta = \dfrac{V_s I_s}{V_p I_p}$ [as power = VI]

Given, $V_s I_s = 100\ W, V_p = 220\ V, I_p = 0.5\ A$

Hence, $\eta = \dfrac{100}{220 \times 0.5} = 0.90 = 90\%$

11. (C) The velocity of electromagnetic waves in free space is given by

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

12. (C) $P_{av} = V_{rms} \cdot i_{rms} \cos\phi = \dfrac{1}{2} V_0 i_0 \cos\phi$

$$\left[\because V_{rms} = \frac{V_0}{\sqrt{2}}, i_{rms} = \frac{i_0}{\sqrt{2}}\right]$$

where, $\cos\phi$ = power factor

13. (A) Power dissipated in series LCR.

$$P = I_{rms}^2 R$$

$$= \frac{\varepsilon_{rms}^2 R}{|Z|^2} = \frac{\varepsilon^2 R}{\left[R^2 + \left(\omega L - \dfrac{1}{\omega C}\right)^2\right]}$$

As $I_{rms} = \dfrac{Vrms}{Z}$

14. (D) Efficiency is defined as the ratio of output power and input power

i.e. $\eta\% = \dfrac{P_{out}}{P_{input}} \times 100 = \dfrac{V_s i_s}{V_p i_p} \times 100$

$$80 = \frac{2 \times 440}{220 \times i_p} \times 100 \Rightarrow i_p = 5\ A$$

15. (B) For series LCR circuit

Voltage $V = \sqrt{V_R^2 + (V_L - V_C)^2}$

Since, $V_L = V_C$

Hence $V = V_R = 220\ V$

Also, current $i = \dfrac{V}{R} = \dfrac{220}{100} = 2.2A$

16. (A) As we know that

$$\tan\phi = \frac{X_L}{R} = \frac{\omega L}{R} \Rightarrow \tan\phi = \frac{3}{5}$$

$\therefore \quad \tan\phi = 1 \Rightarrow \phi = 45°$

So, phase difference = $\dfrac{\pi}{4}$ rad

17. (C) Problem Solving Strategy Compare the given equation with the equation of alternating voltage

i.e.

$$e = e_m \sin\omega t$$

where, $e_m = e_{rms}$

Given,

emf, $e = 200\sqrt{2}\sin 100\ t$

and $C = 1\ \mu F = 1 \times 10^{-6}\ F$

As $e_{rms} = 200\ V$ and $\omega = 100$

$$\therefore \quad X_C = \frac{1}{\omega C} = \frac{1}{1 \times 10^{-6} \times 100} = 10^4\ \Omega$$

$$i_{rms} = \frac{e_{rms}}{X_C} = \frac{200}{10^4} = 2 \times 10^{-2}\ A = 20\ mA$$

18. (C) As we know that phase difference for L, C, R series circuit is given by

$$\tan\phi = \frac{X_L - X_C}{R}$$

When L is removed $\tan\dfrac{\pi}{3} = \dfrac{X_C}{R}$

$$\sqrt{3} = \frac{X_C}{R}$$

$$\Rightarrow \quad X_C = R\sqrt{3}$$

When C is removed, $\tan\dfrac{\pi}{3} = \sqrt{3} = \dfrac{X_L}{R}$

$$\Rightarrow \quad X_L = R\sqrt{3}$$

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Hence, in resonant circuit

$$\tan\phi = \frac{\sqrt{3}R - \sqrt{3}R}{R} = 0$$

So, $\phi = 0$

Power factor, $\cos\phi = 1$

It is the condition of resonance, therefore, phase difference between voltage and current is zero and power factor, $\cos\phi = 1$.

19. (D) When a bulb of resistance R is connected in series with a coil of self-inductance L, then current in the circuit is given by

$$I = \frac{E}{\sqrt{\omega^2 L^2 + R^2}}$$, where E is the voltage of an AC source

As $L = \frac{\mu_0 \mu_r N^2 A}{l}$

$\Rightarrow L \propto \mu_r$

When iron rod is inserted, L increases, therefore current I decreases.

20. (B) Initial power = 3000 W

As efficiency is 90%, then final power

$$= 3000 \times \frac{90}{100} = 2700 \text{ W} \Rightarrow \quad \left.\begin{matrix} V_1 I_1 = 3000 \text{W} \\ V_2 I_2 = 2700 \text{W} \end{matrix}\right]$$

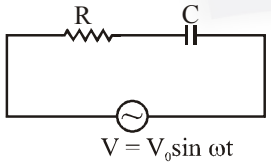
$$V_2 = \frac{2700}{6} = \frac{900}{2} \qquad [\because I_1 = 6 \text{ A}]$$

$\Rightarrow V_2 = 450 \text{ V}$

and $I_1 = \frac{3000}{200}$ $\qquad [\because V_1 = 200 \text{ V}]$

$\Rightarrow I_1 = 15 \text{ A}$

21. (B) Net reactive capacitance,



$V = V_0 \sin \omega t$

$$X_C = \frac{1}{2\pi fC}$$

So, current in circuit, $I = \frac{V}{Z} = \frac{V}{\sqrt{R^2 + \left(\frac{1}{2\pi fC}\right)^2}}$

$$\Rightarrow \quad I = \frac{2\pi fC}{\sqrt{4\pi^2 f^2 C^2 R^2 + 1}} \times V$$

Voltage drop across capacitor, $V_C = I \times X_C$

$$= \frac{2\pi fC}{\sqrt{4\pi^2 f^2 C^2 R^2 + 1}} \times \frac{1}{2\pi fC}$$

i.e. $V_C = \frac{V}{\sqrt{4\pi^2 f^2 C^2 R^2 + 1}}$

When mica is introduced, capacitance will increase hence, voltage across cpacitance get decrease.

22. (A) When a resistor is connected to an AC source.

The power drawn will be

$$P = V_{rms} \cdot I_{rms} = V_{rms} \cdot \frac{V_{rms}}{R} \Rightarrow V_{rms}^2 = PR$$

When an inductor is connected in series with the resistor, then the power drawn will be

$$P' = V_{rms} \cdot I_{rms} \cos\phi$$

where, ϕ = phase difference

$$\therefore \quad P' = \frac{V_{rms}^2}{R} \cdot \frac{R^2}{Z^2} = P \cdot R \cdot \frac{R}{Z^2}$$

$$\therefore \quad P' = \frac{P \cdot R^2}{Z^2} = P\left(\frac{R}{Z}\right)^2$$

23. (A) Impedence of the R-C circuit, $Z = \sqrt{R^2 + X_C^2}$

where, $R = 100\ \Omega$ and $X_C = 100\ \Omega$

$$\Rightarrow \quad \tau = \sqrt{(100)^2 + (100)^2} = 100\sqrt{2}\ \Omega$$

Peak value of the current.

$$I_{max} = \frac{V_{max}}{Z} = \frac{220\sqrt{2}}{100\sqrt{2}} = 2.2 \text{ A}$$

24. (C) Power factor of the L-C-R circuit

$$= \cos\phi = \frac{R}{Z} = \frac{IR}{IZ} = \frac{80}{I\sqrt{(X_L - X_C)^2 + R^2}}$$

$$= \frac{80}{\sqrt{(IX_L - IX_C)^2 + (IR)^2}}$$

$$= \frac{80}{\sqrt{(100 - 40)^2 + (80)^2}}$$

$$= \frac{80}{\sqrt{(60)^2 + (80)^2}} = \frac{80}{100} = 0.8$$

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25. **(C) Key Idea** For better tuning, peak of current growth must be sharp. This is ensured by a high value of quality factor Q.

Now, quality factor is given by $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$

From the given options, highest value of Q is associated with $R = 15\ \Omega$, $L = 3.5$ H and $C = 30\ \mu F$

26. **(D)** Given,

Inductance $L = 20$ mH

Capacitance, $C = 50\ \mu F$

Resistance, $R = 40\ \Omega$

emf, $V = 10 \sin 340\, t$

$\because$ Power loss in AC circuit will be given as

$$P_{av} = I_V^2 R = \left[\frac{E_v}{Z}\right]^2 \cdot R$$

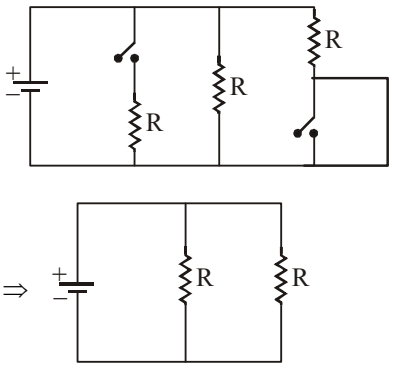
$$= \left(\frac{10}{\sqrt{2}}\right)^2 \cdot \left[40 \frac{1}{40^2 + \left(\frac{340\times 20\times 10^3 - 1}{340\times 50\times 10^{-6}}\right)^2}\right]$$

$$= \frac{100}{2} \times 40 \times \frac{1}{1600 + (6.8 - 58.8)^2}$$

$$= \frac{2000}{1600 + 2704} \approx 0.46\text{W} \approx 0.51\text{ W}$$

27. **(B) Thinking Process** Just after switch is closed, inductor acts like an open swith (open path) and capacitor acts like a closed switch (closed path) because in D.C. circuit inductive resistance becomes zero.

Just after swithc is closed, given circuit is equivalent to the circuit shown below.



So, equivalent resistor

$$= \frac{R}{2} = \frac{9}{2}\text{ohms}$$

Battery emf, $V = 18$ volts

$$\therefore \text{ Current in circuit} = \frac{V}{R} = \frac{18\times 2}{9} = 4\text{A}$$

EXERCISE - 4

P-2 (AIIMS)

1. **(B)** Transformers are used for stepping-up or stepping down an A.C current (A.C voltage source). Leclanche cell gives a D.C. voltage. As the input from a Leclanche cell does not change with time, the magnetic flux linked with the secondary also does not change and hence the induced emf is zero. Hence the output will be zero.

2. **(A)** Since voltage across L, C and R is same, equal to 10 V, therefore $R = X_L = X_C$.

Also total voltage in the circuit is

$I[R^2 + (X_L - X_C)^2]^{1/2} = IR = 10$ V.

When capacitor is short circuited current in the circuit

$$I = \frac{10}{(R^2 + K_L^2)^{1/2}} = \frac{10}{\sqrt{2}R}.$$

Potential drop across inductance

$$= IX_L = IR = (10/\sqrt{2})\text{ V}.$$

3. **(C)** $e_c < e_b < e_0$

Break is more sudden than make. Hence $e_b > e_c$.

The emf of the source is greatest of all.

Thus $e_0 > e_b > e_c$ expresses the result.

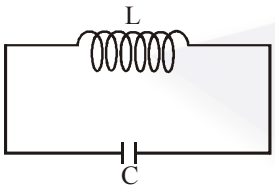
4. **(A)** $X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$

$$= \frac{1}{2\times 3.14\times 1\times 10^3 \times 2\times 10^{-6}} = \frac{10^3}{4\times 3.14}$$

Voltage, $V = i \times X_C = 2\times 10^{-3} \times \frac{10^3}{4\times 3.14} = 0.16\text{ V}.$

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5. **(D)** When the capacitor is connected to a d.c. source and then disconnected, it gets charged and then it starts discharging through the inductor. An induced emf is produced in the circuit which opposes the growth of current in L. When the capacitor is fully discharged, the electric energy stored in the capacitor $\left(\text{i.e.}\frac{1}{2}\frac{q^2}{C}\right)$ gets converted fully into magnetic field energy $\left(\frac{1}{2}LI^2\right)$.



As soon as the discharge of the capacitor is complete, current stops and the magnetic flux linked with L starts collapsing. Therefore, an induced emf is again developed which starts recharging the capacitor in the opposite direction. When the recharging is completed, all magnetic energy stored in L appears as the electric energy between the plates of the capacitor. The entire process keeps on repeating and the energy taken from the cell keeps on oscillating between C and L. Hence the current in the circuit starts oscillating as soon as the d.c. source charging the capacitor is disconnected.

6. **(B)** $\upsilon = 50\ \text{Hz}, V = 20\ \text{V}, V_R = 12\ \text{V}$

In case of RC circuit, $V = \sqrt{V_R^2 + V_C^2}$

$\Rightarrow \quad (20)^2 = (12)^2 + (V_C)^2$

$\Rightarrow \quad (V_C)^2 = 400 - 144 = 256 \Rightarrow V_C = 16\ \text{V}.$

7. **(A)** The circuit shows a tuned filter.

8. **(C) :** Induced emf $\varepsilon = \frac{-MdI_P}{dt}$

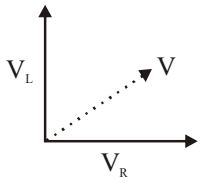
where M is the mutual inductance of two coils and $\frac{dI_P}{dt}$ is the rate of change of current in the primary.

$\therefore \quad 1000\,\text{V} = \frac{-M(0\text{A} - 2\text{A})}{0.01\text{s}}$

or $\quad M = \frac{(1000\,\text{V})(0.01\text{s})}{(2\text{A})} = 5\text{H}.$

9. (B) $V_L = 16\ \text{V}, V_R = 20\ \text{V}.$

In the inductor the current lags by $\frac{\pi}{2}$.



$\therefore \quad V = \sqrt{V_L^2 + V_R^2} = \sqrt{256 + 400}$

$\therefore \quad V_{\text{total}} = 25.6\ \text{V}.$

10. **(A)** Impedance of RL circuit is

$Z = \sqrt{R^2 + X_L^2}$

where $X_L = \omega L = 2\pi f L$

$\therefore \quad Z = \sqrt{R^2 + (2\pi f L)^2}.$

11. **(A)** For dc, V = IR (R is resistance of inductor)

$100 = 1 \times R \Rightarrow R = 100\ \Omega.$

For ac, $Z = \sqrt{R^2 + X_L^2}$

$\because \quad V = IZ$

$\Rightarrow \quad 100 = 0.5\sqrt{R^2 + X_L^2}$

$\Rightarrow \quad 100 = 0.5\sqrt{(100)^2 + X_L^2}$

$\Rightarrow \quad 100 = \frac{5}{10}\sqrt{(100)^2 + X_L^2}$

$X_L^2 = (200)^2 - (100)^2 = 300 \times 100$

$\Rightarrow \quad X_L = \sqrt{3 \times (100)^2} = 100\sqrt{3}$

$\Rightarrow \quad \omega L = 100\sqrt{3} \Rightarrow \quad 2\pi\upsilon L = 100\sqrt{3}$

$\Rightarrow \quad 2 \times \pi \times 50 \times L = 100\sqrt{3}$

$\therefore \quad L = \frac{\sqrt{3}}{\pi} = \frac{\sqrt{3}}{3.14} \quad \Rightarrow \quad L = 0.55\ \text{H}.$

12. **(C)** Average value of A.C. for complete cycle is zero. Hence A.C. can not be measured by D.C. ammeter.

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13. **(A)** The energy loss due to eddy currents is reduced by using laminated core in a transformer.

14. **(A)** The mechanical equivalent of spring constant in LC oscillating circuit is, $K = \frac{1}{C}$.

15. **(A)** In series LCR circuit, the phase angle ϕ is given by

$$\tan\phi \frac{X_L - X_C}{R}$$

When $X_L > X_C$, tan ϕ is positive. Therefore the phase difference is positive.

16. **(C)** If $\frac{dI}{dt}$ is the rate of change of current through inductor L of any instant, then induced emf in the inductor of the same instant is

$$= \left(-\frac{L\,dI}{dt}\right)$$

To maintain the flow of current in the circuit applied voltage must be equal and opposite to the induced voltage.

$$\therefore \quad V = -\left(-L\frac{dI}{dt}\right).$$

Given, $V = V_0 \sin\omega t$ ....(i)

$$\therefore \quad V_0 \sin\omega t = \frac{L\,dI}{dt}$$

$$\frac{dI}{dt} = \frac{V_0}{L}\sin\omega t$$

$$\text{or } I = \frac{-V_0}{L}\frac{\cos\omega t}{\omega} \qquad \text{...(ii)}$$

Instantaneous power,

$\because \quad P = VI$

$$= (V_0 \sin\omega t)\left(-\frac{V_0 \cos\omega t}{L\omega}\right) \text{ (Using (i) \& (ii))}$$

$$= \frac{-V_0^2 \sin 2\omega t}{2L\omega}$$

17. **(A)** The phase angle

$$\theta = \tan^{-1}\left(\frac{X_C - X_L}{R}\right) = \tan^{-1}\left(\frac{8-5}{4}\right)$$

$$\theta = \tan^{-1}\left(\frac{3}{4}\right)$$

Therefore, the current leads the voltage by $\tan^{-1}\left(\frac{3}{4}\right)$.

18. **(A)**

19. **(B)** After a long time the capacitor has become fully charged, the entire battery voltage 60 V appears across the capacitor.

20. **(B)** Restoring force is produced by inductor as it acts as a source of energy.

21. **(B)** iron is most suitable for electromagnets and transformers, because of low energy losses.

22. **(B)** Here, $R = 10\,\Omega$, $L = 2$ H,

$V = 120$ V, $\upsilon = 60$ Hz

$$X_L = \omega L = 2\pi\upsilon L = 2 \times \frac{22}{7} \times 60 \times 2 = 754.3 \text{ W}$$

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{10^2 + (754.3)^2} = 754.35\,\Omega$$

$$I_V = \frac{V}{Z} = \frac{120}{754.3}\text{A} = 0.16\text{A}$$

23. **(B)** $T = RC = (10^9\,\Omega)\,(5 \times 10^{-6}\text{ F}) = 5 \times 10^3$ s

$$= \frac{50 \times 10^3 \text{ s}}{(60\text{s / min})(60\text{ min / h})} = \frac{5000\text{s}}{3600\text{s / h}} = 1.4\text{ h}$$

The initial charge on the capacitor is

$Q_0 = CV = (5 \times 10^{-6}\text{F})\ (3\text{V}) = 1.5 \times 10^{-5}$ C

After t = 1 h, t/T = (1h)/(1.4 h) = 0.71

and $Q = Q_0 e^{-t/T}$

$= (1.5 \times 10^{-5}\text{ C})\,(e^{-0.71})$

$= (1.5 \times 10^{-5}\text{ C})\,(0.49) = 7.4 \times 10^{-6}$ C

24. **(D)** Here, $L = 8\,\mu\text{H} = 8 \times 10^{-6}$ H ;

$C = 0.02\ \mu\text{F} = 0.02 \times 10^{-6}$ F

$\therefore$ Resonant frequency,

$$fr = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{8\times10^{-6}\times0.02\times10^{-6}}}$$

$$= 3.98 \times 10^5 \text{ Hz}$$

If c ($= 3 \times 10^8$ m s^{-1}) is the velocity of the electromagnetic wave, then,

$$\text{Wavelength, } \lambda = \frac{c}{f} = \frac{3\times10^8}{3.98\times10^5} = 7.54\times10^2\text{ m}$$

25. **(B)** $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$ or $\frac{L}{C} = (QR)^2$

$\therefore \quad L = (0.4 \times 2 \times 10^3)^2 \times 0.1 \times 10^{-6} = 0.064$ H

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26. (B) Induced e.m.f. $|\varepsilon| = \frac{Ldi}{dt}$

and current (i) $= \frac{\varepsilon}{R} = \frac{1}{R} \times \frac{Ldi}{dt}$

or, $\frac{L}{R} = \frac{idt}{di} = \frac{\text{current} \times \text{time}}{\text{current}} = \text{time}.$

In order to reduce the rate of increase of current through a solenoid, we increase the time constant (L/R).

27. (B) A step-down transformer converts electrical energy from a high voltage to one at a low voltage. Accordingly the current in the secondary will be larger than that in the primary. In order to produce less heat in the secondary, we use a wire of lesser resistance i.e. thick wire. We also know that when the plane of the armature is parallel to the lines of force of magnetic field, the rate of change of magnetic flux linked with it is maximum. Therefor the e.m.f. induced in the armature in this orientation is maximum

28. (C) Faraday's laws involve conservation of mechanical energy into electrical energy. This is in accordance with the law of conservation of energy. In pure resistance, the e.m.f. is in phase with the current.

29. (C) Assertion is true. When a capacitor is connected to an a.c. circuit, $\varepsilon_{rms} = i_{rms}\left(\frac{1}{C\omega}\right)$ where $\frac{1}{C\omega}$ is the impedance due to capacitative resistance. The power consumed in this circuit is zero because the phase difference ϕ between emf and current in a pure capacitance a.c. circuit is $\frac{\pi}{2}$. Power factor $\cos\phi = 0$. It is only for d.c. that a current does not flow. Reason is false.

30. (C) Assertion is correct but reason is false because inductance reactance $X_L = 2\pi fL$. So, higher the frequency greater will be the inductive reactance.

31. (A)

32. (A) Transformers which convert low voltages into higher ones are called step-up transformers, while those which convert high voltages into lower ones are called step-down transformers. This is possible only for a.c. source and not for d.c. source.

33. (D) At resonance $X_L = X_C$ or $\omega L = \frac{1}{\omega C}$.

Because of this impedance of LCR series circuit become equal to resistance of circuit $\left(Z = \sqrt{R^2 + (X_L - X_C)^2}\right)$.

Therefore from $I = \frac{E}{Z} = \frac{E}{R}$, at resonance, current in LCR series circuit is maximum. Correspondingly phase angle is also equal to zero. Therefore emf and current are in phase in LCR series circuit.

MOCK TEST

1. (A) From Kirchoff's current law,

$i_3 = i_1 + i_2 = 3 \sin \omega t + 4 \sin(\omega t + 90°)$

$= \sqrt{3^2 + 4^2 + 2(3)(4)\cos 90°}\ \sin(\omega t + \phi)$

where $\tan\phi = \frac{4\sin 90°}{3 + 4\cos 90°} = \frac{4}{3}$

$\therefore\ i_3 = 5 \sin(\omega t + 53°)$

2. (B) $\varepsilon = \varepsilon_0 \sin \omega t$

If $i = i_m \sin(\omega t - \phi)$

then $v_C = \left(\frac{1}{\omega C}\right) i_m \sin(\omega t - \phi - \pi/2)$

and $v_L = (\omega L)\, i_m \sin(\omega t - \phi + \pi/2)$.

So $v_C + v_L + v_R = \varepsilon_0 \sin \omega t$

$\Rightarrow 0 + v_R = \varepsilon_0 \sin \omega t \Rightarrow v_R = \varepsilon_0 \sin \omega t$

Also $\tan\phi = \frac{\omega L - \frac{1}{\omega C}}{R} = 0$, so $i = i_m \sin \omega t$

Hence answer is (B)

$z = \sqrt{\left(\omega L - \frac{1}{\omega C}\right)^2 + R^2} = R$

3. (D) When capacitance is removed

$\tan\theta = \frac{\omega L}{R}$ or $\omega L = 100 \tan 60°$ ...(1)

when inductance is removed

$\tan\phi = \frac{1}{(\omega C)(R)}$ or $\frac{1}{\omega C} = 100 \tan 60°$ ...(2)

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From equation (1) & (2) $\omega L = \frac{1}{\omega C}$

So it is condition of resonance.

so $z = R = 100\ \Omega$

$I = v/R = 200/100 = 2A$

Power $P = I^2 R = 4 \times 100 = 400$ W

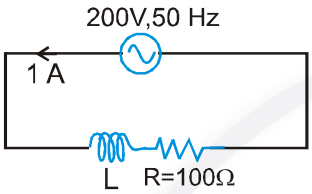
4. **(A)** Current leads emf so circuit is R – C.

$\tan\phi = x_C/R$, $\phi = 45°$, $R = 1000\ \Omega$, $\omega = 100$

since $\tan 45° = \frac{1}{\omega CR}$ So $C = 10\ \mu F$

5. **(D)** From the rating of the bulb , the resistance of the bulb can be calculated.

$$R = \frac{V_{rms}^2}{P} = 100\,\Omega$$



For the bulb to be operated at its rated value the rms current through it should be 1A

Also, $I_{rms} = \frac{V_{rms}}{Z}$

$\therefore\ 1 = \frac{200}{\sqrt{100^2 + (2\pi 50L)^2}}$ $L = \frac{\sqrt{3}}{\pi}$ H

6 **(A)** According to given problem,

$$I = \frac{V}{Z} = \frac{V}{[R^2 + (1/C\omega)^2]^{1/2}} \quad \text{... (1)}$$

and, $\frac{I}{2} = \frac{V}{[R^2 + (3/C\omega)^2]^{1/2}}$ ...(2)

Substituting the value of I from Equation (1) in (2),

$$4\left(R^2 + \frac{1}{C^2\omega^2}\right) = R^2 + \frac{9}{C^2\omega^2}.$$

i.e., $\frac{1}{C^2\omega^2} = \frac{3}{5}R^2$

So that $\frac{X}{R} = \frac{(1/C\omega)}{R} = \frac{\left(\frac{3}{5}R^2\right)^{1/2}}{R} = \sqrt{\frac{3}{5}}$

7. **(B)** $V_{rms} = \sqrt{16^2 + 20^2} = 25.6$ V

8. **(C)** $i = 3\sin\omega t + 4\cos\omega t$

$$= 5\left[\frac{3}{5}\sin\omega t + \frac{4}{5}\cos\omega t\right]$$

$$= 5\left[\sin(\omega t + \delta)\right] \quad \text{.....(1)}$$

$\Rightarrow$ rms value $= \frac{5}{\sqrt{2}}$ $\Rightarrow$ mean value $= \frac{\int_{T_1}^{T_2} i\,dt}{\int_{T_1}^{T_2} dt}$

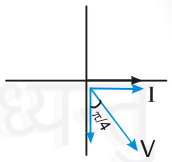
$\therefore$ Initial value of time is not given hence the mean value will be different for various time intervals.

If voltage applied is $V = V_m \sin\omega t$ then i given by equation (1) indicates that it is ahead of V by δ where $0 < \delta < 90$ which indicates that the circuit contains R & C.

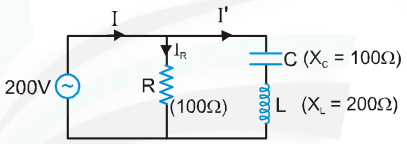
Hence (C).

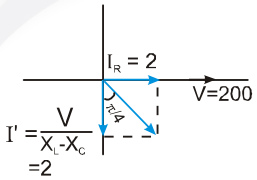
9. **(A)** $v = v_0 \sin(\omega t + \pi/4) = v_0\cos(\omega t - \pi/4)$

Since V lags current, an inductor can bring it in phase with current.



10. **(B)**





$I_R = \frac{V}{R} = \frac{200}{100} = 2A$ $I' = \frac{V}{X_L - X_C} = \frac{200}{100} = 2A$

$I = \sqrt{I_R^2 + I'^2} = 2\sqrt{2}$ Amp.

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11. (C) Resultant voltage = 200 volt

Since V_1 and V_3 are out of phase 180°, the resultant voltage is equal to V_2

$\therefore \quad V_2 = 200$ volt

12. (C) The circuit will have inductive nature if $\omega > \frac{1}{\sqrt{LC}} \left(\omega L > \frac{1}{\omega C}\right)$.

Hence A is false. Also if circuit has inductive nature the current will lag behind voltage. Hence D is also false.

If $\omega = \frac{1}{\sqrt{LC}} \left(\omega L = \frac{1}{\omega C}\right)$ the circuit will have resistance nature. Hence B is false

$$\text{Power factor } \cos\phi = \frac{R}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}} = 1 \text{ it } \omega L$$

$$= \frac{1}{\omega C}. \text{ Hence C is true.}$$

13. (C) $X_L = X_C$ at resonance

$\therefore \quad \frac{X_L}{X_C} = 1.$ for both circuits

14. (D) Since, $\cos\theta = \frac{R}{Z} = \frac{IR}{IZ} = \frac{8}{10} = \frac{4}{5}$

(Also $\cos\theta$ can never be greater than 1)

Hence (C) is wrong.

Also, $Ix_C > Ix_L \Rightarrow x_C > x_L$.

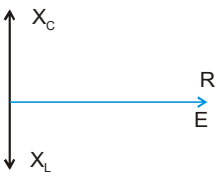
$\therefore$ Current will be leading.

In a LCR circuit

$$v = \sqrt{(v_L - v_C)^2 + v_R{}^2} = \sqrt{(6-12)^2 + 8^2}$$

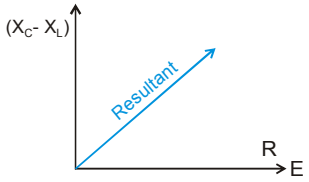
v = 10 ; which is less than voltage drop across capacitor.

15. (C) If we have all R,L and C then I vs. E will be :



To obtain a leading phase difference of $\pi/4$:

if $X_L < X_C$ and we use all R, L and C in the circuit, then the resultant graph will be :



which can give a leading phase difference of $\pi/4$:

Similarly, if we have only resistance and capacitor then we can obtain a phase difference of $\pi/4$ (leading) for suitable values of I , X_C and R. But we cannot obtain a leading phase difference of $\pi/4$ if we use only capacitor (phase difference of $\pi/2$), or only (inductor and resistor) (phase difference of $\pi/2$), or only resistor (phase difference of 0).

16. (A) (i) $V = \frac{V_0}{T/4} t \quad V = \frac{4V_0}{T} t$

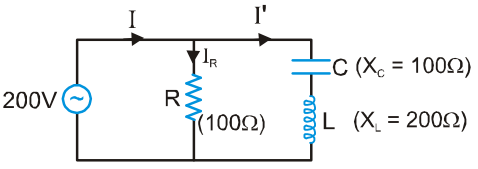
$$\Rightarrow V_{rms} = \sqrt{\langle V^2 \rangle} = \frac{4V_0}{T} \sqrt{\langle t \rangle}$$

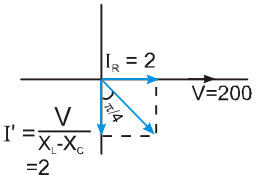
$$= \frac{4V_0}{T} \left\{ \frac{\int_0^{T/4} t^2 dt}{\int_0^{T/4} dt} \right\}^{1/2} = \frac{V_0}{\sqrt{3}}$$

17. (D) $\langle V \rangle = \frac{\int_0^T v dt}{\int_0^T dt} = 0.$

18. (A) $z = \sqrt{3^2 + 4^2} = 5$

19. (B)





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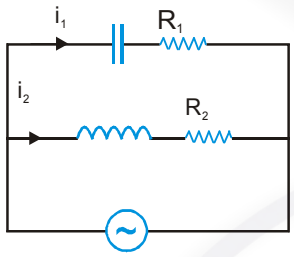
$$I_R = \frac{V}{R} = \frac{200}{100} = 2A$$

$$\Rightarrow I' = \frac{V}{X_L - X_C} = \frac{200}{100} = 2A$$

$$I = \sqrt{I_R{}^2 + I'^2} = 2\sqrt{2} \text{ Amp.}$$

20. (C) $i_{1_{rms}} = \frac{E_{rms}}{\sqrt{X_C^2 + R_1^2}} = \frac{130}{13} = 10\,A$

$$i_{2_{rms}} = \frac{E_{rms}}{\sqrt{X_L^2 + R_2^2}} = 13\,A$$



Power dissipated $= i_{1rms}^2 R_1 + i_{2rms}^2 R_2 = 10^2 \times 5 + 13^2 \times 6$

$= i_{1rms}^2 R_1 + i_{2rms}^2 R_2 = 10^2 \times 5 + 13^2 \times 6$

= power delivered by battery

$= 500 + 169 \times 6 = 1514$ watt

21. (B) $P = VI$

For secondary :

$$V_2 = \frac{P_2}{I_2} = \frac{500}{12.5} = 40 \text{ volts}$$

For an ideal transformer (100% efficient)

$$P_{input} = P_{output}$$

$$\Rightarrow V_1 I_1 = V_2 I_2$$

$$\Rightarrow I_1 = \frac{V_2 I_2}{V_1} = \frac{40(12.5)}{40 \times 5} = 2.5\,A$$

$$\left[\because \frac{n_1}{n_2} = \frac{V_1}{V_2} \Rightarrow \frac{5}{1} = \frac{V_1}{40}\right].$$

22. (B) This is because, when frequency is increased, the capacitive reactance $X_C = \frac{1}{2\pi\nu C}$ decreases and hence the current through the bulb increases.

23. (C) $i_{WL} = i_{rms} \sin\varphi \Rightarrow \sqrt{3} = 2\sin\varphi \Rightarrow \sin\varphi = \frac{\sqrt{3}}{2}$

$$\Rightarrow \varphi = 60^\circ \text{ so p.f.} = \cos\varphi = \cos 60^\circ = \frac{1}{2}$$

24. (C) $Z = \sqrt{R^2 + \left(\frac{1}{2\pi\nu C}\right)^2}$

$$= \sqrt{(3000)^2 + \frac{1}{\left(2\pi \times 50 \times \frac{2.5}{\pi} \times 10^{-6}\right)^2}}$$

$$\Rightarrow Z = \sqrt{(3000)^2 + (4000)^2} = 5 \times 10^3 \Omega$$

So power factor $\cos\varphi = \frac{R}{Z} = \frac{3000}{5 \times 10^3} = 0.6$ and power

$$P = V_{rms} i_{rms} \cos\varphi = \frac{V_{rms}^2 \cos\varphi}{Z}$$

$$\Rightarrow P = \frac{(200)^2 \times 0.6}{5 \times 10^3} = 4.8W$$

25. A → S ; B → P, R, S ; C → Q, S, T ; D → Q, T

(A) For sinusoidal curve $i_{rms} = \frac{i_0}{\sqrt{2}}$

(A) sine $i_{rms} = \frac{i_0}{\sqrt{2}}$

(B) $i_{rms}^2 = \frac{\int_0^T i^2\,dt}{T} = \frac{4\int_0^{T/4} i^2\,dt}{T}$

$$= \frac{\int_0^{T/4} i^2\,dt}{\frac{T}{4}} = \frac{\int_0^{T/4} \left(\frac{i_0 t}{T/4}\right)^2 dt}{\frac{T}{4}} = \frac{i_0^2}{\left(\frac{T}{4}\right)^3}\int_0^{T/4} t^2\,dt = \frac{i_0^2}{3}$$

$$\Rightarrow i_{rms} = \frac{i_0}{\sqrt{3}}$$

For positive half cycle average current

$$= \frac{\int i\,dt}{\int dt} = \frac{\frac{1}{2}(i_0)(T/2)}{(T/2)} = \frac{i_0}{2}$$

Full cycle average current is zero.

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(C) For positive half cycle average current

$$= \frac{\int i\,dt}{\int dt} = \frac{i_0 (T/2)}{T/2} = i_0 \Rightarrow i_{rms} = \left[\frac{\int_0^{T/2} i^2\,dt}{T/2}\right]^{1/2} = i_0$$

(D) For full cycle average current

$$= \frac{\int i\,dt}{\int dt} = \frac{i_0 (T/2) + 0}{T} = \frac{i_0}{2}$$

$$\Rightarrow i_{rms} = \left[\frac{\int_0^{T/2} i^2\,dt}{T/2}\right]^{1/2} = i_0$$

26. A → Q,R ; B → P,T ; C → P,R ; D → Q, T

(a) $\tan\phi = \frac{1/\omega C}{R} \Rightarrow \phi = \frac{\pi}{4}$, current leads source voltage because reactance is capacitive

(b) Pure inductive circuit $\phi = \pi/2$, current lags behind source voltage because reactance is inductive

(c) as $R = 0$, $\tan\phi = \infty$

$\phi = \pi/2$, current leads source voltage because reactance is capacitive

(d) $\tan\phi = \frac{\omega L}{R} = 1 \Rightarrow \phi = \frac{\pi}{4}$, current lags behind source voltage because reactance is inductive

27. (C) Statement–1 is true but Statement–2 is false Both A.C. and D.C. produce heat, which is proportional to square of the current. The reversal of direction of current in A.C. is immaterial so far as production of heat is concerned.

28. (D) Statement 1 is false because the given relation is true if all voltages are instantaneous.

29. (D) In resonance condition when energy across capacitor is maximum, energy stored in inductor is zero, vice versa is also true. Hence statement 1 is false.

30. (A) When current through inductor decreases, the magnetic energy stored in inductor decreases and this energy is absorbed by the ac source.

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CHAPTER 07

GEOMETRICAL OPTICS

Light Brings us the news of the universe

"SIR WILLIAM BRAGG"

INTRODUCTION

Light form of radiant energy, that is energy emitted by excited atoms or molecules which can cause the sensation of vision in a normal human eye.

The branch of Physics which deals with the phenomena concerning light is called Optics. There are two branches of Optics :

(a) Geometrical Optics :

This consists the study of light in which light is considered as moving along a straight line as a ray. A ray of light gives the direction of propagation of light. When light meets a surface which separates two media, reflection and refraction take place. An image or an array of images may be formed due to this.

(b) Physical Optics :

It deals with the theories regarding the nature of light and provides an explanation for the different phenomena in light, such as reflection, refraction, interference, diffraction, polarisation and rectilinear propagation.

Some Definitions

(i) **A Ray :** The 'path' along which light travels is called a ray. They are represented by straight lines with arrows directed towards the direction of travel of light.

(ii) **A Beam :** A bundle of rays is called a beam. A beam is parallel when its rays are parallel; divergent when its rays spread out from a point ; and convergent when its rays meet at a point.

(iii) **A Pencil :** A narrow beam is called a pencil light.

NATURE OF OBJECTS AND IMAGES

Ray Optics primarily deals with determining the position and nature of the image formed when an object is placed in front of an optical element. Before we proceed further, let us clearly define what is an object and what is an image.

Types of Objects

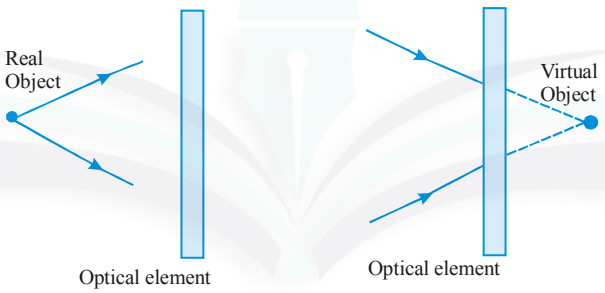
An object is a source of light rays that are incident on an optical element. An object may be a point object or an extended object. Since extended objects can be modeled as a collection of points, we only need to study point objects. Objects are of two kinds : Real objects and Virtual objects.

(i) Real Object :

An object is real if two or more incident rays actually emanate or seem to emanate from a point. Fig. **(a)** is a typical example of a real object. In this case, two rays emanate from the object and are incident on the optical element and the object is actually present. Hence, it is called a real object.

(ii) Virtual Object

Now, consider a converging set of rays as shown in Fig. **(b)**. If not intercepted the rays will meet at a point. However, if the rays are intercepted by an optical element placed as shown in the figure, then the point of convergence is a virtual point behind the optical element. The point is called the virtual object for the optical element.



A real object placed in front of an optical element (a)

A virtual object that appears to be behind the optical element (b)

So, an object is real when two rays emanate or diverge from a point, and an object is virtual when two incident rays seem to converge to that point.

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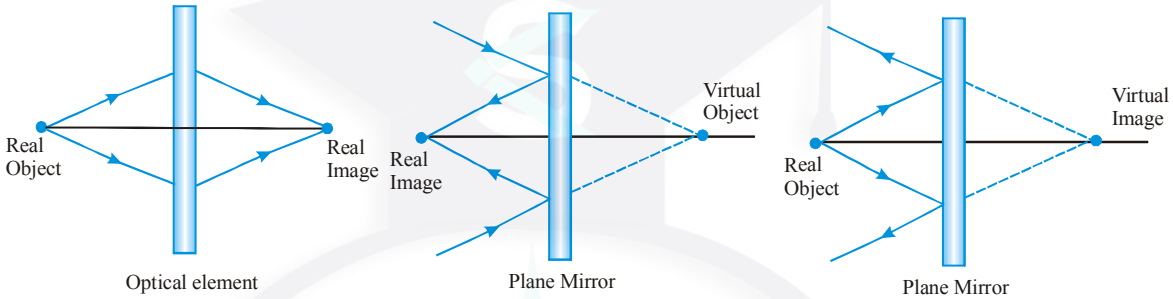
TYPES OF IMAGES

What is an Image ?

An image is the point of convergence or apparent point of divergence of rays after they interact with a given optical element. An object provides rays that will be incident on an optical element. The optical element reflects or refracts the incident light rays which then meet at a point to form an image. As in the case of objects, images too can be real or virtual.

(i) Real Image

Real images are formed when the reflected or refracted rays actually meet or converge to a point. If a screen is placed at that point, a bright spot will be visible on the screen. Thus, a real image can be captured on a screen. Examples of real images are shown in Fig. **(a)** and **(b)**. Note that in the former the object is real while in the latter the object is virtual. Thus, both real and virtual objects can form real images.



(ii) Virtual Image

When light rays, after interacting with the optical element, actually meet at a point the image formed in a real image. However, if the rays do not meet at a point but appear to emanate from a point, then a virtual images is formed. Consider the case of an object placed in front of a plane mirror. Here, the two reflected rays will never meet at any point. However, if we extend the reflected rays will never meet at any point. However, if we extend the reflected rays backwards, they appear to emanate from a point. The point is the virtual image of the object. As we will see later in the section on Lenses, it is possible for a virtual image to be formed by a virtual object as well. Thus, we can conclude that both virtual objects depending on the optical element.

Basic Laws :

(a) **Law of Rectilinear Propagation of Light** : It states that light propagates in straight lines in homogeneous media.

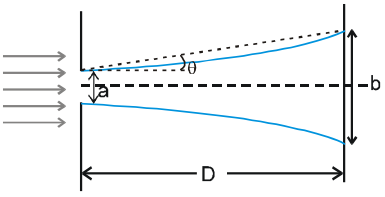
(b) **Law of Independence of Light Rays** : It states that rays do not disturb each other upon intersection.

(c) **Law of Reversibility of Light Rays** : It states that rays retrace their paths when their direction is reversed.

Condition for rectilinear propagation of light

Some part of the optics can be understood if we assume that light travels in a straight line and it bends abruptly when it suffers reflection or refraction.

The assumption that the light travels in a straight line is correct if **(i)** the medium is isotropic, i.e. its behaviour is same in all directions and **(ii)** the obstacle past which the light moves or the opening through which the light moves is not very small.



Consider a slit of width 'a' through which monochromatic light rays pass and strike a screen, placed at a distance D as shown.

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It is found that the light strikes in a band of width 'b' more than 'a'. This bending is called **diffraction**. Light bends by (b-a)/2 on each side of the central line. It can be shown by wave theory of light that $\sin\theta = \frac{\lambda}{a}$ .....(A), where θ is shown in figure.

This formula indicates that the **bending is considerable only when a ~ λ** . Diffraction is more pronounced in sound because its wavelength is much more than that of light and it is of the order of the size of obstacles or apertures. Formula (A) gives $\frac{b-a}{2D} \approx \frac{\lambda}{a}$.

It is clear that the bending is negligible if $\frac{D\lambda}{a} << a$ or $a >> \sqrt{D\lambda}$ .If this condition is fulfilled , light is said to move rectilinearly. In most of the situations including geometrical optics the conditions are such that we can safely assume that light moves in straight line and bends only when it gets reflected or refracted.

Thus geometrical optics is an approximate treatment in which the light waves can be represented by straight lines which are called rays. A **ray** of light is the straight line path of transfer of light energy. Arrow represents the direction of propagation of light.

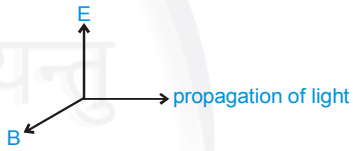
Figure shows a ray which indicates light is moving from A to B.



Properties of Light

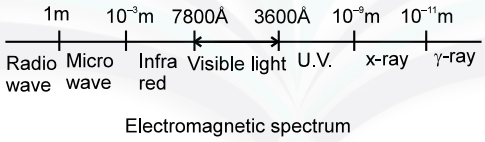
(i) Speed of light in vacuum, denoted by c, is equal to 3×10^8 m/s approximately.

(ii) Light is electromagnetic wave (proposed by Maxwell). It consists of varying electric field and magnetic field.



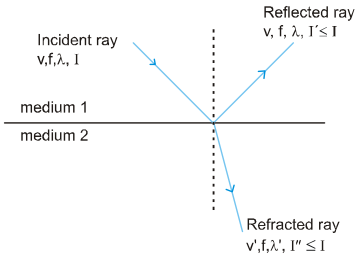
(iii) Light carries energy and momentum.

(iv) The formula v = fλ is applicable to light.



Electromagnetic spectrum

(v) When light gets reflected in same medium, it suffers no change in frequency, speed and wavelength.



(vi) Frequency of light remains unchanged when it gets reflected or refracted.

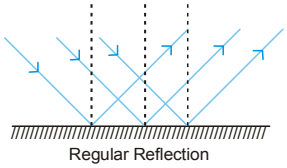
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Reflection of Light

When light rays strike the boundary of two media such as air and glass, a part of light is turned back into the same medium. This is called *Reflection of Light.*

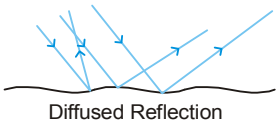
(a) Regular Reflection:

When the reflection takes place from a perfect plane surface it is called **Regular Reflection**. In this case the reflected light has large intensity in one direction and negligibly small intensity in other directions.



(b) Diffused Reflection

When the surface is rough, we do not get a regular behaviour of light. Although at each point light ray gets reflected irrespective of the overall nature of surface, difference is observed because even in a narrow beam of light there are many rays which are reflected from different points of surface and it is quite possible that these



rays may move in different directions due to irregularity of the surface . This process enables us to see an object from any position. Such a reflection is called as **diffused reflection**.

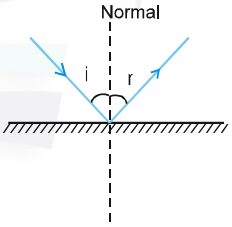
For Ex. reflection from a wall, from a news paper etc. This is why you can not see your face in news paper and in the wall.

1. Laws of Reflection

(a) The incident ray, the reflected ray and the normal at the point of incidence lie in the same plane. This plane is called the **plane of incidence (or plane of reflection)**. This condition can be expressed mathematically as $\vec{R} . (\vec{I} \times \vec{N}) = \vec{N} . (\vec{I} \times \vec{R}) = \vec{I} . (\vec{N} \times \vec{R}) = 0$ where $\vec{I}$, $\vec{N}$ and $\vec{R}$ are vectors of any magnitude along incident ray, the normal and the reflected ray respectively.

(b) The angle of incidence (the angle between normal and the incident ray) and the angle of reflection (the angle between the reflected ray and the normal) are equal, i.e.

$$\angle i = \angle r$$

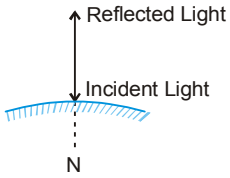


Special Cases :

(a) Normal Incidence : In case light is incident normally,

$i = r = 0$

$\delta = 180^\circ$



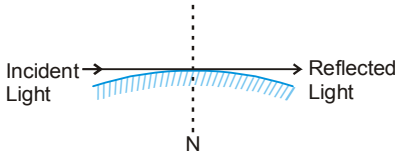
Note : We say that the ray has retraced its path.

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(b) **Grazing Incidence :** In case light strikes the reflecting surface tangentially,

$i = r = 90$

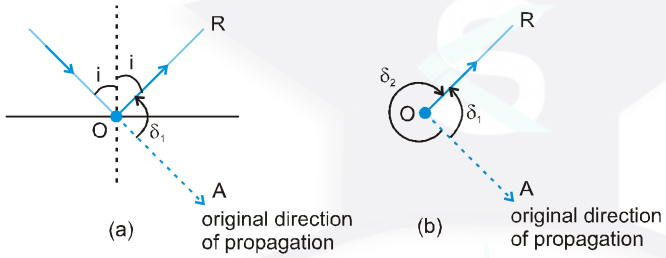
deviation, $d = 0^\circ$ or 360°



Note : In case of reflection speed (magnitude of velocity) of light remains unchanged but in grazing incidence velocity remains unchanged.

Ex. Show that for a light ray incident at an angle 'i' on getting reflected the angle of deviation is $\delta = \pi - 2i$ or $\pi + 2i$.

Sol.



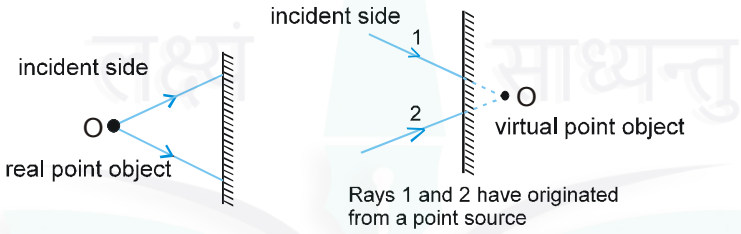
From figure **(b)** it is clear that light ray bends either by δ_1 anticlockwise or by δ_2 $(= 2\pi - \delta_1)$ clockwise.

From figure **(a)** $\delta_1 = \pi - 2i$.

$\therefore$ $\delta_2 = \pi + 2i$.

2. Object and Image

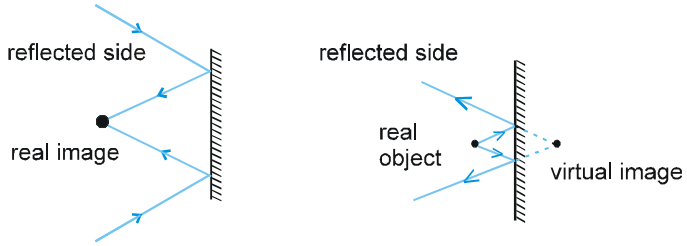
(a) Object (O) : Object is defined as point of intersection of incident rays.



Let us call the side in which incident rays are present as incident side and the side in which reflected (refracted) rays are present, as reflected (refracted) side.

Note : An object is called **real** if it lies on incident side otherwise it is called **virtual**.

(b) Image (I) : Image is defined as point of intersection of reflected rays (in case of reflection) or refracted rays (in case of refraction).

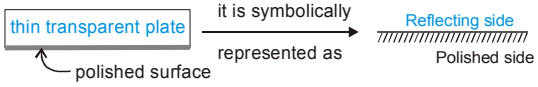


Note : An image is called **real** if it lies on reflected or refracted side otherwise it is called **virtual.**

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Plane Mirror

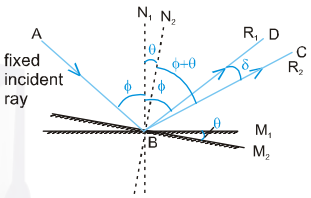
Plane mirror is formed by polishing one surface of a plane thin glass plate .It is also said to be silvered on one side.



PLANE MIRROR

A beam of parallel rays of light, incident on a plane mirror will get reflected as a beam of parallel reflected rays.

Ex. For a fixed incident light ray, if the mirror be rotated through an angle θ (about an axis which lies in the plane of mirror and perpendicular to the plane of incidence), show that the reflected ray turns through an angle 2θ in same sense.



Sol. See figure M_1, N_1 and R_1 indicate the initial position of mirror, initial normal and initial direction of reflected light ray respectively. M_2, N_2 and R_2 indicate the final position of mirror, final normal and final direction of reflected light ray respectively. From figure it is clear that $\angle ABC = 2\phi + \delta = 2(\phi + \theta)$ or $\delta = 2\theta$.

Note : Keeping the mirror fixed if the incident ray is rotated by angle θ about the normal then reflected ray rotates by same angle in the same direction of rotation

Point object

Characteristics of image due to reflection by a plane mirror :

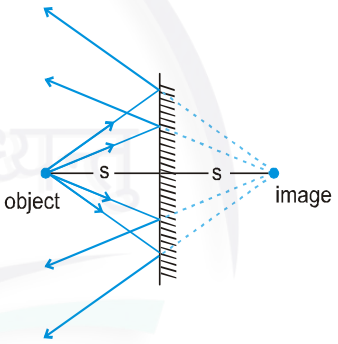
(i) Distance of object from mirror = Distance of image from the mirror.

(ii) All the incident rays from a point object will meet at a single point after reflection from a plane mirror which is called image.

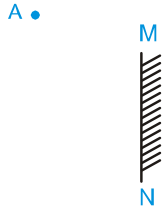
(iii) The line joining a point object and its image is normal to the reflecting surface.

(iv) For a real object the image is virtual and for a virtual object the image is real

(v) The region in which observer's eye must be present in order to view the image is called field of view.

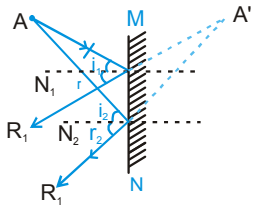


Ex. Figure shows a point object A and a plane mirror MN. Find the position of image of object A, in mirror MN, by drawing ray diagram. Indicate the region in which observer's eye must be present in order to view the image. (This region is called field of view).

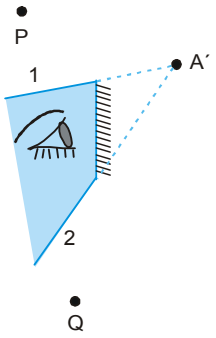


Sol. See figure, consider any two rays emanating from the object. N_1 and N_2 are normal ;

$i_1 = r_1$ and $i_2 = r_2$



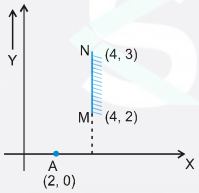
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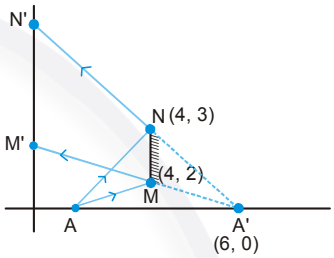
The meeting point of reflected rays R_1 and R_2 is image A'. Though only two rays are considered it must be understood that all rays from A reflect from mirror such that their meeting point is A´. To obtain the region in which reflected rays are present, join A´ with the ends of mirror and extend. The following figure shows this region as shaded. In figure, there are no reflected rays beyond the rays 1 and 2, therefore the observers P and Q cannot see the image because they do not receive any reflected ray.

Ex. Find the region on Y axis in which reflected rays are present.

Object is at A (2, 0) and MN is a plane mirror, as shown.



Sol. The image of point A, in the mirror is at A' (6, 0).



Join A' M and extend to cut Y axis at M' (Ray originating from A which strikes the mirror at M gets reflected as the ray MM' which appears to come from A'). Join A'N and extend to cut Y axis at N' (Ray originating from A which strikes the mirror at N gets reflected as the ray NN' which appears to come from A') .

From geometry.

M' ≡ (0, 6)

N' ≡ (0, 9). M'N' is the region on Y axis in which reflected rays are present.

Extended object :

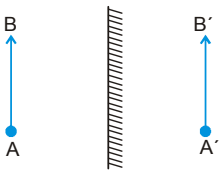
An extended object like AB shown in figure is a combination of infinite number of point objects from A to B. Image of every point object will be formed individually and thus infinite images will be formed. A´ will be image of A, C´ will be image of C, B´ will be image of B etc. All point images together form extended image. Thus extended image is formed of an extended object.



Properties of image of an extended object, formed by a plane mirror :

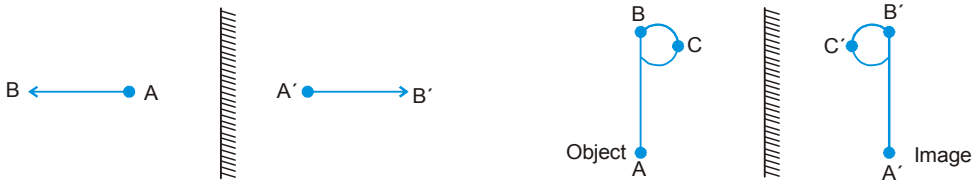
(1) Size of extended object = Size of extended image.

(2) The image is erect, if the extended object is placed parallel to the mirror.

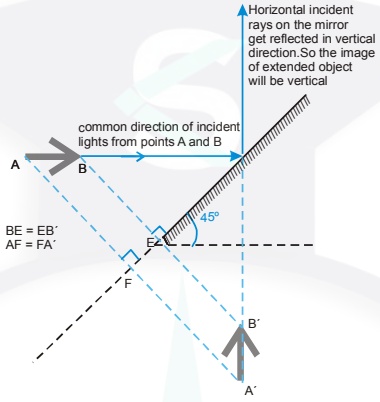


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(3) The image is inverted if the extended object lies perpendicular to the plane mirror.

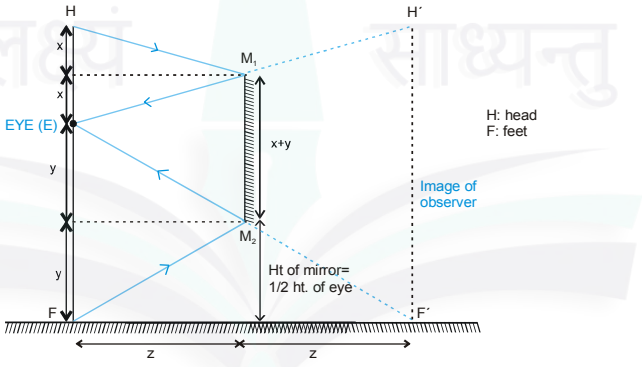


(4) If an extended horizontal object is placed infront of a mirror inclined 45° with the horizontal, the image formed will be vertical. See figure.



Ex. Show that the minimum size of a plane mirror, required to see the full image of an observer is half the size of that observer.

Sol. See the following figure. It is self explanatory if you consider lengths 'x' and 'y' as shown in figure.



Alter :

ΔEM_1M_2 and $\Delta E\,H'F'$ are similar

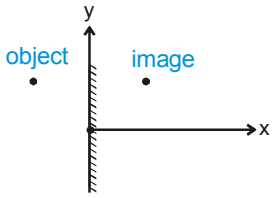
$$\therefore \quad \frac{M_1M_2}{H'F'} = \frac{z}{2z} \quad \text{or} \quad M_1\,M_2 = H'\,F'\,/\,2 = HF\,/\,2$$

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Relation between velocity of object and image :

From mirror property : $x_{im} = -x_{om}$, $y_{im} = y_{om}$ and $z_{im} = z_{om}$

Here x_{im} means 'x' coordinate of image with respect to mirror. Similarly others have corresponding meaning.



Differentiating w.r.t time , we get

$v_{(im)x} = -v_{(om)x}$; $v_{(im)y} = v_{(om)y}$; $v_{(im)z} = v_{(om)z}$,

$\Rightarrow$ For x axis $v_{iG} - v_{mG} = -(v_{oG} - v_{mG})$

but For y axis and z axis $v_{iG} - v_{mG} = (v_{oG} - v_{mG})$ or $v_{iG} = v_{oG}$.

here: v_{iG} = velocity of image with respect to ground.

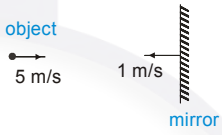
Ex. An object moves with 5 m/s towards right while the mirror moves with 1m/s towards the left as shown. Find the velocity of image.

Sol. Take $\rightarrow$ as + direction. $v_i - v_m = v_m - v_0$

$v_i - (-1) = (-1) - 5$

$\therefore$ $v_i = -7$m/s.

$\Rightarrow$ 7 m/s and direction towards left.



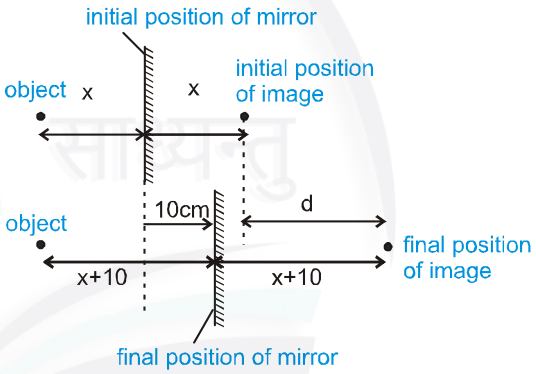
Ex. There is a point object and a plane mirror. If the mirror is moved by 10 cm away from the object find the distance which the image will move.

Sol. We know that $x_{im} = -x_{om}$ or $x_i - x_m = x_m - x_o$

or $\Delta x_i - \Delta x_m = \Delta x_m - \Delta x_o$.

In this question $\Delta x_o = 0$; $\Delta x_m = 10$ cm.

Therefore $\Delta x_i = 2\Delta x_m - \Delta x_o = 20$ cm.

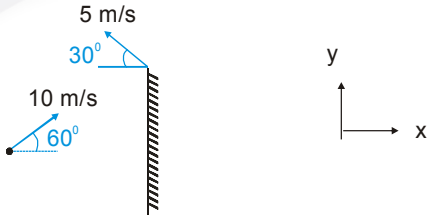


Alter : -

$2(x + 10) = 2x + d$

$\therefore$ $d = 20$ cm

Ex. In the situation shown in figure ,find the velocity of image.



Sol. Along x direction, applying $v_i - v_m = -(v_0 - v_m)$

$v_i - (-5\cos 30°) = -(10\cos 60° - (-5\cos 30°))$

$\therefore$ $v_i = -5(1+\sqrt{3})$ m/s

Along y direction $v_0 = v_i$

$\therefore$ $v_i = 10 \sin 60° = 5\sqrt{3}$ m/s

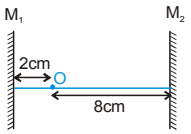
$\therefore$ Velocity of the image $= -5(1+\sqrt{3})\,\hat{i} + 5\sqrt{3}\,\hat{j}$ m/s.

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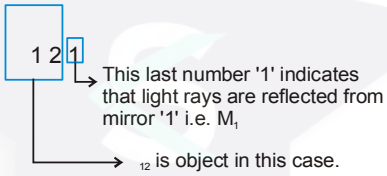
Images formed by two plane mirrors :

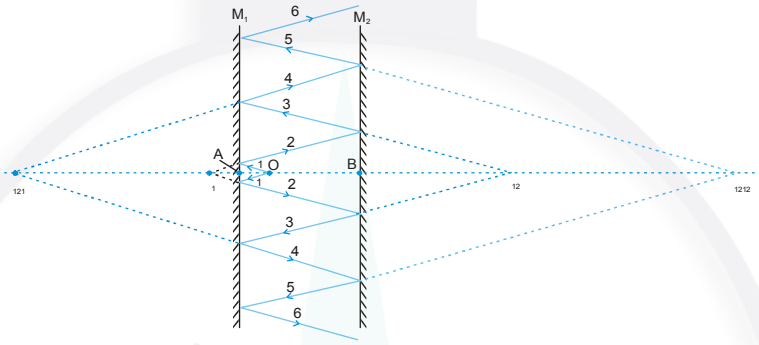
If rays after getting reflected from one mirror strike second mirror, the image formed by first mirror will function as an object for second mirror, and this process will continue for every successive reflection.

Ex. Figure shows a point object placed between two parallel mirrors. Its distance from M_1 is 2 cm and that from M2 is 8 cm. Find the distance of images from the two mirrors considering reflection on mirror M_1 first.



Sol. To understand how images are formed see the following figure and table. You will require to know what symbols like I_{121} stands for. See the following diagram.



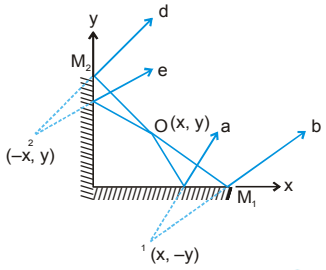


Incident rays	Reflected by	Reflected rays	Object	Image	Object distance	Image distance
Rays 1	M_1	Rays 2	O	I_1	AO = 2cm	AI_1 = 2 cm
Rays 2	M_2	Rays 3	I_1	I_{12}	BI_1 = 12 cm	BI_{12} = 12 cm
Rays 3	M_1	Rays 4	I_{12}	I_{121}	AI_{12} = 22cm	AI_{121} = 22cm
Rays 4	M_2	Rays 5	I_{121}	I_{1212}	BI_{121} =32cm	BI_{1212}=32cm

Similarly images will be formed by the rays striking mirror M_2 first. Total number of images = ∞.

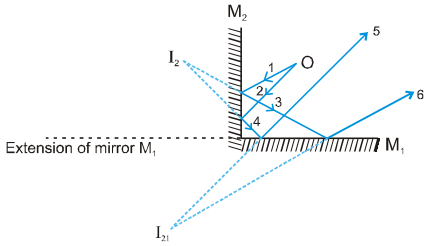
Ex. Consider two perpendicular mirrors. M_1 and M_2 and a point object O. Taking origin at the point of intersection of the mirrors and the coordinate of object as (x, y), find the position and number of images.

Sol. Rays 'a' and 'b' strike mirror M_1 only and these rays will form image I_1 at (x, –y), such that O and I_1 are equidistant from mirror M_1. These rays do not form further image because they do not strike any mirror again. Similarly rays 'd' and 'e' strike mirror M_2 only and these rays will form image I_2 at (–x, y), such that O and I_2 are equidistant from mirror M_2.



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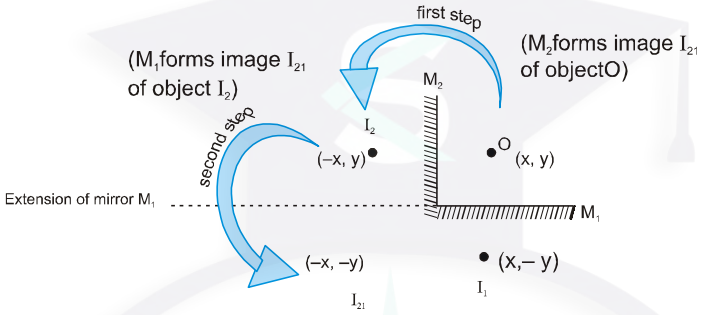
Now consider those rays which strike mirror M_2 first and then the mirror M_1.



For incident rays 1, 2 object is O, and reflected rays 3, 4 form image I_2.

Now rays 3, 4 incident on M_1 (object is I_2) which reflect as rays 5, 6 and form image I_{21}. Rays 5, 6 do not strike any mirror, so image formation stops.

I_2 and I_{21}, are equidistant from M_1. To summarize see the following figure



For rays reflecting first from M_1 and then from M_2, first image I_1 (at (x, –y)) will be formed and this will function as object for mirror M_2 and then its image I_{12} (at (–x, –y)) will be formed.

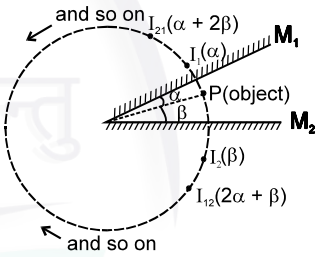
I_{12} and I_{21} coincide.

$\therefore$ Three images are formed

Locating all the images formed by two plane mirrors:

Consider two plane mirrors M_1 and M_2 inclined at an angle $\theta = \alpha+\beta$ as shown in figure.

Point P is an object kept such that it makes angle α with mirror M_1 and angle β with mirror M_2. Image of object P formed by M_1 ,denoted by I_1 ,will be inclined by angle α on the other side of mirror M_1. This angle is written in bracket in the figure besides I_1. Similarly image of object P formed by M_2 ,denoted by I_2 ,will be inclined by angle β on the other side of mirror M_2. This angle is written in bracket in the figure besides I_2.



Now I_2 will act as an object for M_1 which is at an angle $(\alpha+2\beta)$ from M_1 . Its image will be formed at an angle $(\alpha+2\beta)$ on the opposite side of M_1. This image will be denoted as I_{21}, and so on. Think when this will process stop. Hint: The virtual image formed by a plane mirror must not be in front of the mirror or its extension.

Number of images formed by two inclined mirrors

(i) If $\frac{360°}{\theta}$ = even number; number of image = $\frac{360°}{\theta} - 1$

(ii) If $\frac{360°}{\theta}$ = odd number; number of image = $\frac{360°}{\theta} - 1$,

if the object is placed on the angle bisector.

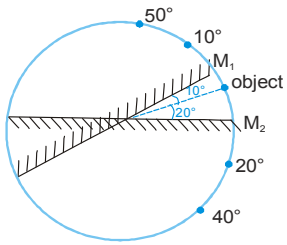
(iii) If $\frac{360°}{\theta}$ = odd number; number of image = $\frac{360°}{\theta}$,

if the object is not placed on the angle bisector.

(iv) If $\frac{360°}{\theta} \neq$ integer, then count the number of images as explained above.

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Ex. Two mirrors are inclined by an angle 30^0. An object is placed making 10^0 with the mirror M_1. Find the positions of first two images formed by each mirror. Find the total number of images using **(i)** direct formula and **(ii)** counting the images.



Sol. Figure is self explanatory.

Number of images

(i) Using direct formula : $\frac{360°}{30°} = 12$ (even number)

$\therefore$ number of images = 12 – 1 = 11

(ii) By counting . See the following table

Image formed by Mirror M_1 (angles are measured from the mirror M_1.)	Image formed by Mirror M_2 (angles are measured from the mirror M_2.)
10^0	20^0
$+30^0$	
50^0	40^0
$+30^0$	
70^0	80^0
$+30^0$	
110^0	100^0
$+30^0$	
130^0	140^0
$+30^0$	
170^0	160^0
Stop because next angle will be more than 180°	Stop because next angle will be more than 180°

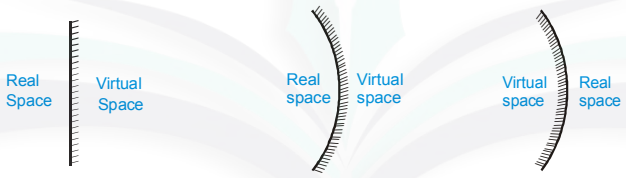
To check whether the final images made by the two mirrors coincide or not : add the last angles and the angle between the mirrors. If it comes out to be exactly 360°, it implies that the final images formed by the two mirrors coincide. Here last angles made by the mirrors + the angle between the mirrors = 160° + 170° + 30° = 360°. Therefore in this case the last images coincide. Therefore the number of images = number of images formed by mirror M_1 + number of images formed by mirror M_2 -1 (as the last images coincide)= 6 + 6 –1 = 11.

Real and Virtual Spaces

A mirror, plane or spherical divides the space into two ;

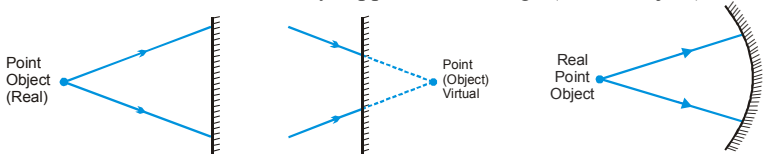
(a) Real space, a side where the reflected rays exist.

(b) Virtual space is on the other side where the reflected rays do not exist.



Object

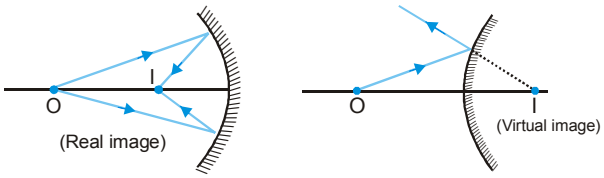
Object is decided by incident rays only. The point object is that point from which the incident rays actually diverge (Real object) or towards which the incident rays appear to converge (virtual object).



Image

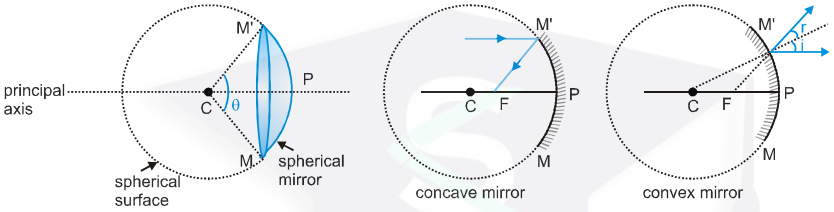
Image is decided by reflected or refracted rays only. The point image is that point at which the refracted / reflected rays reflected from the mirror, actually converge (real image) or from which the refracted /reflected rays appear to diverge (virtual image).

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Spherical (Curved) Mirror

Curved mirror is part of a hollow sphere. If reflection takes place from the inner surface then the mirror is called concave and if its outer surface acts as reflector it is convex.



Definitions For Thin Spherical Mirrors

(i) **Pole** is any point on the reflecting surface of the mirror. For convenience we take it as the midpoint P of the mirror (as shown).

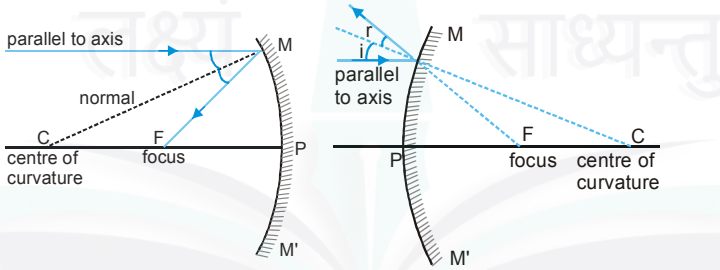
(ii) **Principal–section** is any section of the mirror such as MM' passing through the pole is called principal–section.

(iii) **Centre of curvature** is the centre C of the sphere of which the mirror is a part.

(iv) **Radius of curvature** is the radius R of the sphere of which the mirror is a part.

(v) **Principal–axis** is the line CP, joining the pole and centre of curvature of the mirror.

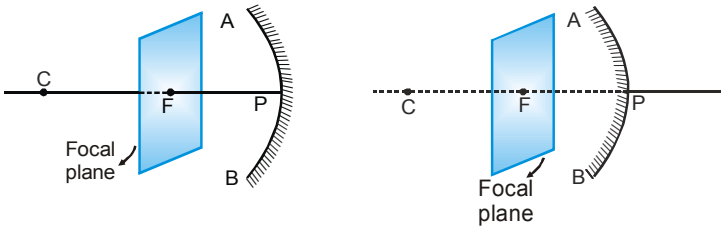
(vi) **Principal– focus** is an image point F on principal axis for which object is at infinity.



(vii) **Focal–length** is the distance PF between pole P and focus F along principal axis.

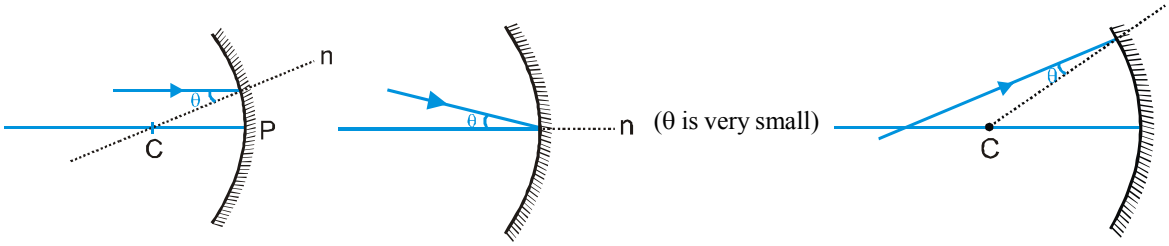
(viii) **Aperture,** in reference to a mirror, means the effective diameter of the light reflecting area of the mirror.

(ix) **Focal Plane** is the plane passing through focus and perpendicular to principal axis.



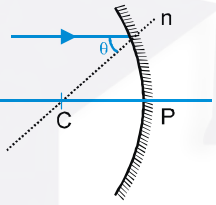
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(x) **Paraxial Rays** Those rays which make small angle with normal at point of incidence and hence are close to principal axis.



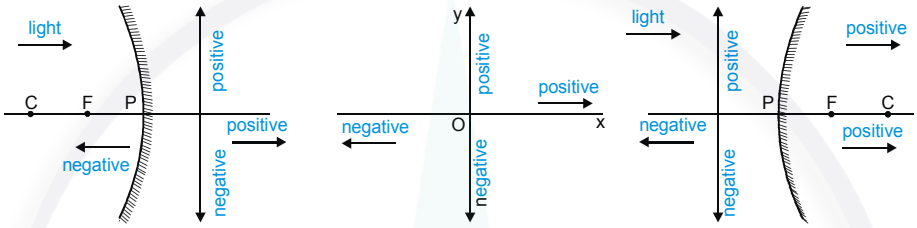
(xi) **Marginal rays :**

Rays having a large angle of incidence



(θ is large)

Sign– Convention



(i) Along principal axis, distances are measured from the pole (pole is taken as the origin).

(ii) Distance in the direction of light are taken to be positive while opposite to be negative.

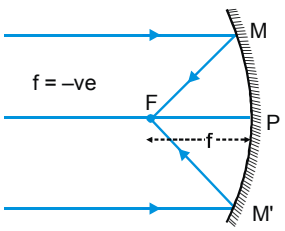
(iii) The distances above principal axis are taken to be positive while below it negative.

(iv) Whenever and wherever possible the ray of light is taken to travel from left to right.

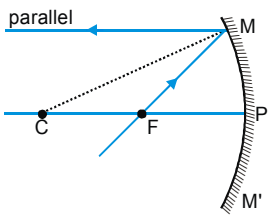
Rules for Image formation (for paraxial rays only)

(These rules are based on the laws of reflection ∠i = ∠r)

(i) A ray parallel to principal axis after reflection from the mirror passes or appears to pass through its focus (by definition of focus).



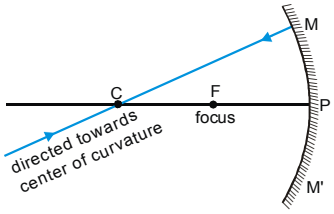
(ii) A ray passing through or directed towards focus, after reflection from the mirror, becomes parallel to the principal axis.

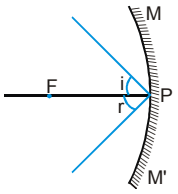


(iii) A ray passing through or directed towards centre of curvature, after reflection from the mirror, retraces its path (as for it ∠ i =0 and so ∠r =0).

(iv) Incident and reflected rays at the pole of a mirror are symmetrical about the principal axis ∠i = ∠r.

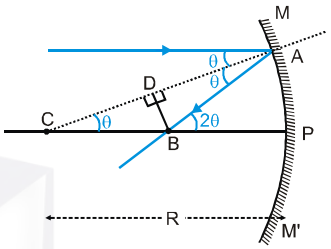
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Relations for Spherical Mirrors

Relation between f and R for the spherical mirror



(i) For Marginal rays

In $\Delta ABC, AB = BC$

$AC = CD + DA = 2BC\cos\theta \Rightarrow R = 2BC\cos\theta$

$$\Rightarrow BC = \frac{R}{2\cos\theta} \text{ and } BP = PC - BC = R - \frac{R}{2\cos\theta}$$

Note : B is not the focus ; it is just a point where a marginal ray after reflection meets.

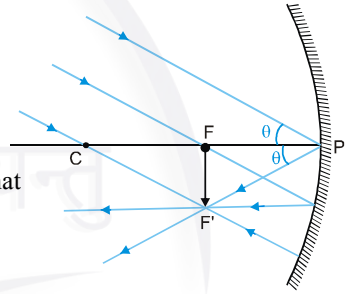
(ii) For paraxial rays (parallel to principal axis)

(θ small so $\sin\theta \simeq \theta$, $\cos\theta \simeq 1$, $\tan\theta \simeq \theta$) . Hence $BC = \frac{R}{2}$ and $BP = \frac{R}{2}$

Thus, point B is the midpoint of PC (i.e. radius of curvature) and is defined as FOCUS so $BP = f = \frac{R}{2}$

(**Definition :** Paraxial rays parallel to the principal axis after reflection from the mirror meet the principal axis at focus)

(iii) BP is the focal length **(f)** $\boxed{f = \frac{R}{2}}$



(iv) Paraxial rays (not parallel to principal axis)

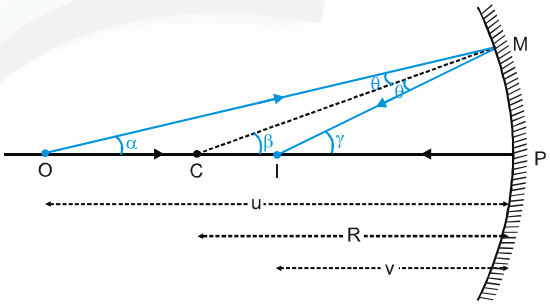
Such rays after reflection meet at a point in the focal plane (F'), such that

$$\frac{FF'}{FP} = \tan\theta \approx \theta \Rightarrow \frac{FF'}{f} = \theta \Rightarrow FF' = f\theta$$

Relation between u,v and f for curved mirror

An object is placed at a distance u from the pole of a mirror and its image is formed at a distance v (from the pole)

If angle is very small : $\alpha = \frac{MP}{u}$, $\beta = \frac{MP}{R}$, $\gamma = \frac{MP}{v}$



from ΔCMO, $\beta = \alpha + \theta \Rightarrow \theta = \beta - \alpha$

from ΔCMI, $\gamma = \beta + \theta \Rightarrow \theta = \gamma - \beta$

so we can write $\beta - \alpha = \gamma - \beta \Rightarrow 2\beta = \gamma + \alpha$

$$\therefore \frac{2}{R} = \frac{1}{v} + \frac{1}{u} \Rightarrow \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

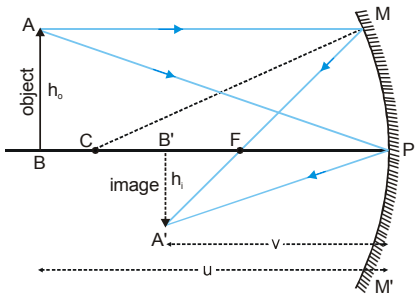
Sign convention for object/image for spherical mirrors

Real object	u – ve	Real image	v – ve
Virtual object	u + ve	Virtual image	v + ve

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Magnification

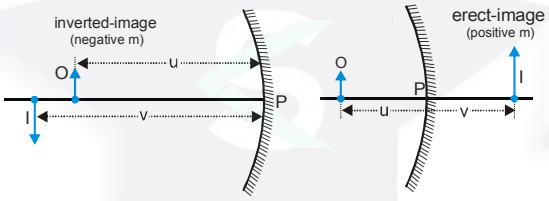
Transverse or lateral magnification



Linear magnification $m = \dfrac{\text{height of image}}{\text{height of object}} = \dfrac{h_i}{h_o}$

ΔABP and $\Delta A'B'P$ are similar so $\dfrac{-h_i}{h_o} = \dfrac{-v}{-u} \Rightarrow \dfrac{h_i}{h_o} = -\dfrac{v}{u}$

Magnification $m = -\dfrac{v}{u}$; $m = -\dfrac{v}{u} = \dfrac{f}{f-u} = \dfrac{f-v}{f} = \dfrac{h_i}{h_o}$



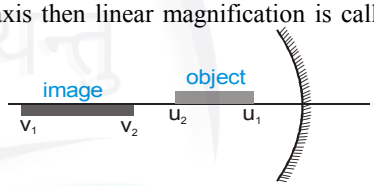
If one dimensional object is placed perpendicular to the principal axis then linear magnification is called transverse or lateral magnification. $\boxed{m = \dfrac{h_i}{h_o} = -\dfrac{v}{u}}$

Magnification	Image	Magnification	Image
$\|m\| > 1$	enlarged	$\|m\| < 1$	diminished
$m < 0$	inverted	$m > 0$	erect

(1) Longitudinal magnification

If one dimensional object is placed with its length along the principal axis then linear magnification is called longitudinal magnification.

Longitudinal magnification: $m_L = \dfrac{\text{length of image}}{\text{length of object}} = \dfrac{|v_2 - v_1|}{|u_2 - u_1|}$

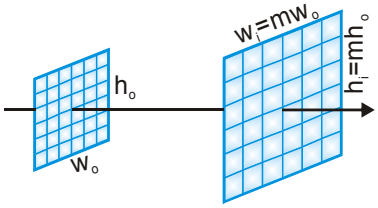


For small objects only : $m_L = -\dfrac{dv}{du}$

differentiation of $\dfrac{1}{v} + \dfrac{1}{u} = \dfrac{1}{f}$ gives us $-\dfrac{dv}{v^2} - \dfrac{du}{u^2} = 0 \Rightarrow -\dfrac{dv}{du} = \left[\dfrac{v}{u}\right]^2$ So $m_L = -\dfrac{dv}{du} = \left[\dfrac{v}{u}\right]^2 = m^2$

(2) Superficial magnification

If two dimensional object placed with its plane perpendicular to principal axis its magnification is known as superficial magnification



Linear magnification $m = \dfrac{h_i}{h_o} = \dfrac{w_i}{w_o}$

$h_i = mh_o$, $w_i = mw_o$ and $A_{obj} = h_o \times w_o$

Area of image : $A_{image} = h_i \times w_i = mh_o \times mw_o = m^2 A_{obj}$

Superficial magnification $m_s = \dfrac{\text{area of image}}{\text{area of object}} = \dfrac{(ma) \times (mb)}{(a \times b)} = m^2$

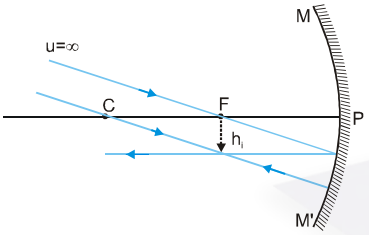
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Image Formation for Spherical Mirrors

1. Concave mirror

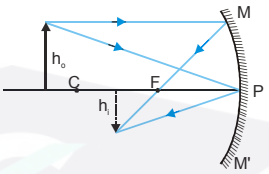
(i) **Object :** Placed at infinity
Image : real, inverted, diminished at F

$|m| << 1$ & $m < 0$



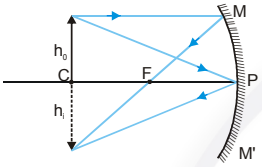
(ii) **Object :** Placed in between infinity and C
Image : real, inverted, diminished in between C and F

$|m| < 1$ & $m < 0$



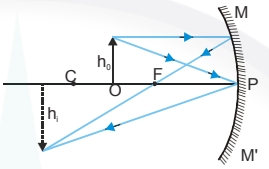
(iii) **Object :** Placed at C
Image : real, inverted, equal at C

$(m = -1)$

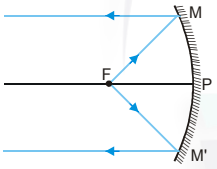


(iv) **Object :** Placed in between F and C
Image : real, inverted, enlarged beyond C

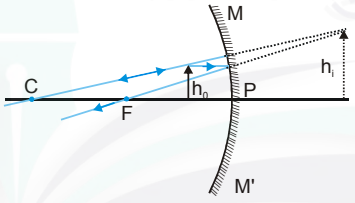
$|m| > 1$ & $m < 0$



(v) **Object :** Placed at F
Image : real, inverted, very large (assumed) at infinity $(m << -1)$



(vi) **Object :** Placed between F and P
Image : virtual, erect, enlarged and behind the mirror $(m > +1)$



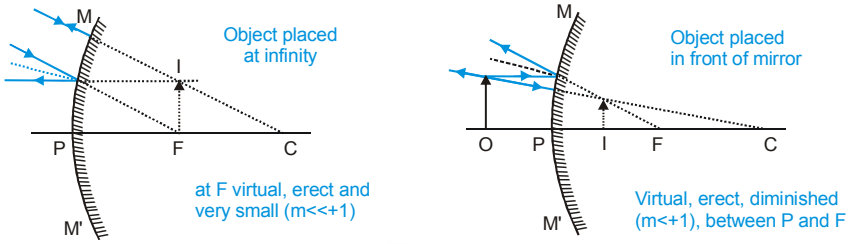
For concave mirror

Object	Image	Magnification
$-\infty$	F	$\|m\| << 1$ & $m < 0$
$-\infty - C$	$C - F$	$\|m\| < 1$ & $m < 0$
C	C	$m = -1$
$C - F$	$-\infty - C$	$\|m\| > 1$ & $m < 0$
Just before F towards C	$-\infty$	$m << -1$
Just after F towards P	$+\infty$	$m >> 1$

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2. Convex mirror

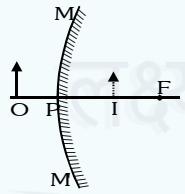
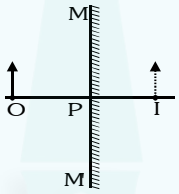
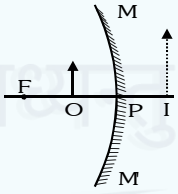
Image is always virtual and erect, whatever be the position of the object and m is always positive.



(i) Differences in real & virtual image for spherical mirror

Real Image	Virtual Image
(i) Inverted w.r.t. object	(i) Erect w.r.t. object
(ii) Can be obtained on screen	(ii) Can not be obtained on screen
(iii) Its magnification is negative	(iii) Its magnification is positive
(iv) Forms in front of mirror	(iv) Forms behind the mirror

(ii) For real extended object, if the image formed by a single mirror is erect it is always virtual (i.e. m is + ve) and in this situation if the size of image is :

Smaller than object the mirror is convex	Equal to object the mirror is plane	Larger than object the mirror is concave
m<+1	m=+1	m>+1
		

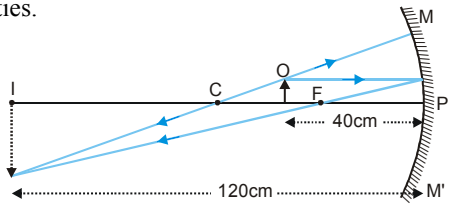
Ex. The focal length of a concave mirror is 30cm. Find the position of the object in front of the mirror, so that the image is three times the size of the object.

Sol. As the object is in front of the mirror it is real and for real object the magnified image formed by concave mirror can be inverted (i.e.,real) or erect (i.e.,virtual), so there are two possibilities.

(a) If the image is inverted (i.e., real)

$$m = \frac{f}{f-u} \Rightarrow -3 = \frac{-30}{-30-u} \Rightarrow u = -40 \text{ cm}$$

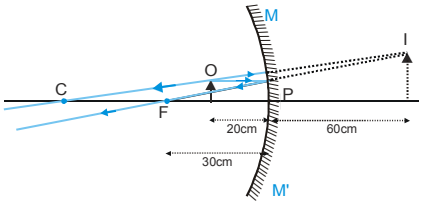
Object must be at a distance of 40 cm in front of the mirror (in between C and F).



(b) If the image is erect (i.e., virtual)

$$m = \frac{f}{f-u} \Rightarrow 3 = \frac{-30}{-30-u} \Rightarrow u = -20 \text{ cm}$$

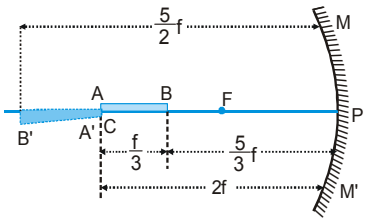
Object must be at a distance of 20 cm in front of the mirror (in between F and P).



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Ex. A thin rod of length $\frac{f}{3}$ is placed along the principal axis of a concave mirror of focal length f such that its image which is real and elongated, just touches the rod. What is magnification ?

Sol. Image is real and enlarged, the object must be between C and F.
One end A' of the image coincides with the end A of rod itself.



So $v_A = u_A$, $\frac{1}{v_A} + \frac{1}{v_A} = \frac{1}{-f}$ **i.e.**, $v_A = u_A = -2f$

so it clear that the end A is at C. $\because$ the length of rod is $\frac{f}{3}$

$\therefore$ Distance of the other end B from P is $u_B = 2f - \frac{f}{3} = \frac{5}{3}f$

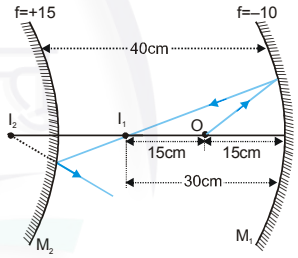
if the distance of image of end B from P is v_B then $\frac{1}{v_B} + \frac{1}{-\frac{5}{3}f} = \frac{1}{-f} \Rightarrow v_B = -\frac{5}{2}f$

$\therefore$ the length of the image $|v_B| - |v_A| = \frac{5}{2}f - 2f = \frac{1}{2}f$ and magnification $m = \frac{|v_B| - |v_A|}{|u_B| - |u_A|} = \frac{\frac{1}{2}f}{-\frac{1}{3}f} = -\frac{3}{2}$

Negative sign implies that image is inverted with respect to object and so it is real.

Ex. A concave mirror of focal length 10 cm and convex mirror of focal length 15 cm are placed facing each other 40 cm apart. A point object is placed between the mirror on their common axis and 15 cm from the concave mirror. Find the position of image produced by the reflection first at concave mirror and then at convex mirror.

Sol.



For M_1 mirror O act as a object, let its image is I_1 then,

$u = -15$ cm, $f = -10$ cm $\Rightarrow \frac{1}{v} + \frac{1}{-15} = \frac{1}{-10} \Rightarrow v = -30$ cm

Image I_1 will act as a object for mirror M_2 its distance from mirror M_2.

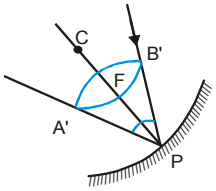
$u_1 = -(40 - 30)$ cm $= -10$ cm

So $\frac{1}{v_1} + \frac{1}{u_1} = \frac{1}{f} \Rightarrow \frac{1}{v_1} - \frac{1}{10} = \frac{1}{15} \Rightarrow v_1 = +6$ cm

So final image I_2 is formed at a distance 6 cm behind the convex mirror and is virtual.

Ex. The sun subtends an angle θ radians at the pole of a concave mirror of focal length f. What is the diameter of the image of the sun formed by the mirror.

Sol. Since the sun is at large distance very distant, u is very large and So $\frac{1}{u} \approx 0$



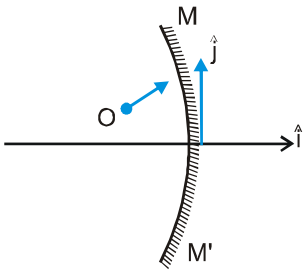
$\therefore \frac{1}{v} + \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{v} = -\frac{1}{f} \Rightarrow v = -f$

The image of sun will be formed at the focus and will be real, inverted and diminished

A'B' = height of image and $\theta = \frac{\text{Arc}}{\text{Radius}} = \frac{A'B'}{FP} \Rightarrow \theta = \frac{d}{f} \Rightarrow d = f\theta$

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Velocity of image of moving object (spherical mirror)



(a) Velocity component along axis (Longitudinal velocity)

When an object is coming from infinite towards the focus of concave mirror

$$\because \frac{1}{v}+\frac{1}{u}=\frac{1}{f} \Rightarrow -\frac{1}{v^2}\frac{dv}{dt}-\frac{1}{u^2}\frac{du}{dt}=0 \Rightarrow \vec{v}_{ix}=-\frac{v^2}{u^2}\vec{v}_{ox}=-m^2\vec{v}_{ox}$$

$$\left[v_{ix}=\frac{dv}{dt}=\text{velocity of image along principal-axis};\ v_{ox}=\frac{du}{dt}=\text{velocity of object along principal-axis}\right]$$

(b) Velocity component perpendicular to axis (Transverse velocity)

$$m=\frac{h_I}{h_0}=-\frac{v}{u}=\frac{f}{f-u} \Rightarrow h_I=\left(\frac{f}{f-u}\right)h_0$$

$$\frac{dh_I}{dt}=\left(\frac{f}{f-u}\right)\frac{dh_0}{dt}+\frac{f h_0}{(f-u)^2}\frac{du}{dt} \qquad \vec{v}_{iy}=\left[m\vec{v}_{oy}+\frac{m^2h_0}{f}\vec{v}_{ox}\right]\tilde{j}$$

$$\left[\begin{array}{l}\frac{dh_I}{dt}=\text{velocity of image } \perp^r \text{ to principal-axis}\\ \frac{dh_o}{dt}=\text{velocity of object } \perp^r \text{ to principal-axis}\end{array}\right]$$

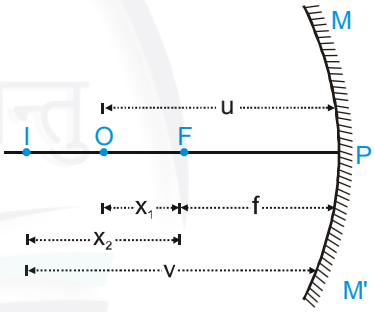
Note : Here principal axis has been taken to be along x–axis.

POWER OF A MIRROR

The power of a mirror is defined as $P=-\frac{1}{f(m)}=-\frac{100}{f(cm)}$

NEWTON'S FORMULA

In case if spherical mirrors if object distance (x_1) and image distance (x_2) are measured from focus instead of pole, $u=-(f+x_1)$ and $v=-(f+x_2)$,



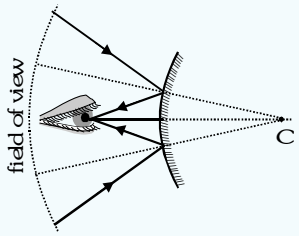
by $\frac{1}{v}+\frac{1}{u}=\frac{1}{f} \Rightarrow -\frac{1}{(f+x_2)}-\frac{1}{(f+x_1)}=-\frac{1}{f}$

on solving $\boxed{x_1x_2=f^2}$ This is Newton's formula.

(i) **Convex mirrors** gives erect, virtual and diminished image.
In convex mirror the field of view is increased as compared to plane mirror. It is used as rear–view mirror in vehicles.

(ii) **Concave mirrors** give enlarged, erect and virtual image, so these are used by dentists for examining teeth. Due to their converging property concave mirrors are also used as reflectors in automobile head lights and search lights

(iii) As focal length of a spherical mirror f = R/2 depends only on the radius of mirror and is independent of wavelength of light and refractive index of medium so the focal length of a spherical mirror in air or water and for red or blue light is same.



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Ex. An extended object is placed perpendicular to the principal axis of a concave mirror of radius of curvature 20 cm at a distance of 15 cm from pole. Find the lateral magnification produced.

Sol. $u = -15$ cm $\quad f = -10$ cm

Using $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$ we get, $v = -30$ cm

$\therefore \quad m = -\frac{v}{u} = -2.$

Aliter : $m = \frac{f}{f-u} = \frac{-10}{-10-(-15)} = -2$

Ex. A person looks into a spherical mirror. The size of image of his face is twice the actual size of his face. If the face is at a distance 20 cm then find the nature and radius of curvature of the mirror.

Sol. Person will see his face only when the image is virtual. Virtual image of real object is erect.

Hence $m = 2$

$\therefore \frac{-v}{u} = 2 \Rightarrow v = 40$ cm

Applying $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$; $f = -40$ cm or $R = -80$ cm (concave) $\therefore$ R.O.C. = 80 cm

Alter : $m = \frac{f}{f-u} \Rightarrow 2 = \frac{f}{f-(-20)}$

$\Rightarrow \quad f = -40$ cm or $R = -80$cm (concave) $\therefore$ R.O.C. = 80 cm

Ex. An image of a candle on a screen is found to be double its size. When the candle is shifted by a distance 5 cm then the image become triple its size. Find the nature and ROC of the mirror.

Sol. Since the images formed on screen it is real. Real object and real image implies concave mirror.

Applying $m = \frac{f}{f-u}$ or $-2 = \frac{f}{f-(u)}$ .....**(1)**

After shifting $-3 = \frac{f}{f-(u+5)}$ .....**(2)**

[Why u + 5 ? , why not u – 5 : In a concave mirror, the size of real image will increase, only when the real object is brought closer to the mirror. In doing so, its x coordinate will increase]

From **(1)** & **(2)** we get,

$f = -30$ cm or $R = -60$ cm (concave) and R.O.C. = 60cm

Ex. A point object is placed 60 cm from pole of a concave mirror of focal length 10 cm on the principle axis. Find

(a) the position of image

(b) If object is shifted 1 mm towards the mirror along principle axis find the shift in image. Explain the result.

Sol. **(a)** $u = -60$ cm

$f = -10$cm

$v = \frac{fu}{u-f} = \frac{-10(-60)}{-60-(-10)} = \frac{600}{-50} = -12$ cm.

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(b) $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$

Differentiating , we get $dv = -\frac{v^2}{u^2}du = -\left(\frac{-12}{-60}\right)^2$ [1 mm] $= -\frac{1}{25}$ mm

[$\because$ du = 1mm; sign of du is + because it is shifted in +ve direction defined by sign convention.]

(A) –ve sign of dv indicates that the image will shift towards negative direction.

(B) The sign of v is negative. Which implies the image is formed on negative side of pole.
(A) and **(B)** together imply that the image will shift away from pole.
Note that differentials dv and du denote small changes only.

(h) **Newton's Formula: $XY = f^2$**
X and Y are the distances (along the principal axis) of the object and image respectively from the principal focus. This formula can be used when the distances are mentioned or asked from the focus.

REFRACTION OF LIGHT

When the light changes its medium, some changes occurs in its properties, the phenomenon is known as refraction.

(i) If the light is incident at an angle ($0° < i < 90°$) then it deviates from its actual path. It is due to change in speed of light as light passes from one medium to another medium.

(ii) If the light is incident normally then it goes to the second medium without bending, but still it is called refraction.

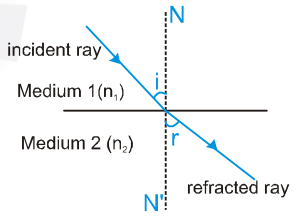
(iii) Refractive index of a medium is defined as the factor by which speed of light reduces as compared to the speed of light in vacuum. $\mu = \frac{c}{v} = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$.

More (less) refractive index implies less (more) speed of light in that medium, which therefore is called denser (rarer) medium.

Laws of Refraction

(a) The incident ray , the normal to any refracting surface at the point of incidence and the refracted ray all lie in the same plane called the plane of incidence or plane of refraction.

(b) $\frac{\sin i}{\sin r}$ = Constant for any pair of media and for light of a given wave length. This is known as *Snell's* Law.



Also, $\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$

For applying in problems remember
$n_1 \sin i = n_2 \sin r$

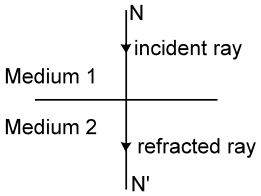
$\frac{n_2}{n_1} = {}_1n_2$ = Refractive Index of the second medium with respect to the first medium.

c = speed of light in air (or vacuum) = 3×10^8 m/s.

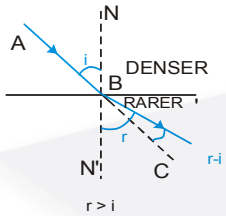
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Special Cases :

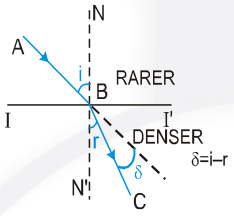
(i) Normal incidence : i = 0
from Snell's law : r = 0



(ii) When light moves from denser to rarer medium it bends away from normal.



(iii) When light moves from rarer to denser medium it bends towards the normal.



Note :

(iv) Higher the value of R.I., denser (optically) is the medium.

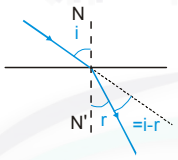
(v) Frequency of light does not change during refraction.

(vi) Refractive index of the medium relative to vacuum = $\sqrt{\mu_r \in_r}$

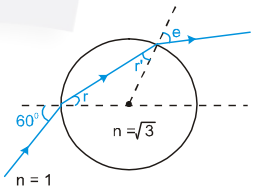
$n_{vacuum} = 1$; $n_{air} = \gtrsim 1$; n_{water} (average value) = 4/3 ; n_{glass} (average value)= 3/2

Deviation of a Ray Due to Refraction

Deviation (δ) of ray incident at ∠ i and refracted at ∠ r is given by δ = |i – r| .



Ex. A light ray is incident on a glass sphere at an angle of incidence 60^0 as shown. Find the angles r, r',e and the total deviation after two refractions.



Sol. Applying Snell's law $1\sin 60^0 = \sqrt{3}\sin r$

$\Rightarrow \quad r = 30^0$

From symmetry $r' = r = 30^0$.

Again applying Snell's law at second surface $1\sin e = \sqrt{3}\sin r$

$\Rightarrow \quad e = 60^0$

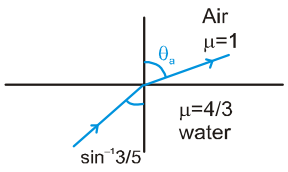
Deviation at first surface = $i - r = 60^0 - 30^0 = 30^0$

Deviation at second surface = $e - r' = 60^0 - 30^0 = 30^0$

Therefore total deviation = 60^0 .

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Ex. Find the angle θ_a made by the light ray when it gets refracted from water to air, as shown in figure.



Sol. Snell's Law

$$\mu_w \sin\theta_w = \mu_a \sin\theta_a \Rightarrow \frac{4}{3}\times\frac{3}{5} = 1 \sin\theta_a \Rightarrow \sin\theta_a = \frac{4}{5} \Rightarrow \theta_a = \sin^{-1}\frac{4}{5}$$

Ex. Find the speed of light in medium 'a' if speed of light in medium 'b' is $\frac{c}{3}$ where c = speed of light in vacuum and light refracts from medium 'a' to medium 'b' making 45° and 60° respectively with the normal.

Sol. : Snell's Law

$$\mu_a \sin\theta_a = \mu_b \sin\theta_b \Rightarrow \frac{c}{v_a}\sin\theta_a = \frac{c}{v_b}\sin\theta_b. \Rightarrow \frac{c}{v_a}\sin 45^\circ = \frac{c}{c/3}\sin 60^\circ. \Rightarrow v_a = \frac{\sqrt{2}c}{3\sqrt{3}}$$

Principle of Reversibility of Light Rays

(a) A ray travelling along the path of the reflected ray is reflected along the path of the incident ray.

(b) A refracted ray reversed to travel back along its path will get refracted along the path of the incident ray. Thus the incident and refracted rays are mutually reversible.

REFRACTION THROUGH A PARALLEL SLAB

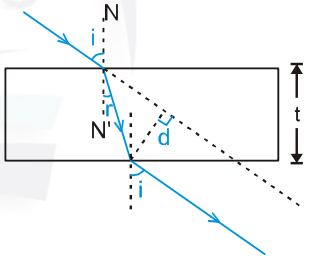
When light passes through a parallel slab, having same medium on both sides, then

(a) Emergent ray is parallel to the incident ray.

Note : Emergent ray will not be parallel to the incident ray if the medium on both the sides of slab are different.

(b) Light is shifted laterally, given by (students should be able to derive it)

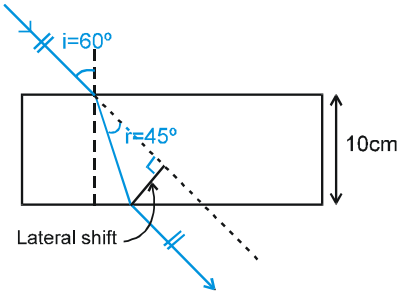
$$d = \frac{t\sin(i-r)}{\cos r} \qquad t = \text{thickness of slab}$$



Ex. Find the lateral shift of light ray while it passes through a parallel glass slab of thickness 10 cm placed in air. The angle of incidence in air is 60° and the angle of refraction in glass is 45°.

Sol. $d = \frac{t\sin(i-r)}{\cos r}$

$$= \frac{10\sin(60^\circ-45^\circ)}{\cos 45^\circ} = \frac{10\sin 15^\circ}{\cos 45^\circ} = 10\sqrt{2}\sin 15^\circ\text{cm}$$



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Apparent Depth and shift of Submerged Object

At near normal incidence (small angle of incidence i) apparent depth (d′) is given by:

$$d' = \frac{d}{n_{relative}} \quad \text{and} \quad v' = \frac{v}{n_{relative}}$$

where $n_{relative} = \frac{n_i (\text{R.I. of medium of incidence})}{n_r (\text{R.I. of medium of refraction})}$

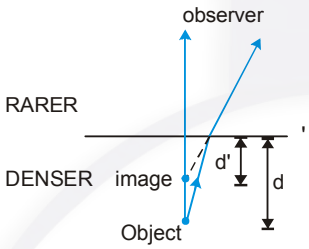
d = distance of object from the interface = real depth

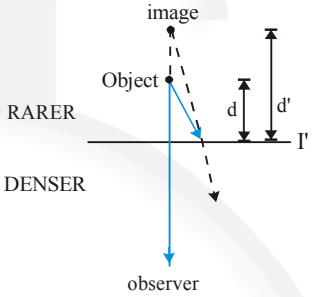
d' = distance of image from the interface = apparent depth

v = velocity of object perpendicular to interface relative to surface.

v′ = velocity of image perpendicular to interface relative to surface.

This formula can be easily derived using Snell's law and applying the condition of nearly normal incidence.... (try it or see in text book).



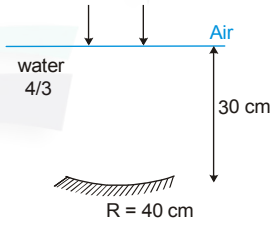


Apparent shift $= d\left(1 - \frac{1}{n_{rel}}\right)$

Ex. An object lies 100 cm inside water .It is viewed from air nearly normally. Find the apparent depth of the object.

Sol. $d' = \frac{d}{n_{relative}} = \frac{100}{4/3} = 75$ cm

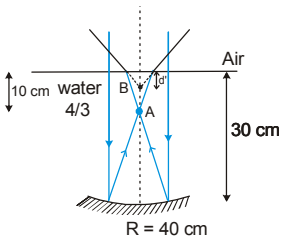
Ex. A concave mirror is placed inside water with its shining surface upwards and principal axis vertical as shown. Rays are incident parallel to the principal axis of concave mirror. Find the position of final image.



Sol. The incident rays will pass undeviated through the water surface and strike the mirror parallel to its principal axis. Therefore for the mirror, object is at ∞ . Its image A (in figure) will be formed at focus which is 20 cm from the mirror.

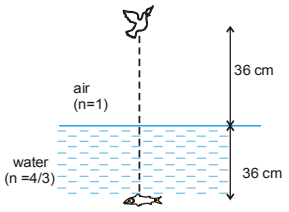
Now for the interface between water and air, d = 10 cm.

$$\therefore \quad d' = \frac{d}{\left(\frac{n_w}{n_a}\right)} = \frac{10}{\left(\frac{4/3}{1}\right)} = 7.5 \text{ cm.}$$



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Ex. See the figure



(i) Find apparent height of the bird.

(ii) Find apparent depth of fish.

(iii) At what distance will the bird appear to the fish?

(iv) At what distance will the fish appear to the bird?

(v) If the velocity of bird is 12 cm/sec downward and the fish is 12 cm/sec in upward direction, then find out their relative velocities with respect to each other.

Sol. **(i)** $d'_B = \dfrac{36}{\dfrac{1}{\left(\frac{4}{3}\right)}} = \dfrac{36}{3/4} = 48$ cm

(ii) $d'_F = \dfrac{36}{4/3} = 27$ cm

(iii) For fish : $d_B = 36 + 48 = 84$ cm

$d_B = 36 + 48 = 84$ cm

(iv) For bird : $d_F = 27 + 36 = 63$ cm.

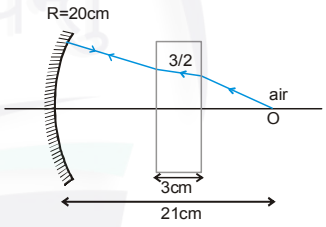
$d_F = 27 + 36 = 63$ cm.

(v) Velocity of fish with respect to bird = $12 + \left(\dfrac{12}{4/3 / 1/1}\right) = 21$ cm/sec.

Velocity of bird with respect to fish = $12 + \left(\dfrac{12}{3/4 / 1/1}\right) = 28$ cm/sec.

Ex. See the figure.

Find the distance of final image formed by mirror



Sol. Shift = $3\left(1 - \dfrac{1}{3/2}\right)$

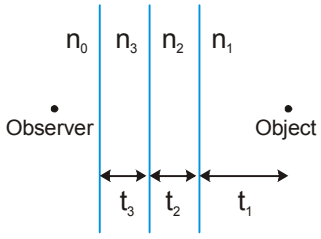
For mirror object is at a distance = $21 - 3\left(1 - \dfrac{1}{3/2}\right)$ = 20 cm

$\therefore$ Object is at the centre of curvature of mirror. Hence the light rays will retrace and image will be formed on the object itself.

Refraction through a composite slab (or refraction through a number of parallel media, as seen from a medium of R. I. n_0)

Apparent depth (distance of final image from final surface)

$$= \frac{t_1}{n_{1\,rel}} + \frac{t_2}{n_{2\,rel}} + \frac{t_3}{n_{3\,rel}} + \ldots\ldots\ldots + \frac{t_n}{n_{n\,rel}}$$



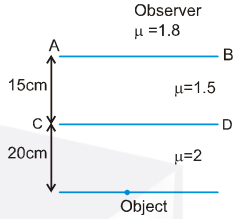
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Apparent shift

$$= t_1\left[1-\frac{1}{n_{1\,rel}}\right]+t_2\left[1-\frac{1}{n_{2\,rel}}\right]+.....+\left[1-\frac{n}{n_{n\,rel}}\right]tn$$

Where 't' represents thickness and 'n' represents the R.I. of the respective media, relative to the medium of observer. (i.e. $n_{1rel} = n_1/n_0$, $n_{2\,rel} = n_2/n_0$ etc.)

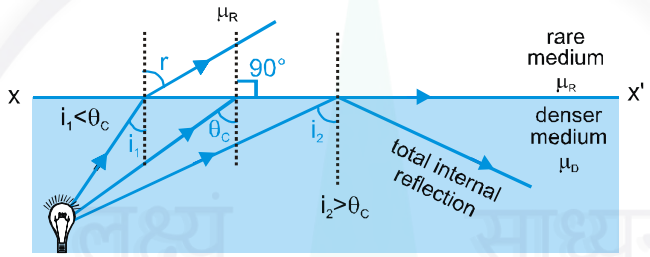
Ex. See the figure. Find the apparent depth of object seen below surface AB.



Sol. $D_{app} = \sum\frac{d}{\mu} = \frac{20}{\left(\frac{2}{1.8}\right)} + \frac{15}{\left(\frac{1.5}{1.8}\right)} = 18 + 18 = 36$ cm.

Total Internal Reflection

When light ray travel from denser to rarer medium it bend away from the normal if the angle of incident is increased, angle of refraction will also increased. At a particular value of angle the refracted ray subtend 90^0 angle with the normal, this angle of incident is known as critical angle (θ_C). If angle of incident further increase the ray come back in the same medium this phenomenon is known as total internal reflection.



Conditions

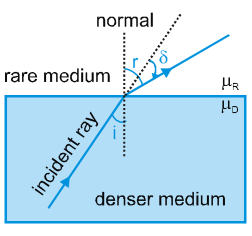
(i) Angle of incident > critical angle $[i > \theta_c]$

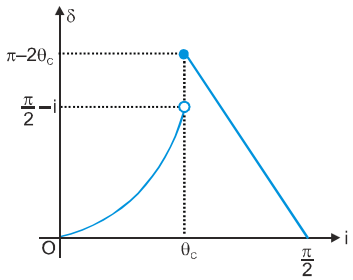
(ii) Light should travel from denser to rare medium $\Rightarrow$ Glass to air, water to air, Glass to water

Snell's Law at boundary xx', $\mu_D \sin\theta_C = \mu_R \sin 90^\circ \Rightarrow \sin\theta_C = \frac{\mu_R}{\mu_D}$

Graph between angle of deviation (δ) and angle of incidence (i) as rays goes from denser to rare medium

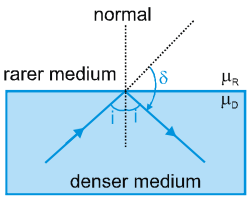
(iii) If $i < \theta_c$ $\mu_D \sin i = \mu_R \sin r$; $r = \sin^{-1}\left(\frac{\mu_D}{\mu_R}\sin i\right)$ So $\delta = r - i = \sin^{-1}\left(\frac{\mu_D}{\mu_R}\sin i\right) - i$



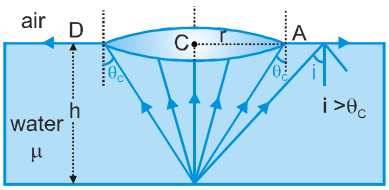


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(iv) If $i > \theta_c$; $\delta = \pi - 2i$



(v) A point object is situated at the bottom of tank filled with a liquid of refractive index μ upto height h. It is found light from the source come out of liquid surface through a circular portion above the object

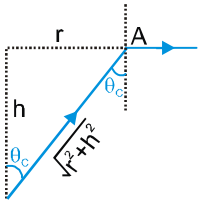


$$\sin\theta_C = \frac{r}{\sqrt{r^2+h^2}} \;\&\; \sin\theta_C = \frac{1}{\mu} \Rightarrow \frac{1}{\mu} = \frac{r}{\sqrt{r^2+h^2}} \Rightarrow \frac{1}{\mu^2} = \frac{r^2}{r^2+h^2}$$

$$\Rightarrow \mu^2 r^2 = r^2 + h^2 \Rightarrow (\mu^2 - 1)r^2 = h^2$$

radius of circular portion

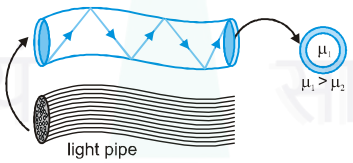
$$r = \frac{h}{\sqrt{\mu^2 - 1}} \text{ and } \text{area} = \pi r^2$$



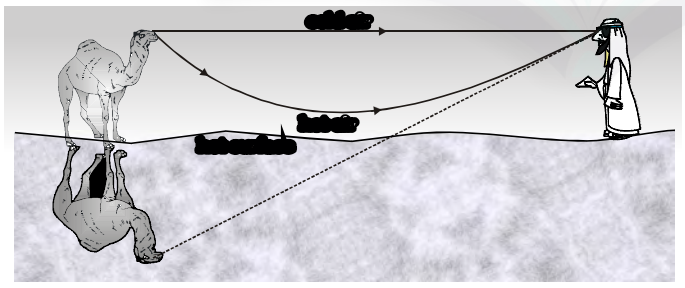
Some Illustrations of Total Internal Reflection

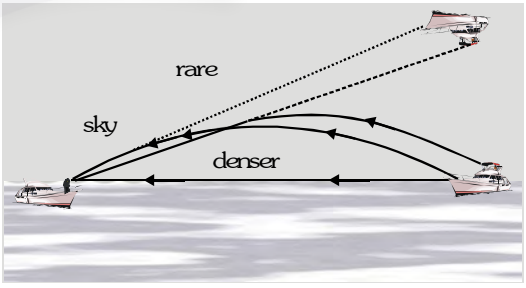
(1) **Sparkling of diamond :** The sparkling of diamond is due to total internal reflection inside it. As refractive index for diamond is 2.5 so $\theta_c = 24°$. Now the cutting of diamond are such that $i > \theta_C$. So TIR will take place again and again inside it. The light which beams out from a few places in some specific directions makes it sparkle.

(2) **Optical Fibre :** In it light through multiple total internal reflections is propagated along the axis of a glass fibre of radius of few microns in which index of refraction of core is greater than that of surroundings.



(3) **Mirage and looming** : Mirage is caused by total internal reflection in deserts where due to heating of the earth, refractive index of air near the surface of earth becomes lesser than above it. Light from distant objects reaches the surface of earth with $i > \theta_C$ so that TIR will take place and we see the image of an object along with the object as shown in figure.





Similar to 'mirage' in deserts, in polar regions 'looming' takes place due to TIR. Here μ decreases with height and so the image of an object is formed in air if $(i > \theta_C)$ as shown in figure.

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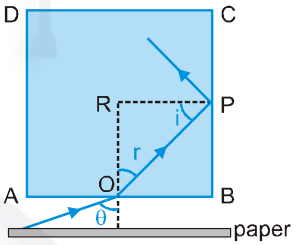
(i) A diver in water at a depth d sees the world outside through a horizontal circle of radius. $r = d \tan \theta_c$.

(ii) In case of total internal reflection, as all (i.e. 100%) incident light is reflected back into the same medium there is no loss of intensity while in case of reflection from mirror or refraction from lenses there is some loss of intensity as all light can never be reflected or refracted. This is why images formed by TIR are much brighter than formed by mirrors or lenses.

Ex. A rectangular block of glass is placed on a printed page laying on a horizontal surface. Find the minimum value of the refractive index of glass for which the letters on the page are not visible from any of the vertical faces of the block.

Sol. The situation is depicted in figure. Light will not emerge out from the vertical face BC if at it

$$i > \theta_C \quad \text{or} \quad \sin i > \sin \theta_C \Rightarrow \sin i > \frac{1}{\mu}\left[\text{as } \sin \theta_C = \frac{1}{\mu}\right] \quad \text{... (i)}$$



But from Snell's law at O $\quad 1 \times \sin \theta = \mu \sin r$

And in Δ OPR, $r + 90 + i = 180 \Rightarrow r + i = 90° \Rightarrow r = 90 - i$

So $\sin \theta = \mu \sin (90 - i) = \mu \cos i \Rightarrow \cos i = \dfrac{\sin \theta}{\mu}$

So $\sin i = \sqrt{1 - \cos^2 i} = \sqrt{1 - \left[\dfrac{\sin \theta}{\mu}\right]^2}$ ... (ii)

so substituting the value of sin i from equation (ii) in (i),

$$\sqrt{1 - \frac{\sin^2 \theta}{\mu^2}} > \frac{1}{\mu} \text{ i.e., } \mu^2 > 1 + \sin^2\theta \because (\sin^2 \theta)_{max} = 1 \therefore \mu^2 > 2 \Rightarrow \mu > \sqrt{2} \therefore \mu_{min} = \sqrt{2}$$

Ex. Find the maximum angle that can be made in glass medium ($\mu = 1.5$) if a light ray is refracted from glass to vacuum.

Sol. $1.5 \sin C = 1 \sin 90°$, where C = critical angle.

$\sin C = 2/3$

$C = \sin^{-1} 2/3$

Ex. Find the angle of refraction in a medium ($\mu = 2$) if light is incident in vacuum, making angle equal to twice the critical angle.

Sol. Since the incident light is in rarer medium. Total Internal Reflection can not take place.

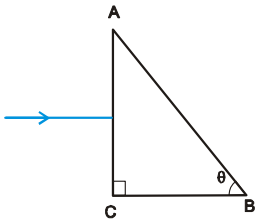
$$C = \sin^{-1} \frac{1}{\mu} = 30° \quad \Rightarrow \quad \therefore \quad i = 2C = 60°$$

Applying Snell's Law. $\quad 1 \sin 60° = 2 \sin r$

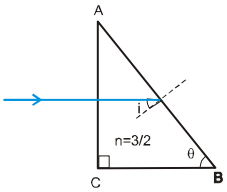
$$\sin r = \frac{\sqrt{3}}{4} \quad \Rightarrow \quad r = \sin^{-1}\left(\frac{\sqrt{3}}{4}\right).$$

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Ex. What should be the value of angle θ so that light entering normally through the surface AC of a prism (n=3/2) does not cross the second refracting surface AB?



Sol. Light ray will pass the surface AC without bending since it is incident normally. Suppose it strikes the surface AB at an angle of incidence i.



$i = 90-\theta$

For the required condition:

$90° - \theta > c$

or $\sin(90° - \theta) > \sin c$

or $\cos\theta > \sin c = \frac{1}{3/2} = \frac{2}{3}$ or $\theta < \cos^{-1}\frac{2}{3}$.

Ex. What should be the value of refractive index n of a glass rod placed in air, so that the light entering through the flat surface of the rod does not cross the curved surface of the rod?

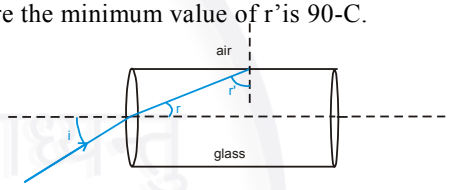
Sol. It is required that all possible r' should be more than critical angle. This will be automatically fulfilled if minimum r' is more than critical angle .....**(A)**

Angle r' is minimum when r is maximum i.e. C(why ?).Therefore the minimum value of r'is 90-C.

From condition **(A)** :

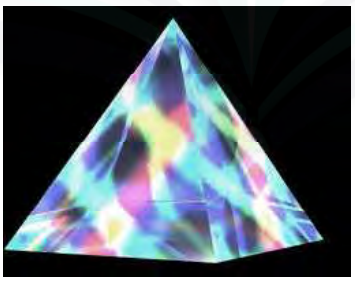
$90° - C > C$ or $C < 45°$

$\sin C < \sin 45°$; $\frac{1}{n} < \frac{1}{\sqrt{2}}$ or $n > \sqrt{2}$.



PRISM

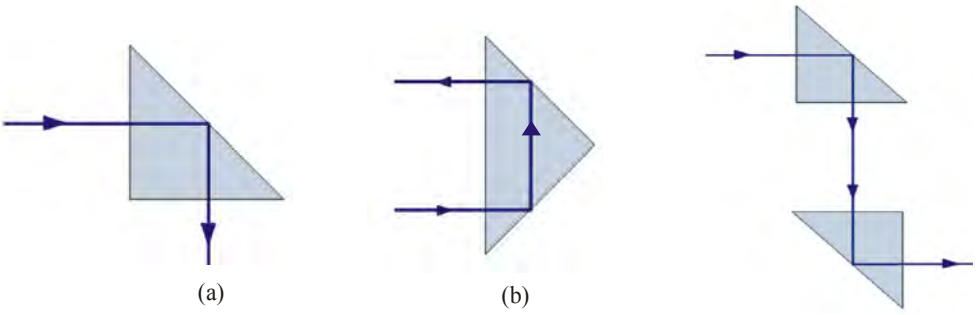
A prism is a temperature medium whose refracting surfaces are not parallel but are inclined to each other.

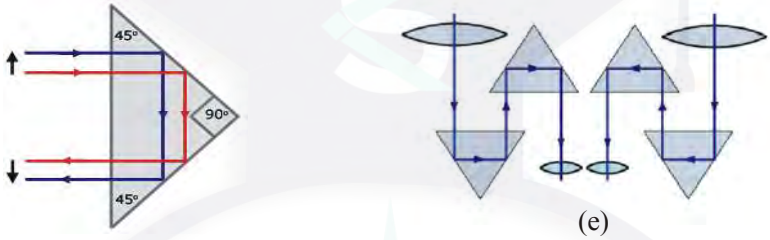


Prism have the property to change the direction of light. Fig. **(a)** to **(e)** present some of the useful applications.

The right-angled prism in fig. **(a)** turns the light through 90°. A poro prism shown in fig. **(b)** is a right-angled prism, it turns light through 180°. Figure **(c)** shows two right-angled prisms used in binoculars. Figures **(d)** and **(e)** illustrate image formation with and without deviation ; in both the cases the image is laterally inverted.

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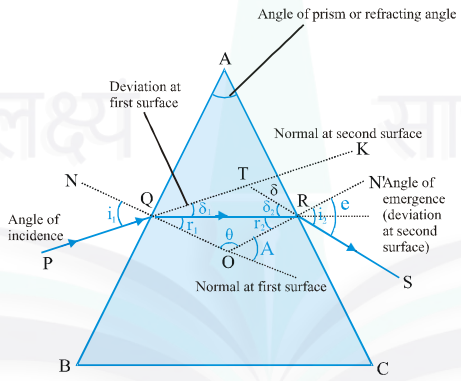




Basic Terms :

(i) Angle of prism or reflecting angle (A) :

The angle between the faces on which light is incident and from which it emerges (in figure)



(ii) Angle of deviation (δ) :

It is the angle between the emergent and the incident ray. It other words, it is the angle through which incident ray turns in passing through a prism.

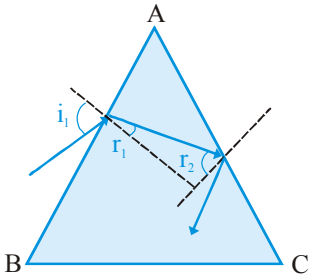
$$\delta = (i - r_1) + (e - r_2) \quad \text{or} \quad \delta = i + e - (r_1 + r_2)$$

or $$\delta = i + e - A$$

(1) Condition of No Emergence

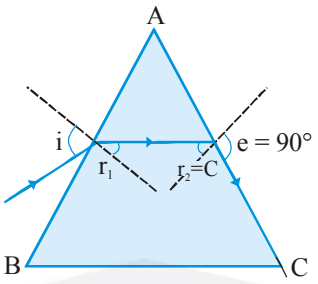
A ray of light incident on prism of angle A and refractive index μ will not emerge out of a prism (whatever may be the angle of incidence) if $A > 2\theta_c$, where q_c is the critical angle, i.e., $\mu > 1/ [\sin(A/2)]$.

(see in figure)



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Ex. What should be the minimum value of refractive index of prism, refracting angle A, so that there is no emergent ray irrespective of the angle of incidence ?



Sol. If the ray just emerges from face AC,

$e = 90°$ and $r^2 = C$ ..... **(i)**

From Snells' law at face AB, we have

$1 \sin i = n \sin r_1$ ..... **(ii)**

$A = r_1 + r_2 = r_1 + C$ .....**(iii)**

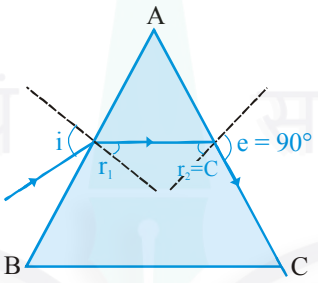
From eq. **(ii)**, n is minimum when r_1 is maximum, i.e., $r_2 = C$. In this case, $i = 90°$

From eq. **(iii)**, $A = 2C$ or $C = A / 2$

As $\sin C = \frac{1}{n} \Rightarrow \sin\frac{A}{2} = \frac{1}{n} \Rightarrow n = \text{cosec}\frac{A}{2}$

(2) Condition of Grazing Emergence

By the condition of grazing emergence, we mean the angle of incidence i at which the angle of emergence becomes 90°. (see figure)



Consider a prism with refracting angle A and refractive index n.

They ray grazes face AC.

So, $e = 90°, r_2 = C$ ..... **(i)** and $A = r_1 + r_2 = r_1 + C$ ..... **(ii)**

Also, $\sin C = 1/n$

from Snell's law at face AB, $1 \sin i = n \sin r_1$

$\sin i = n \sin (A - C)$

$= n[\sin A \cos C - \cos A \sin C]$

$= n\left[\sin A\sqrt{1-\sin^2 C} - \cos A \sin C\right]$

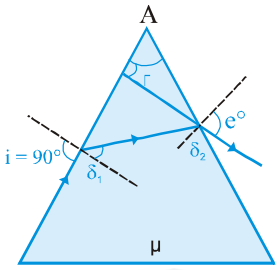
$= \sqrt{n^2-1}\sin A - \cos A$

$i = \sin^{-1}\left[\sqrt{n^2-1}\sin A - \cos A\right]$

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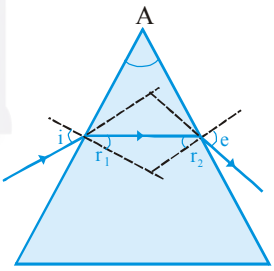
(3) Condition of Maximum Deviation

Maximum deviation occurs when the angle of incidence is 90°. (see in figure)



$\delta_{max} = 90° + e - A$ where $e = \sin^{-1}[\mu \sin(A - \theta_c)]$

(4) Condition of Minimum Deviation



The minimum deviation occurs when the angle of incidence is equal to the angle of emergence (in figure.)

i.e. $i = e$; $d_{min} = 2i - A$

Using Snell's law, we get

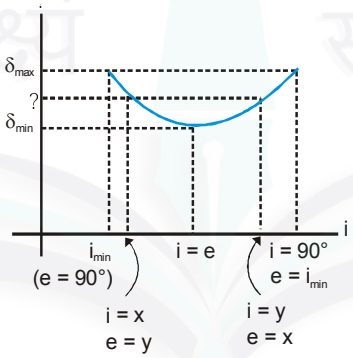
$$\mu = \frac{\sin[(\delta_{min} + A)/2]}{\sin[A/2]}$$

Note that in the condition of minimum deviation the light ray passes through the prism symmetrically, i.e., the ray in the prism becomes parallel to its base.

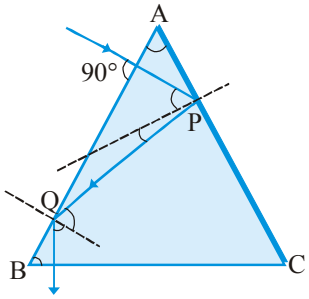
(i) Variation of δ versus i (shown in diagram).

For each δ (except δ_{min}), there are two values of angle of incidence. If i and e are interchanged, then we get the same value of δ because of reversibility principle of light.

(ii) There is one and only one angle of incidence for which the angle of deviation is minimum.



Ex. An isosceles prism has one of the refracting surfaces silvered. A ray of light is incident normally on the refracting face AB. After two reflections, the ray emerges from the base of the prism perpendicular to it. Find the angle of the prism.



Sol. The incident ray passes without deviation from face AB. It suffers reflections at P and Q. From Figure, incident ray and normal at Q are parallel ; therefore

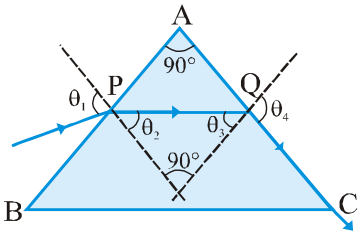
$a = 2A$ ..... **(i)**

Also, $2\alpha + A = 180°$ ..... **(ii)**

On solving Eqs. **(i)** and **(ii)**, we get $A = 36°$, $\alpha = 72°$

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Ex. Figure shows a triangular prism of refracting angle 90°. A ray of light incident at face AB at an angle q_1 refracts at point Q with an angle of refraction 90°.



(a) What is the refractive index of the prism in terms of θ_1 ?

(a) What is the maximum value that the refractive index can have ?

What happens to the light at Q if the incident angle at Q is

(c) Increased slightly, and

(d) Decreased slightly ?

Sol. **(a)** Let the ray be incident at an angle θ_1 at the face AB. It refracts at an angle θ_2 and is incident at an angle θ_3 at face AC. Finally, the ray comes out at an angle $\theta_4 = 90°$.

From Figure, the normal at faces AB and AC make an angle of 90° with each other, $\theta_3 = 90° - \theta_2$

$$\sin\theta_3 = \sin(90° - \theta_2) = \cos\theta_2 = \sqrt{1 - \sin^2\theta_2} \qquad \textbf{(i)}$$

From Snell's law at face AC, $n \sin\theta_3 = 1$

$$n\sqrt{1 - \sin^2\theta_2} = 1 \qquad \textbf{(ii)}$$

From Snell's law at face AB, $1 \sin\theta_1 = n \sin\theta_2$

$$\sin\theta_2 = \frac{\sin\theta_1}{n} \qquad \textbf{(iii)}$$

From Eqs. **(ii)** and **(iii)**, we have

$$n\sqrt{1 - \frac{\sin^2\theta_1}{n^2}} = 1 \qquad \textbf{(iv)}$$

On squaring Eq. **(iv)** and solving for n. we get

$$n = \sqrt{1 + \sin^2\theta_1}$$

(b) The greatest possible value of $\sin^2\theta_1$ is 1, hence the greatest possible value of n is $n_{max} = \sqrt{2} = 1.41$.

(c) For a given n, if θ_1 is increased the angle of refraction θ_2 increases. As θ_3 - 90° – θ_2 , the angle of incidence at face AC is less than the critical angle for total reflection ; hence light emerges into air.

(d) If the angle of incidence is decreased, the angle of refraction θ_2 decreases. So, the angle θ_3 increases. The angle of incidence at the second surface is greater than the critical angle; so light is reflected at Q.

Note : In the condition of minimum deviation, the light ray passes through the prism symmetrically, i.e., the light ray in the prism becames parallel to its base.

Ex. A prism has refracting angle equal to π/2. It is given γ is the angle of minimum deviation and β is the deviation of the ray entering at grazing incidence. Prove that $\sin\gamma = \sin^2\beta$.

Sol. A applying condition of minimum deviation,

$$\mu = \frac{\sin\frac{(A+\gamma)}{2}}{\sin\frac{A}{2}} = \frac{\sin\frac{A}{2}\cos\frac{\gamma}{2} + \cos\frac{A}{2}\sin\frac{\gamma}{2}}{\sin\frac{A}{2}} \quad \Rightarrow \quad \mu = \cos\frac{\gamma}{2} + \cot\frac{A}{2}\sin\frac{\gamma}{2}$$

Using A = 90°, $\mu = \cos\frac{\gamma}{2} + \cot 45° \sin\frac{\gamma}{2}$ $\Rightarrow$ $\cos\frac{\gamma}{2} + \sin\frac{\gamma}{2} = \mu$

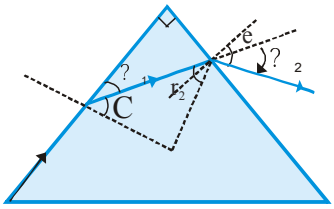
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Squaring, $\cos^2\frac{r}{2}+\sin^2\frac{\gamma}{2}+\gamma=\mu \Rightarrow \sin\gamma=\mu^2=1$ .....(i)

Deviation at grazing incidence,

$$\beta=\delta_1+\delta_2$$

$$\beta=\left(\frac{\pi}{2}-C\right)+(e-r_2)$$



$\Rightarrow \quad \beta=\left(\frac{\pi}{2}-C\right)+\left[e-\left(\frac{\pi}{2}-C\right)\right] \quad \Rightarrow \quad \beta = e$

or $\sin\beta=\sin e=\mu\sin r_2=\mu\sin\left(\frac{\pi}{2}-C\right) \Rightarrow \sin\beta = \mu\cos C$ .....(ii)

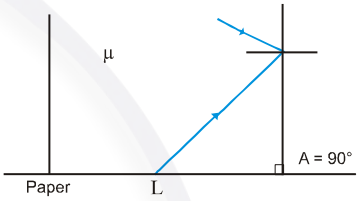
Squaring Eq. (ii),

$$\sin^2\beta=\mu^2\cos^2 C \Rightarrow \sin^2\beta=\mu^2(1-\sin^2 C)$$

Using $\sin C=\frac{1}{\mu}, \sin^2\beta=\mu^2\left(1-\frac{1}{\mu^2}\right) \Rightarrow \sin^2\beta = \mu^2 - 1$ .....(iii)

From Eqs. (i) and (iii), $\sin\gamma = \sin^2\beta$

Ex. A rectangular block of refractive index μ is placed on a printed page lying on a horizontal surface as shown in figure. Find the minimum value of μ so that the letter L on the page is not visible from any of the vertices sides.



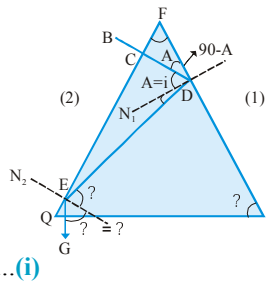
Sol. The letter L will not be visible from the vertical sides if the light ray does not enter through it.

We can apply the condition of no emergence for a prism of angle A = 90°.

That is, $\mu>\frac{1}{\sin\frac{A}{2}}$ or $\mu>\frac{1}{\sin\frac{90°}{2}}$ or $\mu>\sqrt{2}$

Ex. The cross section of a glass prism has the form of an isosceles triangle. One of the refracting faces in silvered. A ray of light falling normally on the other refracting face, being reflected twice, emerges through the base of the prism perpendicular to it. Find the angles of the prism.

Sol. The incident ray BC at normal incidence is reflected at silvered face, along DE and at E it again suffers reflection along EF. Since the ray emerges normally from the base, therefore the ray EF must fall normally on the base and emerges along EG..



We find $i = A$ Also, $\beta = \alpha$

Since $EN_2 \parallel CD$, $\beta = 2i$ (alternate angles)

$\therefore \quad \alpha = 2A \quad (\beta = \alpha, i = A)$ .....(i)

Also, $2\alpha + A = 180°$ ($\because$ Sum of angles of a triangle = 180°) .....(ii)

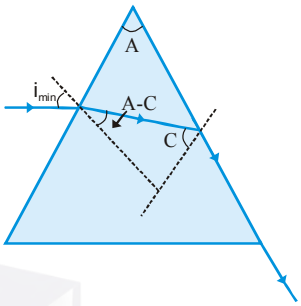
Solving Eqs. (i) and (ii), we get A = 36°, α = 72°

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Ex. For a prism, A = 60°, $n = \sqrt{7/3}$. Find the minimum possible angle of incidence, so that the light ray is refracted from the second surface. Also, find $\delta_{max.}$.

Sol. In minimum incidence case, the angles will be as shown in figure.

Applying Snell's law, we get



$$1 \times \sin i_{min} = \sqrt{\frac{7}{3}} \sin(A - C)$$

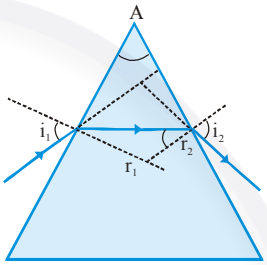
$$= \sqrt{\frac{7}{3}} (\sin A \cos C - \cos A \sin C)$$

$$= \sqrt{\frac{7}{3}} \left(\sin 60 \sqrt{1 - \frac{3}{7}} - \cos 60 \sqrt{\frac{3}{7}} \right) = \frac{1}{2}$$

$\therefore$ $i_{min} = 30°$ $\quad\therefore$ $\delta_{max} + i_{min} + 90° - A = 30° + 90° - 60° = 60°$

THIN PRISMS

In this prisms, the distance between the refracting surfaces is ineligible and the angle of prism **(A)** is very small. Since $A = r_1 + r_2$, therefore if A is small then both r_1 and r_2 are also small, and the same is true for i_1 and i_2.



According to Snell's law,

$\sin i_1 = \mu \sin r_1$

or $\quad i_1 = \mu r_1$

$\sin i_2 = \mu \sin r_2$

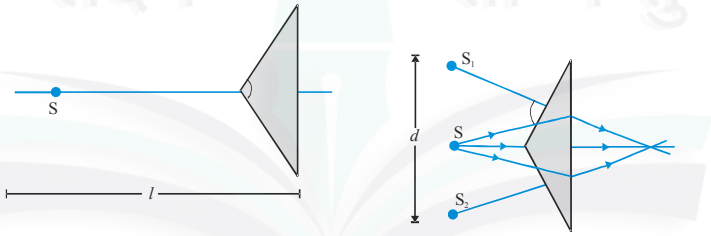
or $\quad i_2 = \mu r_2$

Therefore, deviation, $\delta = (i_1 - r_1) + (i_2 + r_2)$

$\Rightarrow \delta = (r_1 + r_2)(\mu - 1) \Rightarrow \delta = A(\mu - 1)$

Ex. A thin biprism (see figure) of obtuse angle a = 178° is placed at a distance l = 20 cm from a slit.

How many images are formed and what is the separation between them ? Refractive index of the material μ = 1.6.



Sol. Two images are formed by the two thin prisms - one above the axis and the other below the axis by the same distance.

The refracting angle of each thin prism is

$$\frac{\pi - \alpha}{2} = \frac{1}{2}(\pi - \alpha)$$

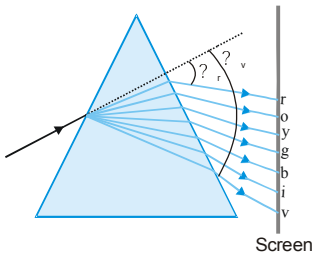
Then, δ (deviation of a ray) = $(\mu - 1)\frac{1}{2}(\pi - \alpha)$

$$\frac{d}{2} = 1\delta \Rightarrow d = 2(\mu - 1)\frac{1}{2}(\pi - \alpha) \Rightarrow d = (\mu - 1)l(\pi - \alpha)$$

$$\Rightarrow d = (1.6 - 1) \times 0.20 \left(\pi - 178 \times \frac{\pi}{180} \right) = 0.6 \times 0.20 \times \pi \times \frac{1}{90} = 0.004 \text{ m} = 4\text{mm}$$

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Ex. A thin prism of angle A = 6° produces a deviation d = 3°. Find the refractive index of the material of prism.





Sol. We know that $d = A(\mu - 1)$ or $\mu = 1 + \frac{\delta}{A}$

Here, $A = 6°$, $d_{min} = 30°$

$$\mu = \frac{\sin\left(\frac{90+30}{2}\right)}{\sin\left(\frac{60}{2}\right)} = \frac{\sin 45°}{\sin 30°} = \sqrt{2} = 1.41$$

Dispersion of Light

When a ray of light passes through a prism, it splits up into rays of constituent colors or wavelengths. This phenomenon is called dispersion of light.

This phenomenon arises due to the fact that refractive index varies with the wavelength. It has been observed for a prism that μ decreases with the increase of wavelength, i.e., $\mu_{blue} > \mu_{red}$

Angular dispersion : $\theta = \delta_v - \delta_r$

Dispersive power : Ratio of angular dispersion to mean deviation.

$$\omega = \frac{\delta_v - \delta_r}{\delta}$$

where δ is deviation of mean ray (yellow)

As $d_v = (\mu_v - 1)A$, $d_r = (\mu_r - 1)A$

$\Rightarrow$ $\omega = \frac{\mu_v - \mu_r}{\mu_y - 1}$ where $\mu_y = \frac{\mu_v - \mu_r}{2}$

Ex. Calculate the dispersive power of crown glass from the given data.

$\mu_v = 1.523$, and μ_r 1.5145

Sol. Here, $\mu_v = 1.523$, and μ_r 1.5145

Mean refractive index,

$$\mu = \frac{1.523 + 1.5145}{2} = 1.51875$$

Dispersive power is given by,

$$\omega = \frac{\mu_v - \mu_r}{(\mu - 1)} = \frac{1.523 + 1.5145}{(1.51875 - 1)} = 0.1639$$

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Ex. Find the dispersion produced by a thin prism of 18° having refractive index for red light = 1.56 and for violet light = 1.68.

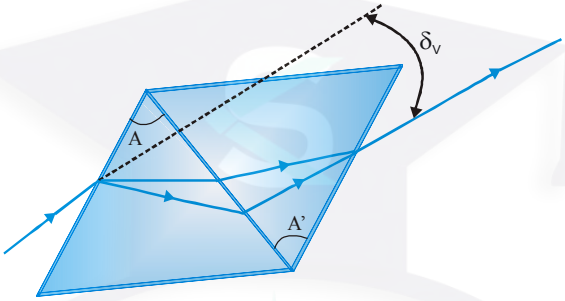
Sol. We know that dispersion produced by a thin prism,

$$\theta = (\mu_v - \mu_r)A$$

Here, $\mu_v = 1.68$, $\mu_r = 1.56$ and $A = 18° \Rightarrow \theta = (1.68 - 1.56) \times 18° = 2.16°$

Deviation Without Dispersion

The means an achromatic combination of two prisms in which net or resultant dispersion is zero and deviation is produced.



For the two prisms,

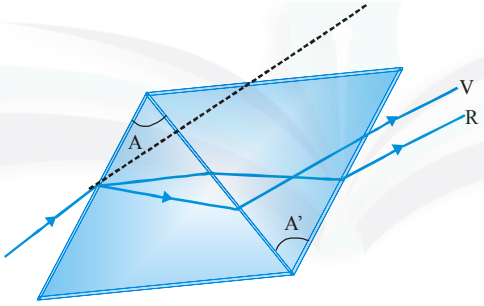
$$(\mu_v - \mu_l)\,A + (\mu_v - \mu_r)\,A = 0$$

$$\Rightarrow \quad A' = \frac{(\mu_v - \mu_r)A}{\mu_v - \mu_r} \quad \text{and} \quad \omega\delta + \omega'\delta' = 0 \Rightarrow \delta = \delta_1\left[1 - \frac{\omega}{\omega'}\right]$$

where ω and ω' are the dispersive powers of the two prisms and δ and δ' their mean deviations.

Dispersion Without Deviation

A combination of two prisms in which deviation produced for the mean ray be the first prism is equal and opposite to that produced by the second prism is called a direct vision prism.



This combination produces dispersion without deviation.

For deviation to be zero, $(\delta + \delta') = 0$

$$\Rightarrow \quad (\mu - 1)A, + (\mu' - 1)A = 0 \Rightarrow A' = \frac{(\mu - 1)A}{(\mu' - 1)}$$

(–ve sign ⇒ prism A' has to be kept inverted) $\theta = \delta(\omega - \omega')$

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Ex. Two thin prisms are combined to form an achromatic combination. For prism I, A = 4°, μ_R = 1.35, μ_Y = 1.40, μ_v =1.42. For prism II, μ'_R = 1.7, μ'_Y = 1.8 and μ'_R = 1.9. Find the prism angle of prism II and the net mean deviation.

Sol. Condition for achromatic combination

$$\theta = \theta'$$

$(\mu_v - \mu_r)A,\ d_r = (\mu'_v - \mu'_r)A'$

$$\Rightarrow \quad A = \frac{(1.42-1.35)4°}{1.9-1.7} = 1.4°$$

$$\delta_{Net} = \delta - \delta' = (\mu_Y - 1)A - (\mu_Y - 1)A'$$

$= (1.40 - 1)\ 4° - (1.8 - 1)\ 1.4° = 0.48°$

Ex. A crown glass prism of angle 5° is to be combined with a flint prism in such a way that the mean ray passes undeviated. Find **(a)** the angle of the flint glass prism needed and **(b)** the angular dispersion produced by the combination when white light goes through it. Refractive indices for red, yellow, and violet light are 1.514, 1.517 and 1.523, respectively, for crown glass and 1.613, 1.620 and 1.632 for flint glass.

Sol. The deviation produced by the crown prism is $\delta = (\mu - 1)A$ and by the flint prism is $\delta' = (\mu' - 1)\ A'$.

The prisms are placed with their angles inverted with respect to each other. The deviations are also in opposite directions. Thus, the net deviation is

$$\delta_{Net} = \delta - \delta' = (\mu - 1)A - (\mu - 1)A' \qquad \text{.....(i)}$$

a. If the net deviation for the mean ray is zero,

$$(\mu - 1)A - (\mu - 1)A' \qquad \text{or} \qquad A' = \frac{(\mu - 1)}{(\mu' - 1)}A = \frac{1.517 - 1}{1.620 - 1} \times 5°$$

b. The angular dispersion produced by the crown prism is

$$\delta_v - \delta_r = (\mu_v - \mu_r)A$$

and that by the flint prism is $\delta'_v - \delta'_r = (\mu'_v - \mu'_r)A$

The net angular dispersion has magnitude 0.0348°.

a. If the net deviation for the mean ray is zero.

$$(\mu - 1)A = (\mu' - 1)A' \qquad \text{or} \qquad A = \frac{(\mu' - 1)}{(\mu' - 1)}A = \frac{1.517 - 1}{1.620 - 1} \times 5°$$

b. The angular dispersion produced by the crown prism is

$$\delta_v - \delta_r = (\mu_v - \mu_r)A$$

and that by the flint prism is $\delta'_v - \delta'_r = (\mu'_v - \mu'_r)A$

The net angular dispersion is

$$(\mu_v - \mu_r)A - (\mu'_v - \mu'_r) = A(1.523 - 1.514) \times 5° - (1.632 - 1.613) \times 4.2° = -0.0348°.$$

The angular dispersion has magnitude 0.034°.

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SPECTRUM

Ordered pattern produced by a beam emerging from a prism after refraction is called *Spectrum*. Types of spectrum:

Types of spectrum:

(a) Line spectrum:

Due to source in atomic state.

(b) Band spectrum:

Due to source in molecular state.

(c) Continuous spectrum:

Due to white hot solid.

In Emission spectrum

Bright colours or lines, emitted from source are observed.

The spectrum emitted by a given source of light is called emission spectrum. It is a wavelength-wise distribution of light emitted by the source. The emission spectra are given by incandescent solids, liquids and gases which are either burnt directly as a flame (or a spark) or burnt under low pressure in a discharge tube.

In Absorption spectrum

Dark lines indicates frequencies absorbed.

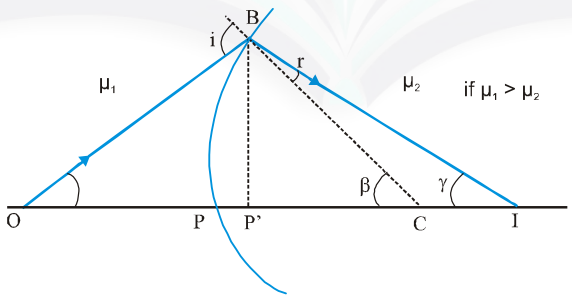
When a beam of light from a hot source is passed through a substance (at a lower temperature), a part of the light is transmitted but rest of it is absorbed. With the help of a spectrometer, we can know the fraction of light absorbed corresponding to each wavelength. The distribution of the wavelength absorption of light by a substance is called an absorption spectrum. Every substance has its own characteristic absorption spectrum.

Spectrometer

Consists of a collimator (to collimate light beam), prism and telescope. It is used to observe the spectrum and also measure deviation.

REFRACTION AT SPHERICAL SURFACES

Consider the point object O placed in a medium with refractive index equal to μ_1.



As $\mu_1 \sin i = \mu_2 \sin r$, and for small aperture $i, r \to 0$

$\Rightarrow \quad \mu_1 i = \mu_2 r \quad \Rightarrow \quad i = \alpha + \beta, \beta = \gamma + r$

$\Rightarrow \quad \mu_1 (\alpha + \beta) = \mu_2 (\beta - \gamma) \quad \Rightarrow \quad \mu_1\alpha + \mu_2\gamma = (\mu_1 - \mu_2)\beta$

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As aperture is small, $\alpha \approx \tan\alpha, \beta = \tan\beta, \gamma = \tan\gamma$

$\Rightarrow$ $\mu_1 \tan\alpha + \mu_2 \tan\gamma = (\mu_2 - \mu_1)\tan\beta$ $\Rightarrow$ $\tan\alpha = \frac{BP'}{OP'}; \tan\beta = \frac{BP'}{P'C}; \tan\gamma = \frac{BP'}{P'I}$

$\Rightarrow$ $\frac{\mu_1}{P'O} + \frac{\mu_2}{P'I} = \frac{\mu_2 - \mu_1}{P'C}$

Applying sign convention, i.e.

P'O = –u, P'I = v, and P'C = R

Therefore, for a spherical surface, $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$

The symbols should be carefully remembered as : μ_2 – refractive index of the medium into which light rays are entering; μ_1 - refractive index of the medium from which light rays are coming. Care should also be taken while applying the sign convention to R.

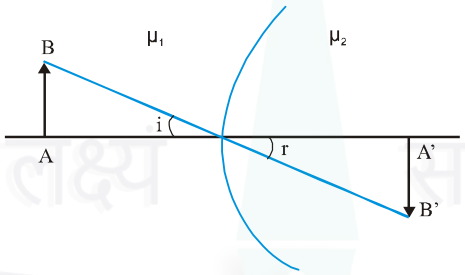
Lateral Magnification for Refracting Spherical Surface

Lateral magnification, $m = \frac{\text{Image height}}{\text{Object height}} = \frac{-(A'B')}{AB}$ Now, $\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$

For small angles of incidence and thus refraction, sin i = tan i and sin r = tan r

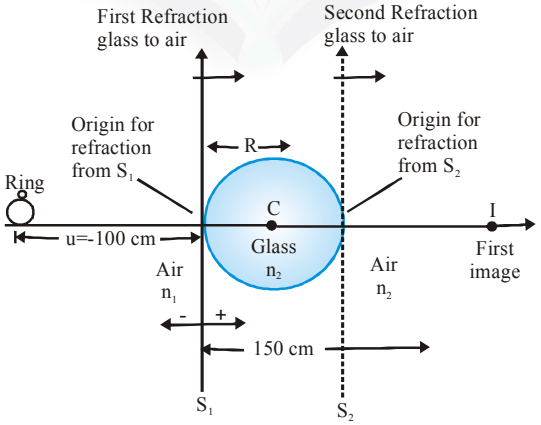
$\Rightarrow$ $\frac{\tan i}{\tan r} = \frac{\mu_2}{\mu_1}$; in triangles ABP and A'B'P', we have

$$\frac{AB/PA}{A'B'/P'A'} = \frac{\mu_2}{\mu_1} \Rightarrow \frac{A'B'}{AB} = -\frac{\mu_2}{\mu_1}\frac{PA'}{PA} = \frac{\mu_2}{\mu_1}\frac{v}{(-\mu_1)} = \frac{\mu_2}{\mu_1}\frac{v}{\mu_2}$$



Ex. A ring of radius 1 cm is placed 1 m in front of a spherical glass ball of radius 25 cm with refractive index 1.50. Determine the position of the final image of the ring and its magnification.

Sol. Light rays from the object are the refrected through the glass ball twice ; first at surface S_1, from air to glass, and second, at surface S_2, from glass to air. We use paraxial approximation, so that single surface refraction equation can be used.



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Refraction at first surface

$n_1 = 1$, $n_2 = 1.5$, u = –100 cm, R = +25 cm

The radius of curvature is positive because centre of curvature is to the right.

Substituting these values in single surface refraction equation,

$$\frac{1.5}{v} - \frac{1}{(-100)} = \frac{(1.5-1)}{25}$$

On solving for v, we get v = +150 cm

The image is located 150 cm to the right of the first refracting surface. The magnification due to refraction at first surface,

$$\mu_1 - \frac{n_1 v}{n_2 u} = \frac{1(150)}{1.5(-100)} = -1$$

Refraction at second surface

For refraction at second surface, the origin of the cartesian coordinate system has to be shifted to the vertex of the second refracting surface.

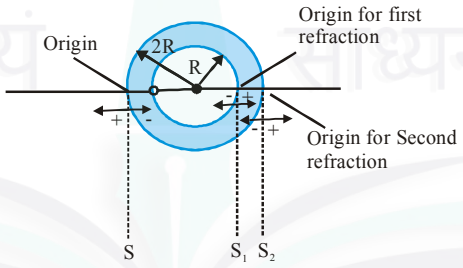
The object distance for refraction at S_2 is u' = +(150–50) = 100 cm.

This is the virtual object for S_2, the light rays converging to I_1 are refracted at S_2 before they can actually converge to form the image.

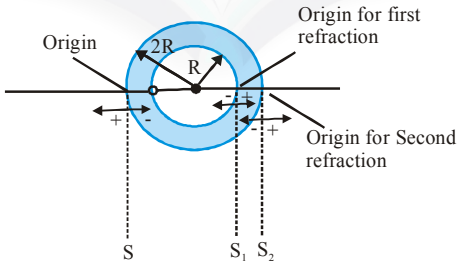
$n_1 = 1.5$, $n_2 = 1$, u = 100 cm, R = –25 cm

$$\frac{I}{v} - \frac{1.5}{(+100)} = \frac{(1-1.5)}{(-25)} \Rightarrow v = +200/7\ cm \Rightarrow \mu_2 = \frac{n_1 v}{n_2 v} = \frac{1.5(200/7)}{1(100)} = \frac{3}{7} \Rightarrow m = m_1 \times m_2 = -1 \times \frac{3}{7} = \frac{3}{7}$$

Ex. A glass sphere os radius 2R, refractive index n has a spherical cavity of radius R, concentric with it. A black spot on the inner surface of the hollow sphere is viewed from the left as well as right. Obtain the shift in position of the object.



Sol. **(i)** Viewer on the left of hollow sphere ; Single refraction takes place at surface S.



From the single surface refraction equation, we have $\mu_2 = 1$, $\mu_1 = n$, u = –R, and R = –2R

$$\frac{1}{v} - \frac{n}{(-R)} = \frac{(1-n)}{(-2R)}$$

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which on solving for v yields, $v = -\left(\frac{-2R}{n+1}\right)$

Image is on the right of refracting surface S.

Shift = Real depth – Apparent depth

$$= R - \left(\frac{2R}{n+1}\right) = \frac{(n-1)}{(n+1)}R$$

(ii) When the viewer is on the right, two refractions take place at surfaces S_1 and S_2. $\mu_2 = n$, $\mu_1 = 1$, $u = -2R$, and $R = -R$

For refraction at surfaces $S_1 : \frac{n}{v_1} - \frac{1}{(-2R)} = \frac{(n+1)}{(-R)}$

which on the solving for v_1 yields $v_1 = \frac{2nR}{2n-1}$

The first lies to the left of S_1 and acts as object for refraction at the second surface. We have to shift the origin of cartesian coordinate system to the vertex of S_2. The object distance for the second surface is

$$u_2 = -\left[\frac{2nR}{2n-1} + R\right] = -\left[\frac{4n-1}{2n-1}\right]R$$

Here $\mu_2 = 1$, $\mu_{\backslash 1} = n$, $R = -2R$

$$\Rightarrow \quad \frac{1}{v_2} - \frac{n}{-\left[\frac{4n-1}{2n-1}\right]R} = \frac{1-n}{-2R}$$

On solving for v_2, we get $v_2 = -\frac{2(4n-1)}{(3n-1)}R$

The minus sign shows that image is virtual and lies to the left of S_2.

Shift - Real depth – Apparent depth $= -\frac{2(4n-1)}{(3n-1)}3R - -\frac{2(4n-1)R}{(3n-1)} = \frac{(n-1)}{(3n-1)}R$

THIN LENS

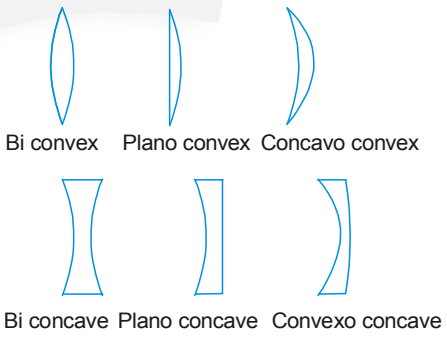
A thin lens is called convex if it is thicker at the middle and it is called concave if it is thicker at the ends. One surface of a convex lens is always convex . Depending on the other surface a convex lens is categorized as

(a) biconvex or convexo convex , if the other surface is also convex,

(b) Plano convex if the other surface is plane and

(c) Concavo convex if the other surface is concave.

Similarly concave lens is categorized as concavo-concave or biconcave, plano-concave and convexo-concave.



For a spherical, thin lens *having the same medium on both sides*:

$$\frac{1}{v} - \frac{1}{u} = (n_{rel} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \text{.....(a)},$$

where $n_{rel} = \frac{n_{lens}}{n_{medium}}$ and R_1 and R_2 are x coordinates of the centre of curvature of the 1st surface and

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2nd surface respectively.

$\frac{1}{f} = (n_{rel} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ Lens Maker's formula .....**(b)**

From **(a)** and **(b)**

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

Lens has two Focii:

If $u = \infty$, then $\frac{1}{v} - \frac{1}{\infty} = \frac{1}{f} \Rightarrow v = f$

$\Rightarrow$ If incident rays are parallel to principal axis then its refracted ray will cut the principal axis at 'f'. It is called 2nd focus.

In case of converging lens it is positive and in case of diverging lens it is negative.



If $v = \infty$ that means $\frac{1}{\infty} - \frac{1}{u} = \frac{1}{f} \Rightarrow u = -f$

$\Rightarrow$ If incident rays cuts principal axis at – f then its refracted ray will become parallel to the principal axis. It is called 1st focus. In case of converging lens it is negative ($\because$ f is positive) and in the case of diverging lens it positive ($\because$ f is negative)



use of – f & + f is in drawing the ray diagrams.

Notice that the point B, its image B′ and the pole P of the lens are collinear. It is due to parallel slab nature of the lens at the middle. This ray goes straight. (Remember this)



From the relation $\frac{1}{f} = (n_{rel} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ it can be seen that the second focal length depends on two factors.

(A) The factor $\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ is

(i) **Positive** for all types of **convex** lenses and

(ii) **Negative** for all types of **concave** lenses.

(B) The factor $(n_{rel} - 1)$ is

(i) **Positive** when **surrounding medium is rarer than the medium of lens.**

(ii) **Negative** when **surrounding medium is denser than the medium of lens.**

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(C) So a lens is **converging** if **f is positive** which happens when **both the factors (A) and (B) are of same sign**.

(D) And a lens is **diverging** if **f is negative** which happens when the **factors (A) and (B) are of opposite signs**.

(E) Focal length of the lens depends on medium of lens as well as surrounding.

(F) It also depends on wavelength of incident light. Incapability of lens to focus light rays of various wavelengths at single point is known as **chromatic aberration**.

Ex. Find the behaviour of a concave lens placed in a rarer medium.

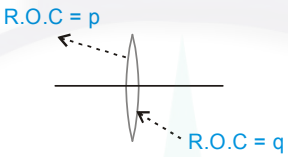
Sol. Factor (A) is negative , because the lens is concave.

Factor (B) is **positive** , because the **lens is placed in a rarer medium**.

Therefore the focal length of the lens, which depends on the product of these factors , is negative and hence the lens will behave as diverging lens.

Ex. Show that the factor $\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$ (and therefore focal length) does not depend on which surface of the lens light strike first.

Sol. Consider a convex lens of radii of curvature p and q as shown.



CASE 1: Suppose light is incident from left side and strikes the surface with radius of curvature p, first.

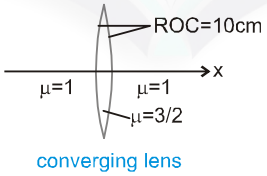
Then $R_1 = +p$; $R_2 = -q$ and $\left(\frac{1}{R_1}-\frac{1}{R_2}\right) = \left(\frac{1}{p}-\frac{1}{-q}\right)$

CASE 2: Suppose light is incident from right side and strikes the surface with radius of curvature q, first.

Then $R_1 = +q$; $R_2 = -p$ and $\left(\frac{1}{R_1}-\frac{1}{R_2}\right) = \left(\frac{1}{q}-\frac{1}{-p}\right)$

Though we have shown the result for biconvex lens , it is true for every lens.

Ex. Find the focal length of the lens shown in the figure.



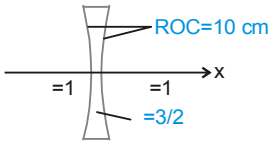
converging lens

Sol. : $\because \quad \frac{1}{f} = (n_{rel} - 1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

$$\Rightarrow \frac{1}{f} = (3/2 - 1)\left(\frac{1}{10}-\frac{1}{(-10)}\right) \Rightarrow \frac{1}{f} = \frac{1}{2}\times\frac{2}{10} \Rightarrow f = +10 \text{ cm}.$$

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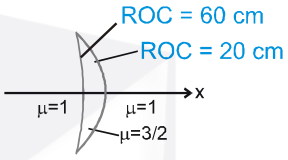
Ex. Find the focal length of the lens shown in figure



Sol. : $\frac{1}{f} = (n_{rel} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \left(\frac{3}{2} - 1\right)\left(\frac{1}{-10} - \frac{1}{10}\right)$

$f = -10$ cm

Ex. Find the focal length of the lens shown in figure
(a) If the light is incident from left side.
(b) If the light is incident from right side.



Sol. : **(a)** $\frac{1}{f} = (n_{rel} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \left(\frac{3}{2} - 1\right)\left(\frac{1}{-60} - \frac{1}{-20}\right) \Rightarrow f = 60$ cm

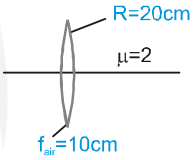
(b) $\frac{1}{f} = (n_{rel} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \left(\frac{3}{2} - 1\right)\left(\frac{1}{20} - \frac{1}{60}\right) \Rightarrow f = 60$ cm

Ex. Point object is placed on the principal axis of a thin lens with parallel curved boundaries i.e., having same radii of curvature. Discuss about the position of the image formed .

Sol. $\frac{1}{f} = (n_{rel} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = 0$ $\quad [\because R_1 = R_2]$

$\frac{1}{v} - \frac{1}{u} = 0$ or $v = u$ i.e. rays pass without appreciable bending.

Ex. Focal length of a thin lens in air, is 10 cm. Now medium on one side of the lens is replaced by a medium of refractive index μ=2. The radius of curvature of surface of lens, in contact with the medium, is 20 cm. Find the new focal length.



Sol. : Let radius of I surface be R_1 and refractive index of lens be μ . Let parallel rays be incident on the lens. Applying refraction formula at first surface

$$\frac{\mu}{v_1} - \frac{1}{\infty} = \frac{\mu - 1}{R_1} \qquad \text{...(1)}$$

At II surface $\quad \frac{2}{v} - \frac{\mu}{v_1} = \frac{2 - \mu}{-20} \qquad$ ...(2)

Adding **(1)** and **(2)**

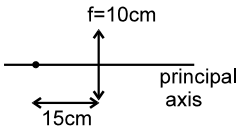
$$\frac{\mu}{v_1} - \frac{1}{\infty} + \frac{2}{v} - \frac{\mu}{v_1} = \frac{\mu - 1}{R_1} + \frac{2 - \mu}{-20}$$

$$= (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{-20}\right) - \frac{\mu - 1}{20} - \frac{2 - \mu}{20} = \frac{1}{f} \text{ (in air)} + \frac{1}{20} - \frac{2}{20}$$

$\Rightarrow \quad v = 40$ cm $\quad \Rightarrow \quad f = 40$ cm

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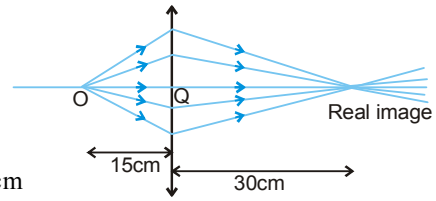
Ex. Figure shows a point object and a converging lens. Find the final image formed.



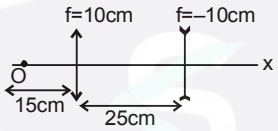
Sol. : $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

$\frac{1}{v} - \frac{1}{-15} = \frac{1}{10}$

$\frac{1}{v} = \frac{1}{10} - \frac{1}{15} = \frac{1}{30}$ $\quad v = +30$ cm



Ex. See the figure. Find the position of final image formed.



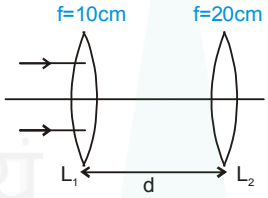
Sol. For converging lens

$u = -15$ cm, $f = 10$ cm $\quad v = \frac{fu}{f+u} = 30$ cm

For diverging lens

$u = 5$ cm $\quad f = -10$ cm $\quad v = \frac{fu}{f+u} = 10$ cm

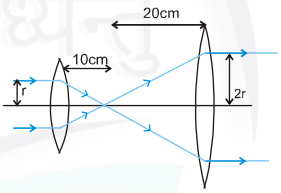
Ex. Figure shows two converging lenses. Incident rays are parallel to principal axis. What should be the value of d so that final rays are also parallel.



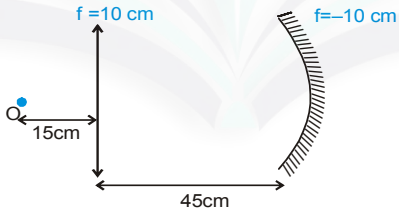
Sol. Final rays should be parallel. For this the II focus of L_1 must coincide with I focus of L_2.

$d = 10 + 20 = 30$ cm

Here the diameter of ray beam becomes wider.



Ex. See the figure. Find the position of final image formed.



Sol. For lens,

$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{v} - \frac{1}{-15} = \frac{1}{10} \Rightarrow v = +30$ cm

Hence it is object for mirror

$u = -15$ cm

$\frac{1}{v} + \frac{1}{-15} = \frac{1}{-10} \Rightarrow v = -30$ cm

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Now for second time it again passes through lens

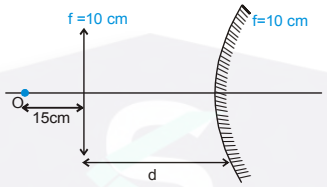
$u = -15$ cm

$v = ?$; $f = 10$ cm

$$\frac{1}{v} - \frac{1}{-15} = \frac{1}{10} \quad \Rightarrow \quad v = +30$$

Hence final image will form at a distance 30 cm from the lens towards left.

Ex. What should be the value of d so that image is formed on the object itself.

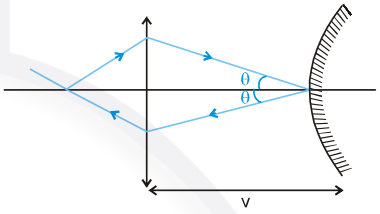


Sol. For lens :

$$\frac{1}{v} - \frac{1}{-15} = \frac{1}{10} \qquad v = +30 \text{ cm}$$

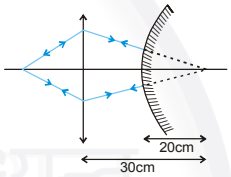
Case I :

If d = 30, the object for mirror will be at pole and its image will be formed there itself.



Case II :

If the rays strike the mirror normally, they will retrace and the image will be formed on the object itself



$\therefore$ d = 30 – 20 = 10 cm

Transverse magnification (m)

Transverse magnification (m) of (of dimension perpendicular to principal axis) is given by

$$m = \frac{v}{u}$$

If the lens is thick or/and the medium on both sides is different, then we have to apply the formula given for refraction at spherical surfaces step by step.

Ex. An extended real object of size 2 cm is placed perpendicular to the principal axis of a converging lens of focal length 20 cm. The distance between the object and the lens is 30 cm.

(i) Find the lateral magnification produced by the lens.

(ii) Find the height of the image.

(iii) Find the change in lateral magnification, if the object is brought closer to the lens by 1 mm along the principal axis.

Sol. Using $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

and $m = \frac{v}{u}$ we get $m = \frac{f}{f+u}$ .....**(A)** $\therefore \quad m = \frac{+20}{+20+(-30)} = \frac{+20}{-10} = -2$

–ve sign implies that the image is inverted.

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(ii) $\frac{h_2}{h_1} = m \qquad \therefore\ h_2 = mh_1 = (-2)\,(2) = -4$ cm

(iii) Differentiating **(A)** we get

$$dm = \frac{-f}{(f+u)^2}\,du = \frac{-(20)}{(-10)^2}\,(0.1) = \frac{-2}{100} = -.02$$

Note that the method of differential is valid only when changes are small.

Alternate method :

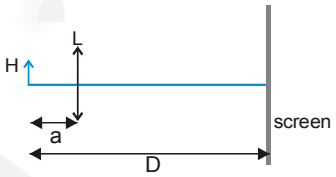
u (after displacing the object) $= -(30 + 0.1) = -29.9$ cm

Applying the formula

$$m = \frac{f}{f+u} \quad \Rightarrow \quad m = \frac{20}{20+(-29.9)} = -2.02 \quad \therefore \quad \text{change in 'm'} = -0.02.$$

Since in this method differential is not used, this method can be used for any changes, small or large.

Displacement Method to find Focal length of Converging Lens :



Fix an object of small height H and a screen at a distance D from object (as shown in figure). Move a converging lens from the object towards the screen. Let a sharp image forms on the screen when the distance between the object and the lens is 'a'. From lens formula we have

$$\frac{1}{D-a} - \frac{1}{-a} = \quad \text{or} \quad a^2 - Da + fD = 0 \quad \text{...(A)}$$

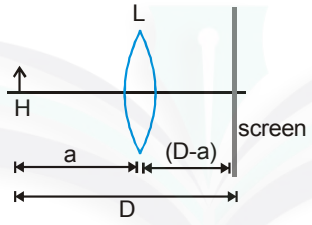
This is quadratic equation and hence two values of 'a' are possible. Call them a_1 and a_2. Thus a, and a_2 are the roots of the equation. From the properties of roots of a quadratic equation,

$\therefore \quad a_1 + a_2 = D \quad \Rightarrow \quad a_1 a_2 = fD$

Also $(a_1 - a_2) = \sqrt{(a_1+a_2)^2 - 4a_1a_2} = \sqrt{D^2 - 4fD} = d$ (suppose).

'd' physically means the separation between the two position of lens.

The focal length of lens in terms of D and d.



So, $a_1 - a_2 = \sqrt{(a_1+a_2)^2 - 4a_1a_2}$

$$\sqrt{D^2 - 4fd} = d \quad \Rightarrow \quad \boxed{f = \frac{D^2 - d^2}{4D}}$$

condition, d = 0, i.e. the two position coincide

$$f = \frac{D^2}{4D} \quad \therefore \quad \boxed{D = 4f}$$

Roots of the equation $a^2 - Da + fD = 0$, become imaginary if

$b^2 - 4ac < 0. \quad = D^2 - 4fD < 0 \quad = D(D - 4f) < 0. \quad = \boxed{D - 4f < 0}$

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for real value of a in equation $a^2 - Da + fD = 0$

$b^2 - 4ac \geq 0.$ $= D^2 - 4fD \geq 0.$

So, $D \geq 4f \Rightarrow$ $\boxed{D_{min} = 4f}$

Lateral magnification in displacement method:

if m_1 and m_2 be two magnifications in two positions (In the displacement method)

$$m_1 = \frac{v_1}{u_1} = \frac{(D - a_1)}{-a_1} \Rightarrow m_2 = \frac{v_2}{u_2} = \frac{D - a_2}{-a_2} = \frac{a_1}{-(D - a_1)}$$

So $m_1 m_2 = \frac{(D - a_1)}{-a_1} \times \frac{a_1}{-(D - a_1)} = 1.$

If image length are h_1 and h_2 in the two cases,

then $m_1 = -\frac{h_1}{H} \Rightarrow m_2 = -\frac{h_2}{H} \Rightarrow m_1 m_2 = 1$

$\therefore \frac{h_1 h_2}{H^2} = 1 \Rightarrow h_1 h_2 = H^2 \Rightarrow H = \sqrt{h_1 h_2}$

COMBINATION OF LENSES

The equivalent focal length of thin lenses in contact is given by

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} \ldots$$

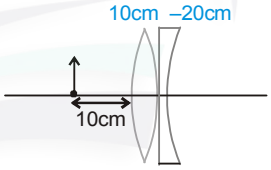
where f_1 , f_2 , f_3 are focal lengths of individual lenses.

If two converging lenses are separated by a distance d and the incident light rays are parallel to the common principal axis ,then the combination behaves like a single lens of focal length given by the relation

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$

and the position of equivalent lens is $\frac{-d\ F}{f_1}$ with respect to 2nd lens

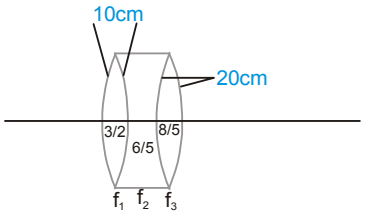
Ex. Find the lateral magnification produced by the combination of lenses shown in the figure.



Sol. $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{10} - \frac{1}{20} = \frac{1}{20} \Rightarrow f = +20$

$\therefore \frac{1}{v} - \frac{1}{-10} = \frac{1}{20} \Rightarrow \frac{1}{v} = \frac{1}{20} - \frac{1}{10} = \frac{-1}{20} = -20 \text{ cm} \quad \therefore m = \frac{-20}{-10} = 2$

Ex. Find the focal length of equivalent system.



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Sol.

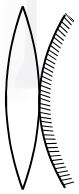
$$\frac{1}{f_1} = \left(\frac{3}{2}-1\right)\left(\frac{1}{10}+\frac{1}{10}\right) = \frac{1}{2}\times\frac{2}{10} = \frac{1}{10}$$

$$\frac{1}{f_2} = \left(\frac{6}{5}-1\right)\left(\frac{-1}{10}-\frac{1}{20}\right) = \frac{1}{5}\times\left(\frac{-30}{10\times 20}\right) = \frac{-3}{100}$$

$$\frac{1}{f_3} = \left(\frac{8}{5}-1\right)\left(\frac{1}{20}+\frac{1}{20}\right) = \frac{3}{50}$$

$$\frac{1}{f} = \frac{1}{f_1}+\frac{1}{f_2}+\frac{1}{f_3} = \frac{1}{10}+\frac{-3}{100}+\frac{3}{50} \quad f = \frac{100}{13}$$ **Ans.**

COMBINATION OF LENS AND MIRROR

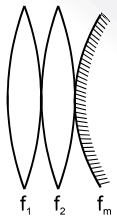


The combination of lens and mirror behaves like a mirror of focal length 'f' given by

$$\frac{1}{f} = \frac{1}{F_m} - \frac{2}{F_\ell}$$

If lenses are more than one, 'f' is given by

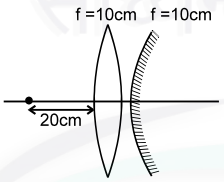
$$\frac{1}{f} = \frac{1}{F_m} - 2\left(\sum\frac{1}{f_\ell}\right)$$



For the following figure

'f' is given by $\frac{1}{f} = \frac{1}{F_m} - 2\left(\frac{1}{f_1}+\frac{1}{f_2}\right)$

Ex. Find the position of final image formed.
(The gap shown in figure is of negligible width)



Sol.

$$\frac{1}{f_{eq}} = \frac{1}{10} - \frac{2}{10} = \frac{-1}{10} \Rightarrow f_{eq} = -10 \text{ cm}$$

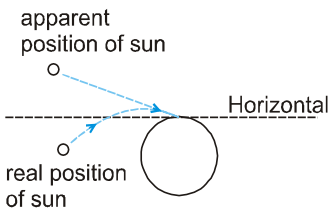
$$\frac{1}{v} + \frac{1}{-20} = \frac{1}{-10} \Rightarrow v = -20 \text{ cm}$$

Hence image will be formed on the object itself

Some interesting facts about light :

(1) The Sun Rises before it actually rises and sets after it actually sets :

The atmosphere is less and less dense as its height increase, and it is also known that the index of refraction decrease with a decrease in density. So, there is a decrease of the index of refraction with height. Due to this the light rays bend as they move in the earth's atmosphere



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(2) The Sun Is Oval Shaped At The Time Of Its Rise And Set :

The rays diverging from the lower edge of the sun have to cover a greater thickness of air than the rays from the upper edge. Hence the former are refracted more than the latter, and so the vertical diameter of the sun appears to be a little shorter than the horizontal diameter which remains unchanged.

(3) The Stars Twinkle But Not The Planets :

The refractive index of atmosphere fluctuates by a small amount due to various reasons. This causes slight variation in bending of light due to which the apparent position of star also changes, producing the effect of twinkling.

(4) Glass Is Transparent, But Its Powder Is White :

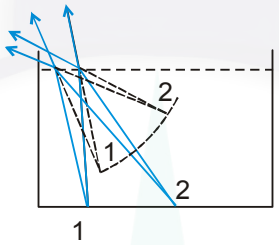
When powdered, light is reflected from the surface of innumerable small pieces of glass and so the powder appears white. Glass transmits most of the incident light and reflects very little hence it appears transparent.

(5) Greased or Oiled Paper is Transparent, But Paper is White :

The rough surface of paper diffusely reflects incident light and so it appears white. When oiled or greased, very little reflection takes place and most of the light is allowed to pass and hence it appears transparent.

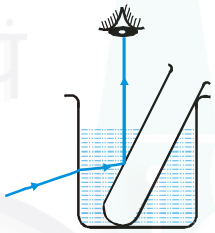
(6) An Extended Water Tank Appears Shallow At The Far End :

This is due to Total internal reflection



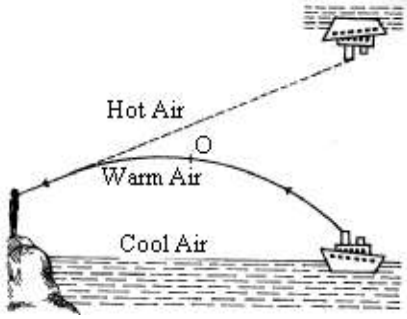
(7) A Test Tube or A Smoked Ball Immersed In Water pears Silvery White When Viewed From The Top :

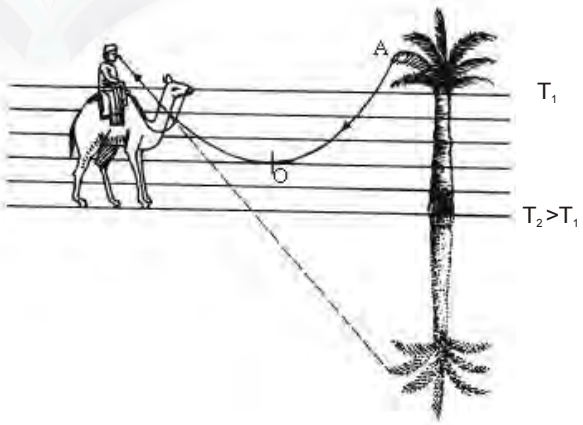
This is due to Total internal reflection



(8) Ships Hang Inverted In The Air In Cold Countries And Trees Hang Inverted Underground In Deserts:

This is due to Total internal reflection





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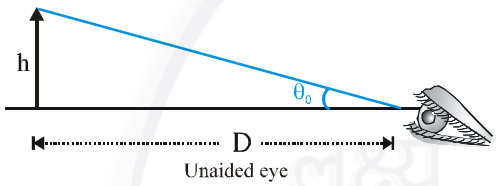
OPTICAL INSTRUMENTS

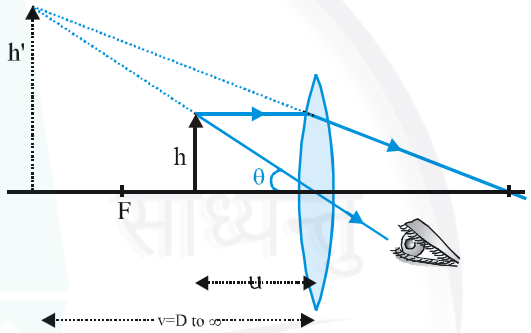
Microscopes

The apparent size of an object is determined by the size of its retinal image which, in turn, if the eye is unaided, depends upon the angle subtended by the object at the eye. When one wants to examine a small object in detail, one brings it close to the eye in order that the angle subtended and the retinal image may be as large as possible. Since the eye cannot focus sharply on objects closer than the nearer point, a given object subtends the maximum possible angle at unaided eye when placed at this point. By placing a converging lens in front of the eye, the accommodation may, in effect, be increased. The object may then be brought closer to the eye than the near point and will subtend a correspondingly larger angle. The optical instrument which is used to increase the visual angle of eye is termed as microscope.

(i) **Simple Microscope or Magnifier or Magnifying Glass :** A converging lens used for the above mentioned purpose is termed as magnifier or simple microscope. The magnifier forms a virtual image of the object and eye looks at this virtual image, i.e., we can say the object is placed in between the focus and optical centre of lens and eye close to it on the other side. Since a normal eye can focus sharply on an object anywhere between the near point and infinity, the image can be seen equally clearly if it is formed anywhere within this range.

Magnifying power or angular magnification of an optical instrument is defined as the ratio of visual angle with instrument to the maximum visual angle for clear vision when the eye is unaided (i.e., when the object is at the near point).





$$\gamma = \text{Magnifying power} = \frac{\tan\theta}{\tan\theta_0}$$

where θ and θ_0 are clearly shown in figure. $\tan\theta = \frac{h'}{v}$, where v = D to ∞ and D is the least distance of distinct vision.

$$\tan\theta_0 = \frac{h}{D}$$

$\gamma = \frac{h'}{v} \times \frac{D}{h}$, where $\frac{h'}{v} = \frac{h}{u}$, u is being the object distance from the lens.

For v = D, $\gamma = \gamma = \left[1 + \frac{D}{f}\right]$. In this situation, the magnifying power is maximum and eye is under maximum strain.

For v = ∞, $\gamma = \frac{D}{f}$. In this situation, magnifying power is minimum and eye is the least strained.

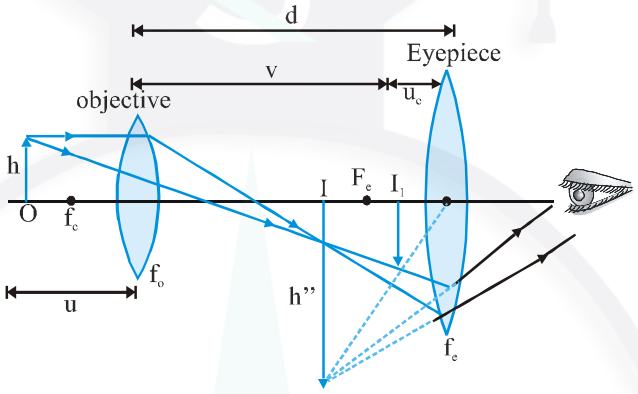
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Thus, angular magnification of a simple magnifier of focal length 10 cm is 2.5 × (as D = 25 cm), i.e., height of retinal image of an object viewed through the magnifier is 2.5 times as greater as, when viewed with unaided eye at minimum distance of distinct vision, i.e., the near point. (This is the situation when eye is the least strained, the most general case.)

- It seems that can be increased as much as desired by decreasing f, but actually it is not possible due to aberrations of simple lens.
- Simple magnifier is an essential part of most of the optical instruments (compound microscope or telescope) in the form of eyepiece or oculars.

(ii) **Compound Microscope :** When an angular magnifications higher than that attainable with a simple magnifier is desired it is necessary to use a compound microscope, simply termed as a microscope.

It consist of two convergent lenses of short focal lengths and apertures arranged coaxially. One is termed as objective while the other is eyepiece or ocular, object is placed near to objective while eyepiece is arranged in such a way that it is facing the eye. The objective has smaller aperture and focal length as compared to the eyepiece. The separation between the objective and eyepiece can be varied. Construction and ray diagram outlining the basic principle of a microscope is shown in figure.



An object O is placed just beyond the focus of the objective, whose image I_1 is formed by the objective within the focus and optical centre of eye piece.

This image I_1 is real, inverted, and enlarged w.r.t. object O. The eyepiece then forms a virtual image of the object between D and ∞. This final image is inverted, virtual, and enlarged w.r.t. the object O.

Angular magnification or magnifying power of the instrument is

$$\gamma = \frac{\tan\theta}{\tan\theta_0} \Rightarrow \tan\theta = \frac{h'}{u_e} \quad \text{and} \quad \tan\theta_0 = \frac{h}{D}$$

So, $$\gamma = \frac{h'}{h} \times \frac{D}{u_e} = m\gamma_e = -\frac{u}{v} \times \gamma_e$$

where m is the lateral magnification produced by the objective and γ is the angular magnification produced by the eyepiece.

(a) When final image is formed at the least distance of distance vision **(D)**, the eye is most strained and

$$\gamma = -\frac{v}{u}\left[1 + \frac{D}{f_e}\right] \text{ with } \quad L = v + \frac{f_e D}{f_e + D}\gamma \text{ is maximum in this mode.}$$

(b) In general, as f_0 is small and object is close to objective first focus, i.e., u; f_0 and L; v as u_e << v, so for normal adjustment [i.e., when final image is at for point] $\gamma; \frac{L}{f_0} \times \frac{D}{f_e}$

(c) In this case, γ is –ve. Hence, the final image is inverted.

(d) In normal adjustment, if eyepiece and objective lenses are interchanged, the angular magnification remains unchanged.

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(e) Due to small apertures of lenses, spherical aberration is decreased to a great extent.

(f) F_0 is taken smaller than f_e to increase the field of view and to increase brightness of the image.

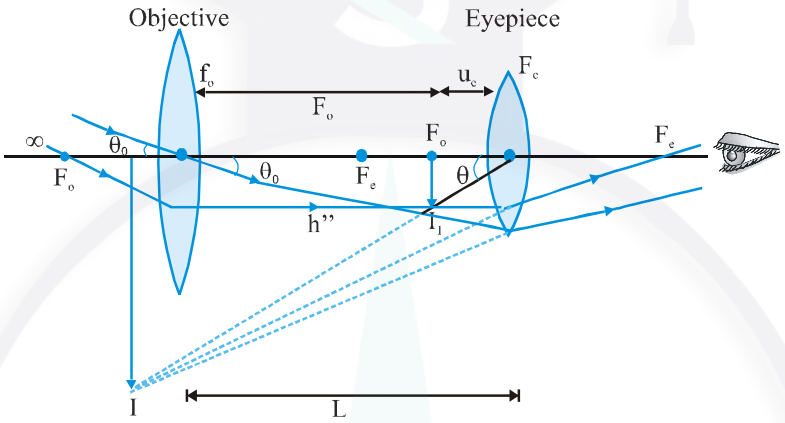
(g) With respect to microscope, the minimum distance between two lines at which they are just distinct is called limit of resolution (Δx) and the reciprocal of limit of resolution is called resolving power.

$$\text{Resolving Power} = \frac{1}{\Delta x} \propto \frac{1}{\lambda}$$

Telescopes

(i) **Refracting Telescope :** The optical system of a refracting telescope is essentially the same as that of a compound microscope. In both instruments, the image formed by the objective is viewed through an ocular (eyepiece), the difference is the telescope is used to examine large objects at large distance while microscope is used to examine small objects close at hands.

(ii) **Astronomical Telescope :** The working diagram of astronomical telescope is as shown in figure :



(a) While seeing the object through telescope, the object is between ∞ and 2F of the objective which forms real, inverted, and diminished image within the focus and optical centre of eyepiece which then forms its virtual, erect (w.r.t. intermediate image), and magnified image at a distance between D to ∞ from the eye. This means final image is inverted (w.r.t. object), at a distance between D to ∞ from the eye.

(b) In a telescope, the aperture and focal length of objective are greater than that of eyepiece.

(c) Magnifying power, $\gamma = \frac{\tan\theta}{\tan\theta_0} = -\frac{y/u_e}{y/f_0} = -\frac{f_0}{u_e}$

(d) In general case, final image is formed at ∞ and hence $\gamma = -\frac{f_0}{f_e}$. In this case, eye is the least strained and magnification power is minimum with length of tube, $L = f_0 + f_e$.

(e) In normal adjustment (i.e., final image is at ∞), to have large magnifying power, f_0 must be as large as practically possible while as to be kept small.

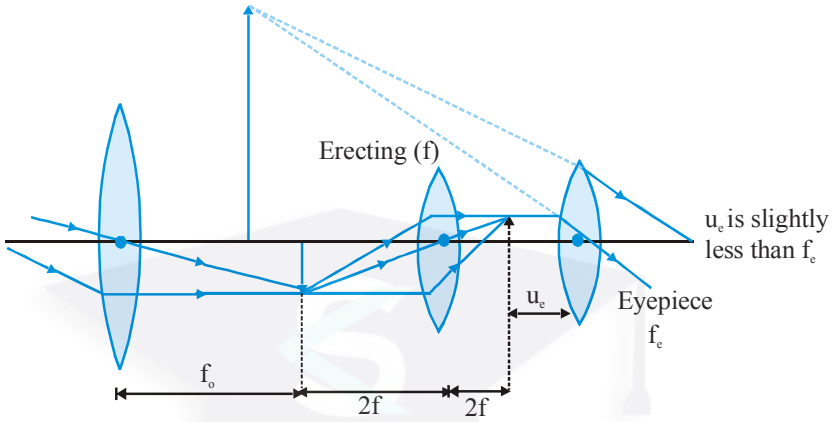
(f) Resolving power of a telescope depends on the aperture of objective and wavelength of light.

$$\text{RP} \propto \frac{\text{Aperture of objective}}{\text{Wavelength}}$$

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Terrestrial Telescope

While an inverted image is not a disadvantage if the instrument is to be used for astronomical observation, it is desirable that a terrestrial telescope shall form an erect image. This can be accomplished by using an erecting lens in the astronomical telescope.



Magnifying power for terrestrial telescope is,

$$\gamma_e = \frac{f_0}{f_e}$$ [for relaxed eye)

Length of tube, $L = f_0 + 4f + f_e$

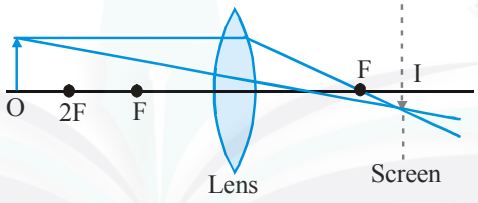
Reflecting Telescope

It is an astronomical telescope, in which objective lens is replaced by a concave mirror.

The reflecting telescope is cheap, light, and portable as compared to astronomical telescope.

Lens Camera

In lens camera, the image of the object formed by a converging lens is allowed to fall on a screen (in figure). In camera, the aperture of lens and its separation from film/screen can be adjusted. Generally, the object is placed between F and 2F and hence the image forms between F and 2F which is real (hence can be taken on film), inverted, and diminished.



During photographing of the object, first image is focused on the film by adjusting the separation between film and lens. After this, the film is exposed to light through a shutter for a given time. How much energy is incident on the film also depends on the aperture of the lens.

For proper exposure of a particular film, a definite amount of energy is incident on the film. Let the film has been exposed for time t and the intensity of light is I, then $I \times A \times$ = constant. Where A is light transmitting area of the lens.

$A = d^2$, where d is the aperture of lens.

So, Id^2t = constant

The ratio of focal length to aperture of lens is called f - number of the camera.

$$\text{f - number} = \frac{\text{Focal length}}{\text{Aperture}}$$

For a given camera, f-number gives us the idea about aperture.

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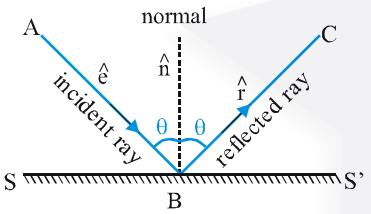
tips& formulas

REFLECTION

1. Law of Reflection :

The incident ray (AB), the reflected ray (BC) and normal (NB) to the surface (SS') of reflection at the point of incidence **(B)** lie in the same plane. This plane is called the plane of incidence (also plane of reflection).

The angle of incidence (the angle between normal and the incident ray) and the angle of reflection (the angle between the reflected ray and the normal) are equal $\boxed{\angle i = \angle r}$



In vector form $\boxed{\hat{r} = \hat{e} - 2(\hat{e}.\hat{n})\hat{n}}$

2. Object :

Real : Point from which rays actually diverge.

Virtual : Point towards which rays appear to converge

3. Image :

Image is decided by reflected or refracted rays only. The point image for a mirror is that point towards which the rays reflected from the mirror, actually converge (real image).

OR

From which the reflected rays appear to diverge (virtual image).

4. Characteristic of Reflection by a Plane Mirror :

The size of the image is the same as that of the object.

For a real object the image is virtual and for a virtual object the image is real.

For a fixed incident light ray, if the mirror be rotated through an angle θ the reflected ray turns through an angle 2θ in the same sense.

5. Number of images (n) in inclined mirror

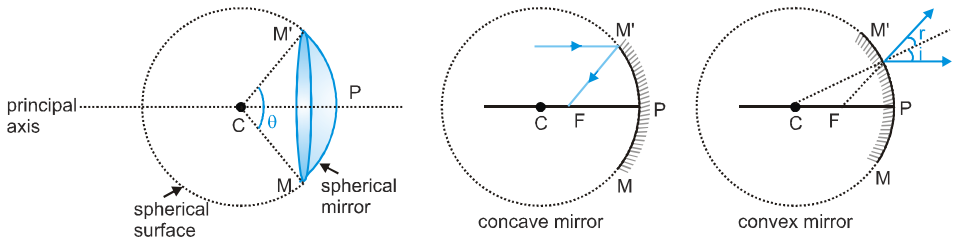
Find $\frac{360}{\theta} = m$

(i) If m even, then n = m – 1, for all position of object.

(ii) If m odd, then n = m, If object not on bisector and n = m – 1, If object at bisector

(iii) If m fraction then n = nearest even number

6. Spherical Mirrors



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7. Paraxial Rays :

Rays which forms very small angle with axis are called paraxial rays. All formulae are valid for paraxial ray only.

8. Sign Convention :

9. We follow cartesian co-ordinate system convention according to which the pole of the mirror is the origin.

10. The direction of the incident rays is considered as positive x-axis. Vertically up is positive y-axis.

11. All distance are measured from pole.

Note : According to above convention radius of curvature and focus of concave mirror is negative and of convex mirror is positive.

12. MIRROR FORMULA : $\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$

f = x-coordinate of focus u = x-coordinates of object

v = x-coordinates of image **Note :** Valid only for paraxial rays.

13. Transverse Magnification : $m=\frac{h_2}{h_1}=-\frac{v}{u}$

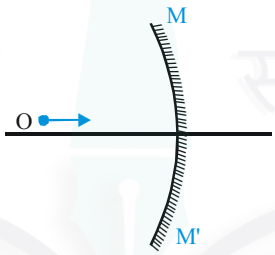
h_2 = y co-ordinate of image h_1 = y co-ordinate of the object

(both perpendicular to the principle axis of mirror)

Longitidinal magnification : m_2 $m_2=\frac{\text{Length of image}}{\text{Length of object}}$

for small objects $m_2=-m_t^2$ m_t = transverse magnification

14. Velocity of Image of Moving Object (Spherical Mirror)



When an object is coming from infinite towards the focus of concave mirror

$\because \frac{1}{v}+\frac{1}{u}=\frac{1}{f}$ $\therefore -\frac{1}{v^2}+\frac{dv}{dt}-\frac{1}{u^2}\frac{du}{dt}=0 \Rightarrow \vec{v}_{IM}=-\frac{v^2}{u^2}\vec{v}_{ox}=-m^2\vec{v}_{OM}$

$v_{IM}=\frac{dv}{dt}$ = velocity of image with respect to mirror

$v_{OM}=\frac{du}{dt}$ = velocity of object with respect to mirror

15. NEWTON'S FORMULA :

Applicable to a pair of real object and real image position only. They are called conjugate positions or foci, X_1, X_2 are the distance along the principal axis of the real object and real image respectively from the principal focus.

$$\boxed{X_1X_2=f^2}$$

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16. **OPTICAL POWER :** Optical power of a mirror (in Diopters) $= -\frac{1}{f}$

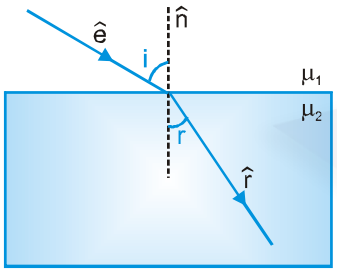
where f = focal length (in meters) with sign.

REFRACTION - PLANE SURFACE

17. **Laws of Refraction (At any Refracting Surface)**

18. **Laws of Refraction**

(a) Incident ray, refracted ray and normal always lie in the same plane



In vector form $\boxed{(\hat{e}\times\hat{n}).\hat{r}=0}$

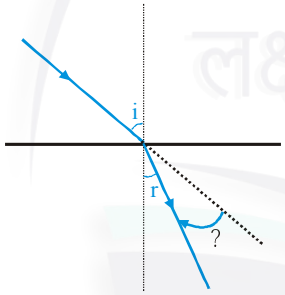
(b) The product of refractive index and sine of angle of incidence at a point in a medium is constant $\mu_1 \sin i = \mu_2 \sin r$ (Snell's law)

Snell's law :

$\boxed{\frac{\sin i}{\sin r} = {}_1n_2 = \frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}}$ In vector form $\boxed{\mu_1|\hat{e}\times\hat{n}| = \mu_2|\hat{r}\times\hat{n}|}$

Note : Frequency of light does not change during refraction.

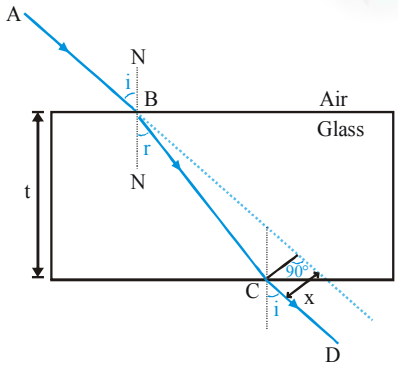
19. **Deviation of a ray due to refraction**



angle of deviation, $\delta = i - r$

20. **Refraction Through A parallel Slab :**

Emerged ray is parallel to the incident ray, if medium is same on both sides.

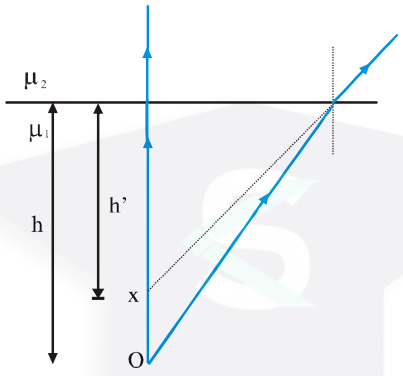


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Lateral shift $x = \frac{t\sin(i-r)}{\cos r}$; t = thickness of slab

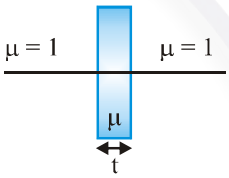
Note : Emerged ray will not be parallel to the incident ray if the medium on both the sides are different.

21. Apparent Depth of Submerged Object : (h' < h)



For near normal incidence $h' = \frac{\mu_2}{\mu_1}h$

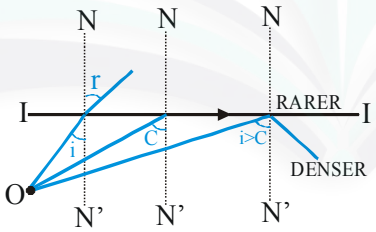
Apparent shift $= t\left(1-\frac{1}{\mu}\right)$



always in direction of incidence ray.

Note : h and h' are always measured from surface.

22. Critical Angle & Total Internal Reflection (TIR)



Conditions of TIR

Ray is going from denser to rarer medium

Angle of incidence should be greater than the critical angle (i > C).

Critical angle $C = \sin^{-1}\frac{n_r}{n_i}$

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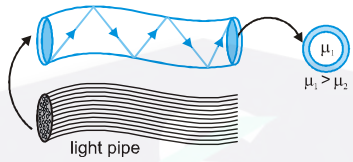
23. Some Illustrations of Total Internal Reflection

(a) Sparking of diamond

The sparking of diamond is due to total internal reflection inside it. As refractive index for diamond is 2.5 so C = 24°. Now the cutting of diamond are such that i > C. TIR will take place again inside it. The light which beams out from a few places in some specific directions makes it sparkle.

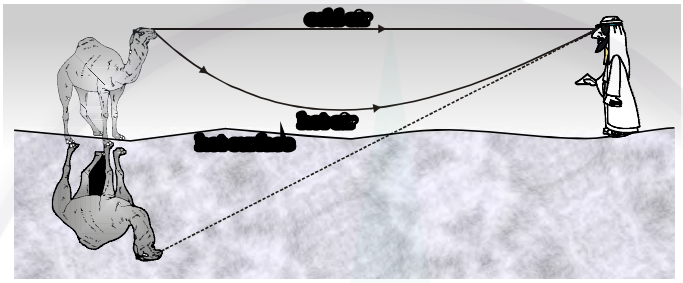
(b) Optical Fibre

In it light through multiple total internal reflections is propagated along the axis of a glass fibre of radius of few microns in which index of refrection of core is greater than that of surroundings (cladding)

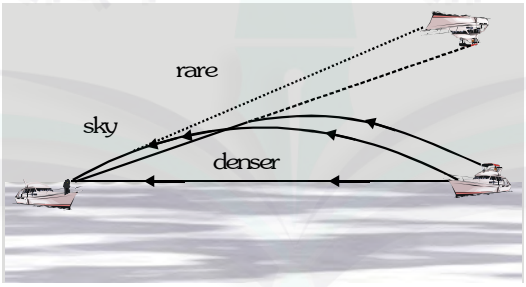


(iii) Mirage and looming

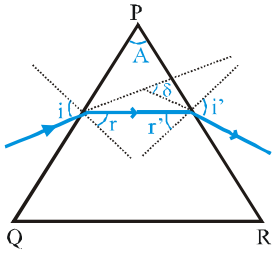
Mirage is caused by total internal reflection in deserts where due to heating of the earth, refractive index of air near the surface of earth become lesser than above it. Light from distant objects reaches the surface of earth with $i > \theta_C$ so that TIR will take place and we see the image of an object along with the object as shown in figure.



Similar to 'mirage' in deserts, in polar regions 'looming' takes place due to TIR. Here μ decreases with height and so the image of an object is formed in air if (i > C) as shown in figure.



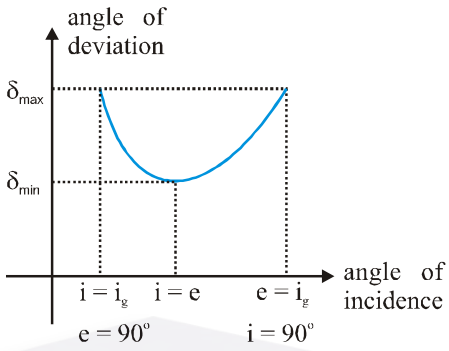
24. Refraction Through Prism :



(a) $\delta = (i + i') - (r + r')$ **(b)** $r + r' = A$

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(c) Variation of δ versus i



(d) There is one and only one angle of incidence for which the angle of deviation is minimum. When $\delta = \delta_m$ then $i = i'$ & $r = r'$, the ray passes symmetrically about the prism, & then $n = \dfrac{\sin\left[\dfrac{A+\delta m}{2}\right]}{\sin\left[\dfrac{A}{2}\right]}$, where n = absolute R.I of glass

Note : When the prism is dipped in a medium then n = R.I. of glass w.r.t. medium.

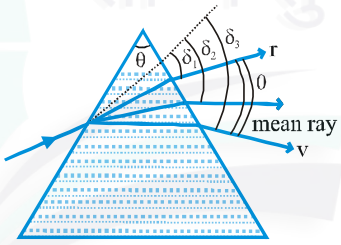
For a thin prism ($A \leq 10^o$) ; $\delta = (n-1)A$

25. **Dispersion of Light :** The angular splitting of a ray of white light into a number of components when it is refracted in a medium other than air is called Dispersion of Light.

26. **Angle of Dispersion :** Angle between the rays of the extreme colours in the refracted (dispersed) light is called Angle of Dispersion. $\theta = \delta_v - \delta_r$

27. Dispersive power (ω) of the medium of the material of prism.

$$\omega = \frac{\text{angular dispersion}}{\text{deviation of mean ray (yellow)}}$$



For small angled prism ($A \leq 10^o$) ; $\omega = \dfrac{\delta_v - \delta_R}{\delta_y} = \dfrac{n_v - n_R}{n-1}$; $n = \dfrac{n_v + n_R}{2}$

n_v, n_R & n are R.I. of material for violet, red & yellow colours respectively

28. **Combination of Two Prism :**

(a) **Achromatic Combination :** It is used for deviation without dispersion. Condition for this $(n_v - n_r)A = -(n'_v - n'_r)A'$.

Net mean deviation $= \left[\dfrac{n_v + n_R}{2} - 1\right]A - \left[\dfrac{n'_v + n'_R}{2} - 1\right]A'$ or $\omega\delta + \omega'\delta' = 0$ where ω, ω' are dispersive power for the two prism & δ, δ' are the mean deviation.

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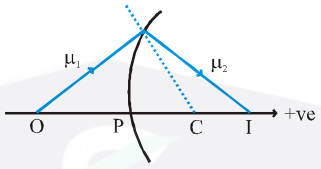
(b) **Direct Vision Combination :** It is used for producing dispersion without deviation condition for this

$$\left[\frac{n_v + n_R}{2} - 1\right] A = \left[\frac{n'_v + n'_R}{2} - 1\right] A'$$

Net angle of dispersion = $(n_v - n_r)\, A - (n'_v - n'_r)\, A'$

REFRACTION AT SPHERICAL SURFACE

(a) $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$



v, u & R are to be kept with sign as

v = PI

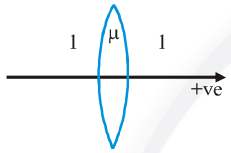
u = – PO

R = PC

(Note : Radius is with sign)

(b) $m = \frac{\mu_1 v}{\mu_2 u}$

29. Lens Formula :

(a) 

$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ **(b)** $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ **(c)** $m = \frac{v}{u}$

30. Power of Lenses :

Reciprocal of focal length in meter is known as power of lens.

SI unit : dioptre **(D)** **Power of lens :** $P = \frac{1}{f(m)} = \frac{100}{f(cm)}$ dioptre

31. Combination of Lenses

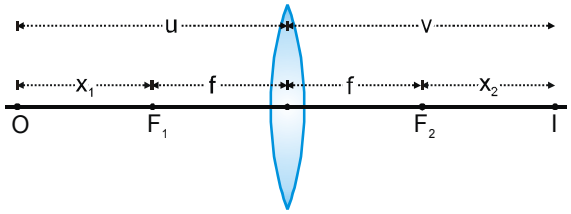
Two thin lens are placed in contact to each other



Power of combination, $P = P_1 + P_2 \Rightarrow \frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$

Using sign convention when solve numericals

32. Newton's Formula



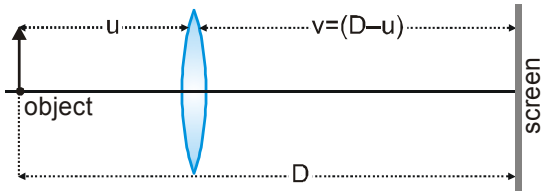
$\boxed{f = \sqrt{x_1 x_2}}$

x_1 = distance of object from focus; x_2 = distance of image from focus

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33. Displacement Method

It is used for determination of focal length of convex lens in laboratory. A thin convex lens of focal length f is placed between an object and a screen fixed at a distance D apart.



(a) For D < 4f : u will be imaginary hence physically no position of lens is possible

(b) For D = 4f : $u = \frac{D}{2} = 2f$ so only one position of lens is possible and since $v = D - u = 4f - 2f = u = 2f$

(c) For D > 4f : $u_1 = \frac{D - \sqrt{D(D-4f)}}{2}$ and $u_2 = \frac{D + \sqrt{D(D-4f)}}{2}$

So there are two positions of lens for which real image will be formed on the screen.

For two positions of the lens distances of object and image are interchangeable

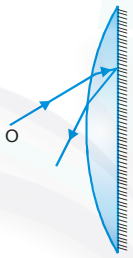
So $u_1 = \frac{D-x}{2} = v_2$ and $v_1 = \frac{D+x}{2} = u_2$

$m_1 = \frac{I_1}{O} = \frac{v_1}{u_1} = \frac{D+x}{D-x}$ and $m_2 = \frac{I_2}{O} = \frac{v_2}{u_2} = \frac{D-x}{D+x}$

Now $m_1 \times m_2 = \frac{D+x}{D-x} \times \frac{D-x}{D+x} \Rightarrow \frac{I_1 I_2}{O^2} = 1 \Rightarrow \boxed{O = \sqrt{I_1 I_2}}$

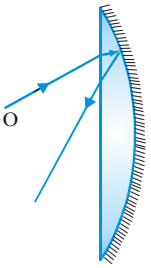
34. Silvering of one surface of lens [use $P_{eq} = 2P_\ell + P_m$]

(i) When plane surface is silvered



$F = \frac{R}{2(\mu - 1)}$

When convex surface is silvered



$F = \frac{R}{2\mu}$

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OPTICAL INSTRUMENTS

35. For Simple microscope

(a) Magnifying power when image is formed at D : MP = 1 + D/f

(b) When image is formed at infinity MP = D/f

36. For Compound microscope : $MP = \frac{v_0}{u_0}\left(\frac{D}{u_e}\right)$

(a) Magnifying power when final image is formed at D, $MP = -\frac{v_0}{u_0}\left(1+\frac{D}{f_e}\right)$

(b) Tube length $L = v_0 + |u_e|$

(c) When final image is formed at infinity $MP = -\frac{v_0}{u_0}\times\frac{D}{f_e}$ and $v_0 + f_e$

37. Astronomical Telescope : $MP = \frac{f_0}{u_e}$

(a) Magnifying power when final image is formed at D : $MP = -\frac{f_0}{f_e}\times\left(1+\frac{f_e}{D}\right)$

(b) Tube length : $L = f_0 + |u_e|$

(c) When final image is formed at infinity : $MP = -\frac{f_0}{f_e}$ and $L = f_0 + f_e$

38. For terrestrial telescope : $MP = \frac{f_0}{f_e}$ $L = f_0 + f_e + 4f$

39. For Galilean telescope : $MP = \frac{f_0}{f_e}$ & $L = f_0 - f_e$

40. Lens camera : Time of exposure $\propto \frac{1}{(\text{aperture})^2}$, $f-\text{number} = \frac{\text{focal length}}{\text{aperture}}$

41. For myopia or short-sightedness or near sightedness $\frac{1}{\text{F.P.}} - \frac{1}{\text{object}} = \frac{1}{f} = P$

42. For long-sightedness or hypermetropia $\frac{1}{\text{N.P.}} - \frac{1}{\text{object}} = \frac{1}{f} = P$

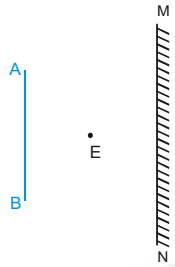
43. Limit of resolution for microscope $= \frac{1.22\lambda}{2\mu\sin\theta} = \frac{1}{\text{resolving power}}$

44. Limit of resolution for telescope $= \frac{1.22\lambda}{a} = \frac{1}{\text{resolving power}}$

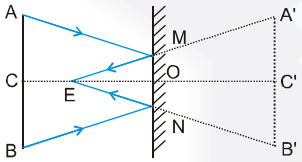
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SOLVED EXAMPLE

Ex.1 Figure shows an object AB and a plane mirror MN placed parallel to object. Indicate the mirror length required to see the image of object if observer's eye is at E.



Sol. Required length of mirror = MN.



Δ MNE & ΔA'B'E are similar

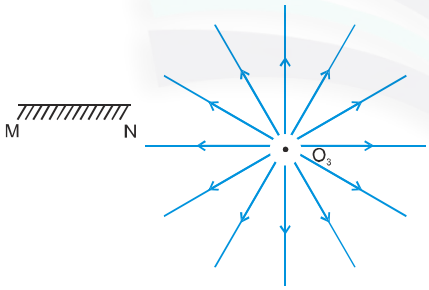
$$\frac{MN}{OE} = \frac{A'B'}{C'E}$$

$$\Rightarrow MN = \frac{A'B'}{2} = \frac{AB}{2}.$$

Ex.2 See the following figure. Which of the objects shown in figure will not form its image in the mirror.



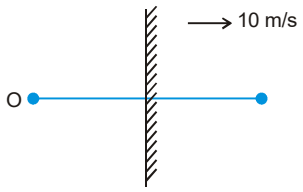
Sol.



No ray from O_3 is incident on reflecting surface of the mirror, so its image is not formed.

Ex.3 An object is kept fixed in front of a plane mirror which is moved by 10 m/s away from the object, find the velocity of the image.

Sol. $\vec{V}_{IM} = -\vec{V}_{OM}$

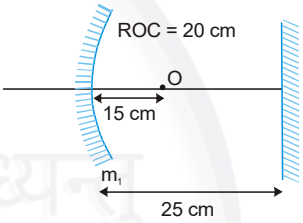


$$\vec{V}_{I,G} - \vec{V}_{M,G} = -\vec{V}_{O,G} + \vec{V}_{M,G}$$

$$\Rightarrow \vec{V}_{M,G} = \frac{\vec{V}_{I,G} + \vec{V}_{O,G}}{2} = \frac{\vec{V}_{I,G}}{2} \quad (\because \vec{V}_{O,G} = 0)$$

$$\frac{\vec{V}_{I,G}}{2} = 10\,\hat{i}\ \text{m/s} \Rightarrow \vec{V}_{I,G} = 20\,\hat{i}\ \text{m/s}$$

Ex.4 Find the position of final image after three successive reflections taking first reflection on m_1



Sol. **1st reflection at m_1**

u = – 15cm

f = –10 cm

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} = \frac{-3+2}{30} = -\frac{1}{30}$$

v = – 30 cm

2nd reflection at plane mirror :

u = 5 cm

v = – 5 cm

For III reflection on curved mirror again :

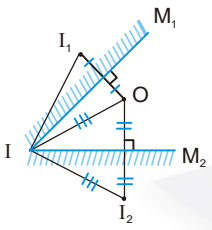
u = – 20 cm

$$v = \frac{uf}{u-f} = \frac{(-20)\times(-10)}{-20+10} = \frac{200}{-10} = -20\ \text{cm}$$

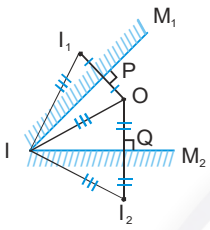
Image is 20 cm right of m_1

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Ex.5 Figure shows two inclined plane mirrors M_1 and M_2 and an object O. Its images formed in mirrors M_1 and M_2 individually are I_1 and I_2 respectively. Show that I_1 and I_2 and O lie on the circumference of a circle with centre at I. [This result can be extended to show that all the images will also lie on the same circle. Note that this result is independent of the angle of inclination of mirrors.]. I is the point of intersection of the mirrors.



Sol. Clearly,



ΔIOQ and $\Delta I\, I_2 Q$ are congruent

and ΔIOP and ΔII_1P are congruent

So, $II_1 = IO$ and $IO = II_2$

Hence, $II_1 = IO = II_2$

So, I_1 and I_2 and O lie on the circumference of a circle with centre I.

Ex.6 A small statue has a height of 1 cm and is placed in front of a spherical mirror . The image of the statue is inverted and is 0.5cm tall and located 10 cm in front of the mirror. Find the focal length and nature of the mirror.

Sol. We have $m = \frac{h_2}{h_1} = -\frac{0.5}{1} = -0.5$

$v = -10$ cm (real image)

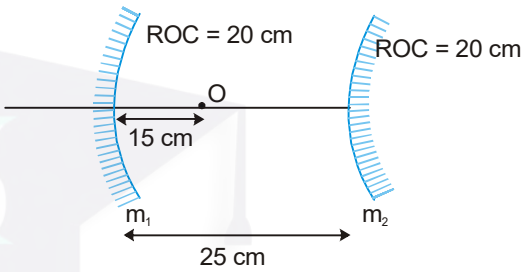
But $m = \frac{f - v}{f}$ $-0.5 = \frac{f + 10}{f} \Rightarrow f = \frac{-20}{3}$ cm So, concave mirror. **Ans.**

Ex.7 A coin is placed 10 cm in front of a concave mirror . The mirror produces a real image that has diameter 4 times that of the coin. What is the image distance.

Sol. $m = \frac{d_2}{d_1} = -\frac{v}{u} \Rightarrow -4 = -\frac{v}{u}$

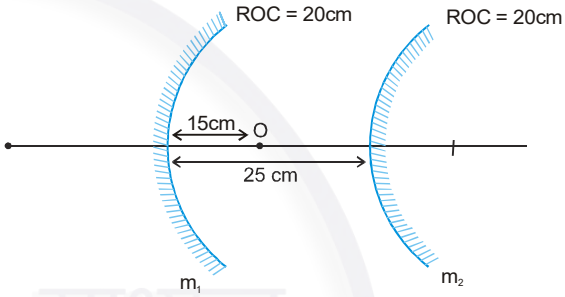
$\Rightarrow v = 4u = 4 \times (-10) = -40$ cm

Ex.8 Find the position of final image after three successive reflections taking first reflection on m_1.



Sol. 1st reflection at mirror m_1 :

$u = -15$ cm, $f = -10$cm



$\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$

$\therefore \quad v = \frac{uf}{u - f} = \frac{(-15) \times (-10)}{(-15) + 10} = \frac{150}{-5}$ cm $= -30$ cm.

Thus, image is formed at a point 5 cm right of m_2 which will act as an object for the reflection at m_2

For 2nd reflection at m_2

$u = 5$ cm, $f = 10$ cm

$v = \frac{uf}{u - f} = \frac{5 \times 10}{5 - 10} = \frac{50}{-5} = -10$ cm.

3rd reflection at m_1 again.

$u = -15$ cm $\quad f = -10$ cm

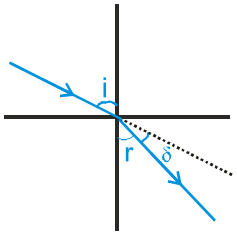
$v = \frac{uf}{u - f} = \frac{-15 \times (-10)}{(-15) + 10} = -30$ cm. **Ans.**

Image is formed at 30 cm right of m_1

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Ex.9 A light ray deviates by 30^0 (which is one third of the angle of incidence) when it gets refracted from vacuum to a medium. Find the refractive index of the medium.

Sol. $\delta = i - r$



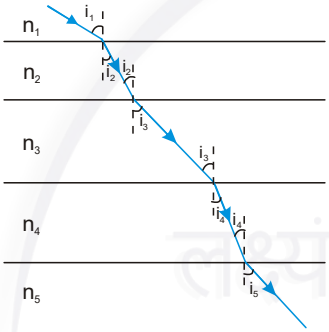
$\Rightarrow \quad \frac{i}{3} = i - r = 30^o. \qquad \Rightarrow i = 90^o$

$\Rightarrow \quad 2i = 3r$

$\therefore \quad r = \frac{2i}{3} = 60^o$

So, $\mu = \frac{\sin 90^o}{\sin 60^o} = \frac{1}{\sqrt{3}/2} = \frac{2}{\sqrt{3}}$ **Ans.**

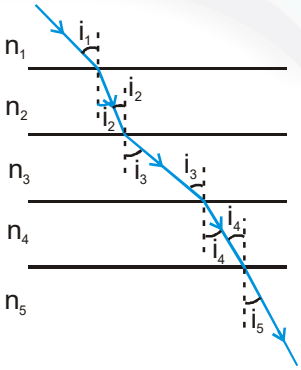
Ex.10 A light passes through many parallel slabs one by one as shown in figure.



Prove that $n_1 \sin i_1 = n_2 \sin i_2 = n_3 \sin i_3 = n_4 \sin i_4 = ...$ **[Remember this].** Also prove that if $n_1 = n_4$ then light rays in medium n_1 and in medium n_4 are parallel.

Sol. We have,

$\frac{\sin i_1}{\sin i_2} = \frac{n_2}{n_1}$



$\Rightarrow \quad n_1 \sin i_1 = n_2 \sin i_2 \qquad$ ....(i)

Similarly $n_2 \sin i_2 = n_3 \sin i_3$

so on

So, $\quad n_1 \sin i_1 = n_2 \sin i_2 = n_3 \sin i_3 = ...$

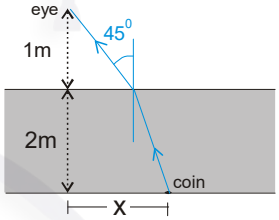
$n_1 \sin i_1 = n_4 \sin i_4 \Rightarrow \sin i_1 = \sin i_4$

$(\therefore n_1 = n_2)$

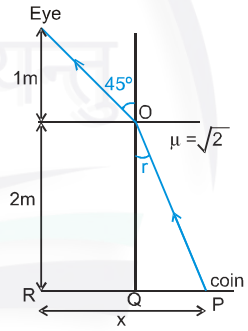
So, $i_1 = i_4$

Hence, light rays in medium n_1 and in medium n_4 are parallel.

Ex.11 A coin lies on the bottom of a lake 2m deep at a horizontal distance x from the spotlight (a source of thin parallel beam of light) situated 1 m above the surface of a liquid of refractive index $\mu = \sqrt{2}$ and height 2m. Find x.



Sol. $\sqrt{2} = \frac{\sin 45^o}{\sin r}$



$\Rightarrow \sin r = \frac{1}{2} \qquad \Rightarrow \qquad r = 30^o$

$x = RQ + QP$

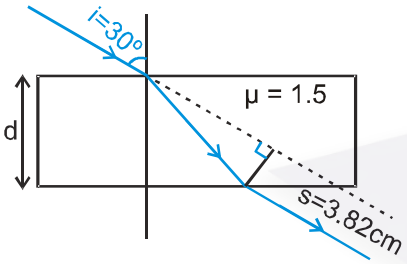
$= 1m + 2\tan 30^\circ m = \left(1 + \frac{2}{\sqrt{3}}\right) m$ **Ans.**

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Ex.12 A ray of light falls at an angle of 30° onto a plane-parallel glass plate and leaves it parallel to the initial ray. The refractive index of the glass is 1.5. What is the thickness d of the plate if the distance between the rays is 3.82 cm?

[Given : $\sin^{-1}\left(\frac{1}{3}\right) = 19.5°$; $\cos 19.5° = 0.94$; $\sin 10.5° = 0.18$]

Sol.



Using $s = \frac{d\sin(i-r)}{\cos r}$

$\Rightarrow \quad d = \frac{3.82 \times \cos r}{\sin(30° - r)}$ .....(1)

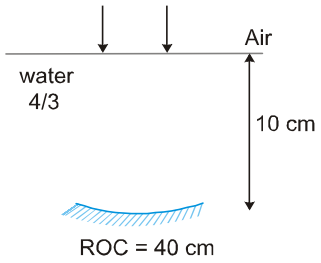
Also, $1.5 = \frac{\sin 30°}{\sin r} \Rightarrow \sin r = \frac{1}{3}$

So, $r = 19.5°$

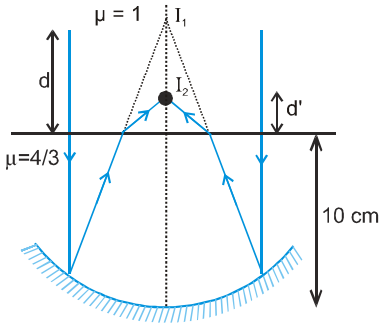
So, $d = \frac{3.82 \times \cos 19.5°}{\sin(30° - 19.5°)} = \frac{3.82 \times 0.94}{\sin 10.5°}$

$= \frac{3.82 \times 0.94}{0.18} = 19.948\,\text{cm} \approx 0.2\,\text{m}$

Ex.13 A concave mirror is placed inside water with its shining surface upwards and principal axis vertical as shown. Rays are incident parallel to the principal axis of concave mirror. Find the position of final image.



Sol. We have,



$u = -\infty$, $f = -20\,\text{cm}$

So, $v = -20\,\text{cm}$

So, $d = 10\,\text{cm}$

$\therefore \quad d' = \frac{d}{\mu_{rel}} = \frac{10\ \text{cm}}{4/3}$

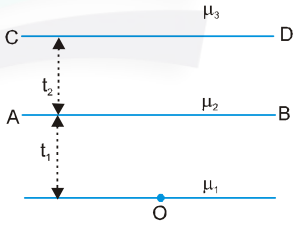
$= \frac{30}{4}\,\text{cm} = 7.5\,\text{cm}$ **Ans.**

Ex.14 An object lies 90 cm in air above water surface .It is viewed from water nearly normally. Find the apparent height of the object.

Sol. $d' = \frac{d}{n_{rel}} = \frac{d}{n_i / n_r} = \frac{90\,\text{cm}}{\frac{1}{4/3}} = \frac{90 \times 4}{3}\,\text{cm}$

$= 120\,\text{cm}$ **Ans.**

Ex.15 Find the apparent depth of object O below surface AB, seen by an observer in medium of refractive index μ_2

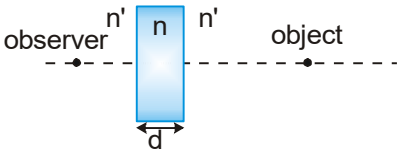


Sol. $d_{app.} = \frac{t_1}{\mu_1 / \mu_2}$

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Ex.16 Prove that the shift in position of object due to parallel slab is given by shift $= d\left(1-\frac{1}{n_{rel}}\right)$

where $n_{rel} = \frac{n}{n'}$.



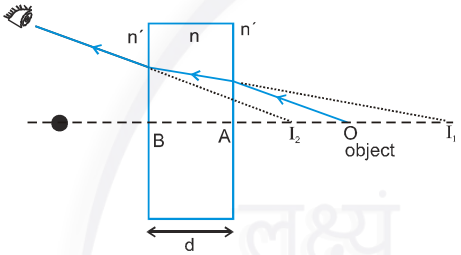
Sol. Because of the ray refraction at the first surface, the image of O is formed at I_1. For this refraction, the real depth is AO = x and apparent depth is AI_1.

Thus : $AI_1 = \frac{AO}{n_i / n_r} = \frac{AO}{n'/n} = \frac{n(AO)}{n'}$.

The point I_1 acts as the object for the refraction of second surface. Due to this refraction, the image of I_1 is formed

at I_2. Thus,

$$BI_2 = \frac{(BI_1)}{(n/n')} = \frac{n'}{n}(BI_1)$$



$= n'/n\,(AB + AI_1)$

$= \frac{n'}{n}\left[d + \frac{n}{n'}(AO)\right] = \frac{n'}{n}d + AO.$

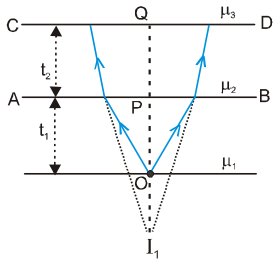
Net shift $= OI_2 = BO - BI_2$

$= d + (AO) - \frac{n'}{n}d - AO = d\left(1 - \frac{n'}{n}\right)$

$= d\left(1 - \frac{1}{n_{rel}}\right)$ where $n_{rel} = \frac{n}{n'}$. **Ans.**

Ex.17 In above question what is the depth of object corresponding to incident rays striking on surface CD in medium μ_2.

Sol. Depth of the object corresponding to incident

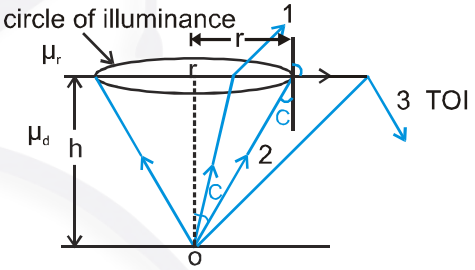


ray striking on the surface CD in medium $\mu_2 = t_2 + PI_1$

$= t_2 + \frac{t_1}{\mu_1 / \mu_2}$

Ex.18 Find the radius of circle of illuminance, if a luminous object is placed at a distance h from the interface in denser medium.

Sol.



$\tan C = \frac{r}{h}$. $\therefore$ $r = h \tan C$.

But $C = \sin^{-1}\frac{1}{(\mu_d / \mu_r)}$

So, $r = h \tan\left[\sin^{-1}\frac{1}{(\mu_d / \mu_r)}\right]$

$= h.\frac{\mu_r}{\sqrt{\mu_d^2 - \mu_r^2}}$

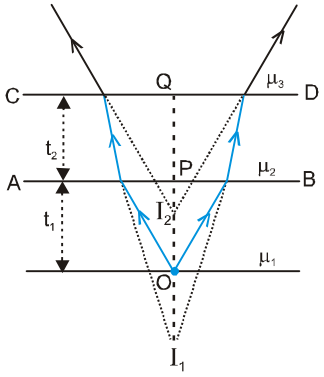
Ex.19 In above question if observer is in medium μ_3, what is the apparent depth of object seen below surface CD.

Sol. If the observer is in medium μ_3. apparent depth below surface CD $= QI_2$.

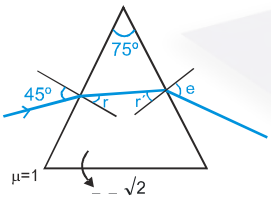
$= \sum \frac{t_i}{(n_{rel})_i}$

$= \frac{t_2}{\mu_2 / \mu_3} + \frac{t_1}{\mu_1 / \mu_3}$

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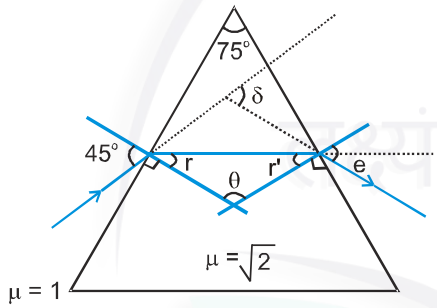
Ex.20 Find r, r′, e, δ for the case shown in figure.



Sol. Here $\theta = 180° - 75° = 105°$

$$\sin 45° = \sqrt{2}\sin r$$

$$\therefore r = \sin^{-1}\frac{1}{2} = 30°.$$



$r' = 180° - (r + \theta) = 180° - 30° - 105° = 45°$

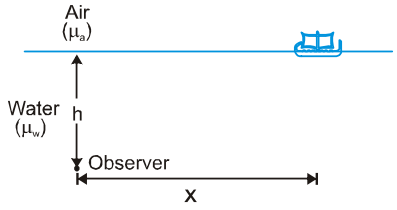
$\sin e = \sqrt{2}\sin r'$

$\therefore \sin e = \sqrt{2} \times \sin 45° = 1$

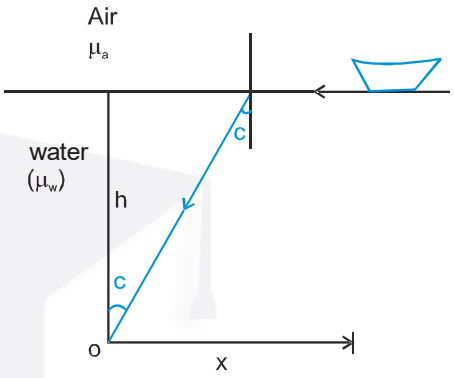
$\therefore$ $\boxed{e = 90°}$

So, $\delta = i + e - A = 45° + 90° - 75° = 60°.$

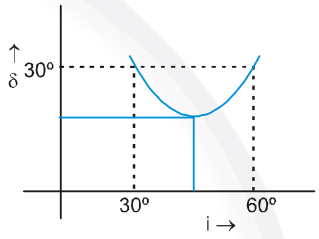
Ex.21 A ship is sailing in river. An observer is situated at a depth h in water (μ_w). If x >> h, find the angle made from vertical, of the line of sight of ship.



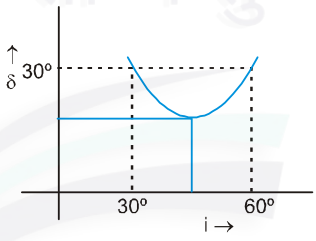
Sol. $C = \sin^{-1}\left(\frac{\mu_a}{\mu_w}\right)$



Ex.22 From the graph of angle of deviation δ versus angle of incidence i, find the prism angle



Sol. From the graph ;



$\delta = i + e - A.$

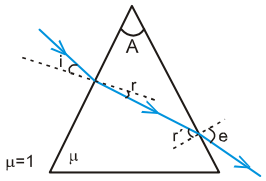
$30° = 30° + 60° - A$

$\therefore$ $\boxed{A = 60°}$

(use the result : If i and e are interchanged then we get same value of δ)

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Ex.23 For the case shown in figure prove the relations $r' - r = A$ and $\delta = |(i - e) + A|$ (do not try to remember these relations because the prism is normally not used in this way).

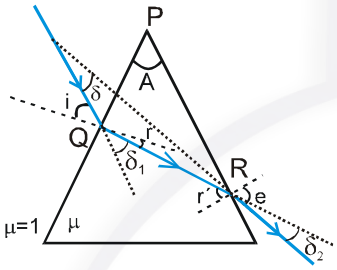


Sol. In ΔPQR,

$$A + \angle PQR + \angle QRP = 180°$$

$$= A + r + 90° + 90° - r' = 180°$$

$$\therefore \quad \boxed{r' - r = A}$$



Deviation after I[st] refraction

$$\delta_1 = (i - r) \qquad \text{(anticlock wise)}$$

Deviation after II[nd] refraction

$$\delta_2 = (e - r') \qquad \text{(clock wise)}$$

Hence net deviation

$$\delta = \delta_1 - \delta_2$$
$$= (i - r) - (e - r') = i - e + A$$

Ex.24 The dispersive powers of crown and flint glasses are 0.03 and 0.05 respectively. The refractive indices for yellow light for these glasses are 1.517 and 1.621 respectively. It is desired to form an achromatic combination of prisms of crown and flint glasses which can produce a deviation of 1^0 in the yellow ray. Find the refracting angles of the two prisms needed.

Sol. $\omega_c = 0.03 = \dfrac{n_v - n_r}{n_y - 1}$

$\therefore \quad (n_v - n_r) = 0.03\,(1.5\,17 - 1) = 0.0155$

and, $\omega_f = 0.05 = \dfrac{n'_v - n'_r}{n'_y - 1}$

$\therefore \quad n'_v - n'_r = 0.05 \times (1.6\,21 - 1) = 0.031$

$\theta = (n_v - n_r)\,A - (n'_v - n'_r)\,A$

$= \ 0.0155\,A - 0.031\,A' \qquad \text{.....(1)}$

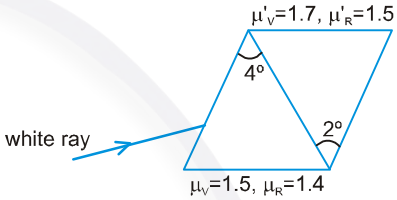
But $\delta_{net} = 1$

So, $(n_y - 1)\,A - (n'_y - 1)\,A' = 1$

$= 0.517\,A - 0.621\,A' = 1 \qquad \text{.....(2)}$

$\therefore \ A = 4.8°$ and $A' = 2.4°$

Ex.25 If two prisms are combined, as shown in figure, find the net angular dispersion and angle of deviation suffered by a white ray of light incident on the combination.

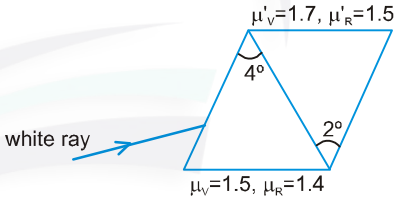


Sol. Net angular dispersion

$= (\delta_v - \delta_r) - (\delta'_v - \delta'_r)$

$= (\mu_v - \mu_r)\,A - (\mu'_v - \mu'_r)\,A'$

$= (1.5 - 1.4) \times 4° - (1.7 - 1.5) \times 2° \ = 0$



Angle of deviation

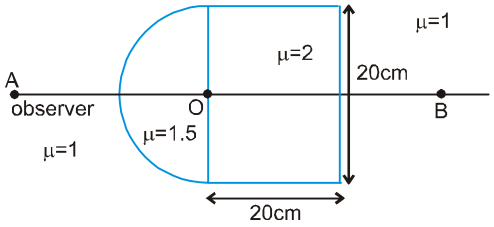
$$= \left(\frac{\mu_v + \mu_r}{2} - 1\right) A - \left(\frac{\mu'_v + \mu'_r}{2} - 1\right) A'$$

$$= \left(\frac{1.5 + 1.4}{2} - 1\right) \times 4° - \left(\frac{1.7 + 1.5}{2} - 1\right) \times 2°$$

$= 0.6°$

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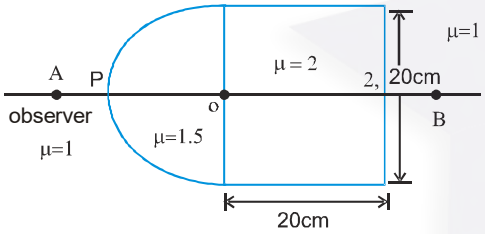
Ex.26 See the situation shown in figure



(1) Find the position of image as seen by observer A.

(2) Find the position of image as seen by observer B.

Sol. **(i)** As seen by observer A .



$R = -10$ cm.

$u = -10$ cm.

So, $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$, $\frac{1}{v} - \frac{1.5}{(-10)}$

$= \frac{1-1.5}{(-10)}$

$v = -10$ cm (at O)

(ii) As seen by observer B

$R = \infty$

$u = -20$ cm

$\frac{1}{v} - \frac{2.0}{-20} = \frac{1-2.0}{\infty}$

$v = -10$cm

image will be formed 10 cm right of O.

Ex.27 Find the focal length of a plano-convex lens with $R_1 = 15$ cm and $R_2 = \infty$. The refractive index of the lens material n = 1.5.

Sol. $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = (1.5-1)\left(\frac{1}{15} - \frac{1}{\infty}\right)$.

$= 0.5 \times \frac{1}{15}$

$\therefore f = 30$ cm.

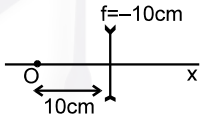
Ex.28 Find the focal length of a double-convex lens with $R_1 = 15$ cm and $R_2 = -25$ cm. The refractive index of the lens material n = 1.5.

Sol. $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = (1.5-1)\left(\frac{1}{15} + \frac{1}{25}\right)$

$= 0.5\left(\frac{10+6}{150}\right) = \frac{8}{150}$.

$f = \frac{150}{8} = 18.75$ cm

Ex.29 Figure shows a point object and a diverging lens. Find the final image formed.



Sol. $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

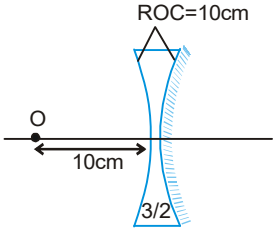
$\frac{1}{v} = \frac{1}{-10} + \frac{1}{(-10)} = -\frac{2}{10}$. $\Rightarrow v = -5$ cm

Ex.30 Find the focal length of a concavo-convex lens (positive meniscus) with $R_1 = 15$ cm and $R_2 = 25$ cm. The refractive index of the lens material n = 1.5.

Sol. $\frac{1}{f} = (1.5-1)\left(\frac{1}{15} - \frac{1}{25}\right) = 0.5\left(\frac{10-6}{150}\right)$.

$\therefore f = \frac{300}{4} = 75$ cm

Ex.31 See the figure Find the equivalent focal length of the combination shown in the figure and position of image.



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Sol. For the concave lens

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \left(\frac{3}{2} - 1\right)\left(\frac{1}{-10} - \frac{1}{10}\right)$$

$$= -\frac{1}{2} \times \frac{2}{10} = \frac{1}{10}$$

And, $f_m = \frac{R}{2} = \frac{10}{2} = 5$ cm

$$\therefore \frac{1}{f_{eq}} = \frac{1}{f_m} - 2\frac{1}{f}$$

$$= \frac{1}{5} + 2 \times \frac{1}{10} = \frac{2}{5}$$

$f_{eq} = 2.5$ cm **Ans.**

Ex.32 An extended real object is placed perpendicular to the principal axis of a concave lens of focal length –10 cm, such that the image found is half the size of object.

(A) Find the object distance from the lens

(B) Find the image distance from the lens and draw the ray diagram

(C) Find the lateral magnification if object is moved by 1 mm along the principal axis towards the lens.

Sol. **(A)** We have, $f = -10$ cm.

$$m = \frac{h_2}{h_1} = 0.5 = \frac{v}{u}$$

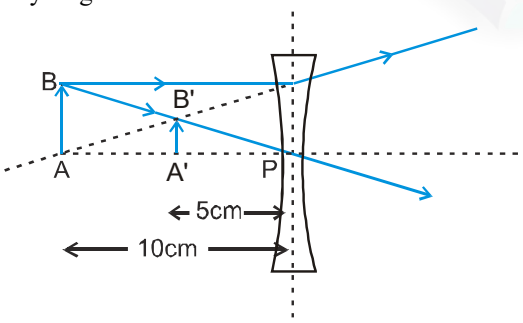
So, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ gives.

$$\Rightarrow \frac{1}{0.5u} - \frac{1}{u} = \frac{1}{-10} \qquad \therefore u = -10\text{cm}$$

(B) $\frac{v}{u} = 0.5.$

$\therefore v = 0.5 \times (-10)$ cm. $= -5$ cm

Ray diagram :-



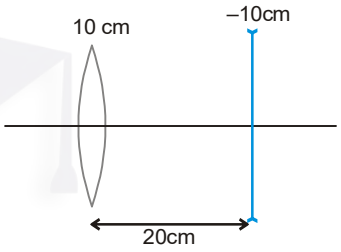
(C) $m = \frac{f}{f+u}$

$$\Rightarrow dm = \frac{-f}{(f+u)^2}\, du = \frac{(+10)}{(-10-10)^2} \quad (0.1)$$

$= 0.0025$ cm

So, final lateral magnification (m+dm) = 0.5025 cm **Ans.**

Ex.33 Find the equivalent focal length of the system for araxial rays parallel to axis.



Sol. $\frac{1}{f_{eq}} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2} = \frac{1}{10} + \frac{1}{-10} - \frac{20}{10(-10)} = \frac{1}{5}$

$\Rightarrow f_{eq} = 5$ cm

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Exercise # 1 SINGLE OBJECTIVE NEET LEVEL

1. Two vertical plane mirrors are inclined at an angle of $60°$ with each other. A ray of light travelling horizontally is reflected first from one mirror and then from the other. The resultant deviation is

(A) 60° **(B)** 120°
(C) 180° **(D)** 240°

2. A plane mirror reflects a pencil of light to form a real image. Then the pencil of light incident on the mirror is

(A) Parallel **(B)** Convergent
(C) Divergent **(D)** None of the above

3. What should be the angle between two plane mirrors so that whatever be the angle of incidence, the incident ray and the reflected ray from the two mirrors be parallel to each other

(A) 60° **(B)** 90°
(C) 120° **(D)** 175°

4. A plane mirror reflecting a ray of incident light is rotated through an angle θ about an axis through the point of incidence in the plane of the mirror perpendicular to the plane of incidence, then

(A) The reflected ray does not rotate
(B) The reflected ray rotates through an angle θ
(C) The reflected ray rotates through an angle 2θ
(D) The incident ray is fixed

5. A plane mirror is approaching you at a speed of $10\,cm/sec$ You can see your image in it. At what speed will your image approach you

(A) 10cm / sec **(B)** 5cm / sec
(C) 20cm / sec **(D)** 15cm / sec

6. A light bulb is placed between two plane mirrors inclined at an angle of 60°. The number of images formed are

(A) 6 **(B)** 2
(C) 5 **(D)** 4

7. It is desired to photograph the image of an object placed at a distance of 3m from the plane mirror. The camera which is at a distance of 4.5m from the mirror should be focussed for a distance of

(A) 3m **(B)** 4.5m
(C) 6m **(D)** 7.5m

8. A thick plane mirror shows a number of images of the filament of an electric bulb. Of these, the brightest image is the

(A) First **(B)** Second
(C) Fourth **(D)** Last

9. A man is 180cm tall and his eyes are 10 cm below the top of his head. In order to see his entire height right from toe to head, he uses a plane mirror kept at a distance of 1m from him. The minimum length of the plane mirror required is

(A) 180cm **(B)** 90cm
(C) 85cm **(D)** 170cm

10. A person is in a room whose ceiling and two adjacent walls are mirrors. How many images are formed

(A) 5 **(B)** 6
(C) 7 **(D)** 8

11. A convex mirror of focal length f forms an image which is $\frac{1}{n}$ times the object. The distance of the object from the mirror is

(A) $(n-1)f$ **(B)** $\left(\frac{n-1}{n}\right)f$
(C) $\left(\frac{n+1}{n}\right)f$ **(D)** $(n+1)f$

12. A diminished virtual image can be formed only in

(A) Plane mirror **(B)** A concave mirror
(C) A convex mirror
(D) Concave-parabolic mirror

13. Which of the following could not produce a virtual image

(A) Plane mirror
(B) Convex mirror
(C) Concave mirror
(D) All the above can produce a virtual image

14. An object $5cm$ tall is placed $1m$ from a concave spherical mirror which has a radius of curvature of $20\,cm$ The size of the image is

(A) $0.11\,cm$ **(B)** $0.50\,cm$
(C) $0.55\,cm$ **(D)** $0.60\,cm$

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15. The focal length of a concave mirror is $50\,cm$. Where an object be placed so that its image is two times and inverted

(A) 75 *cm* **(B)** 72 *cm*

(C) 63 *cm* **(D)** 50 *cm*

16. An object of size $7.5\,cm$ is placed in front of a convex mirror of radius of curvature $25\,cm$ at a distance of $40\,cm$. The size of the image should be

(A) 2.3 cm **(B)** 1.78 cm

(C) 1 cm **(D)** 0.8 cm

17. The field of view is maximum for

(A) Plane mirror **(B)** Concave mirror

(C) Convex mirror **(D)** Cylindrical mirror

18. The focal length of a concave mirror is f and the distance from the object to the principle focus is x. The ratio of the size of the image to the size of the object is

(A) $\frac{f+x}{f}$ **(B)** $\frac{f}{x}$

(C) $\sqrt{\frac{f}{x}}$ **(D)** $\frac{f^2}{x^2}$

19. Image formed by a convex mirror is

(A) Virtual **(B)** Real

(C) Enlarged **(D)** Inverted

20. In a concave mirror experiment, an object is placed at a distance x_1 from the focus and the image is formed at a distance x_2 from the focus. The focal length of the mirror would be

(A) $x_1 x_2$ **(B)** $\sqrt{x_1 x_2}$

(C) $\frac{x_1 + x_2}{2}$ **(D)** $\sqrt{\frac{x_1}{x_2}}$

21. To an observer on the earth the stars appear to twinkle. This can be ascribed to

(A) The fact that stars do not emit light continuously

(B) Frequent absorption of star light by their own atmosphere

(C) Frequent absorption of star light by the earth's atmosphere

(D) The refractive index fluctuations in the earth's atmosphere

22. The ratio of the refractive index of red light to blue light in air is

(A) Less than unity

(B) Equal to unity

(C) Greater than unity

(D) Less as well as greater than unity depending upon the experimental arrangement

23. The refractive index of a piece of transparent quartz is the greatest for

(A) Red light **(B)** Violet light

(C) Green light **(D)** Yellow light

24. The refractive index of a certain glass is 1.5 for light whose wavelength in vacuum is 6000 Å. The wavelength of this light when it passes through glass is

(A) 4000 Å **(B)** 6000 Å

(C) 9000 Å **(D)** 15000 Å

25. When light travels from one medium to the other of which the refractive index is different, then which of the following will change

(A) Frequency, wavelength and velocity

(B) Frequency and wavelength

(C) Frequency and velocity

(D) Wavelength and velocity

26. A light wave has a frequency of 4×10^{14} Hz and a wavelength of 5×10^{-7} meters in a medium. The refractive index of the medium is

(A) 1.5 **(B)** 1.33

(C) 1.0 **(D)** 0.66

27. How much water should be filled in a container 21 *cm* in height, so that it appears half filled when viewed from the top of the container (given that ${}_a\mu_\omega = 4/3$)

(A) 8.0 *cm* **(B)** 10.5 *cm*

(C) 12.0 *cm* **(D)** None of the above

28. Light of different colours propagates through air

(A) With the velocity of air

(B) With different velocities

(C) With the velocity of sound

(D) Having the equal velocities

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29. Monochromatic light is refracted from air into the glass of refractive index μ. The ratio of the wavelength of incident and refracted waves is

(A) $1:\mu$ **(B)** $1:\mu^2$

(C) $\mu:1$ **(D)** $1:1$

30. A monochromatic beam of light passes from a denser medium into a rarer medium. As a result

(A) Its velocity increases

(B) Its velocity decreases

(C) Its frequency decreases

(D) Its wavelength decreases

31. A cut diamond sparkles because of its

(A) Hardness

(B) High refractive index

(C) Emission of light by the diamond

(D) Absorption of light by the diamond

32. A diver in a swimming pool wants to signal his distress to a person lying on the edge of the pool by flashing his water proof flash light

(A) He must direct the beam vertically upwards

(B) He has to direct the beam horizontally

(C) He has to direct the beam at an angle to the vertical which is slightly less than the critical angle of incidence for total internal reflection

(D) He has to direct the beam at an angle to the vertical which is slightly more than the critical angle of incidence for the total internal reflection

33. Finger prints on a piece of paper may be detected by sprinkling fluorescent powder on the paper and then looking it into

(A) Mercury light **(B)** Sunlight

(C) Infrared light **(D)** Ultraviolet light

34. Critical angle of light passing from glass to air is minimum for

(A) Red **(B)** Green

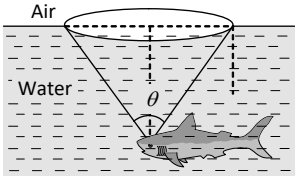
(C) Yellow **(D)** Violet

35. The wavelength of light in two liquids 'x' and 'y' is 3500 Å and 7000 Å, then the critical angle of x relative to y will be

(A) 60° **(B)** 45°

(C) 30° **(D)** 15°

36. A fish is a little away below the surface of a lake. If the critical angle is 49°, then the fish could see things above the water surface within an angular range of θ^o where



(A) $\theta = 49^o$ **(B)** $\theta = 90^o$

(C) $\theta = 98^o$ **(D)** $\theta = 24\frac{1^o}{2}$

37. If the critical angle for total internal reflection from a medium to vacuum is 30°, the velocity of light in the medium is

(A) $3\times10^8\ m/s$ **(B)** $1.5\times10^8\ m/s$

(C) $6\times10^8\ m/s$ **(D)** $\sqrt{3}\times10^8\ m/s$

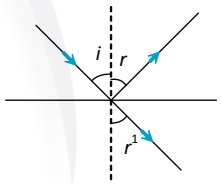
38. A ray of light is incident at an angle i from denser to rare medium. The reflected and the refracted rays are mutually perpendicular. The angle of reflection and the angle of refraction are respectively r and r', then the critical angle will be

(A) $\sin^{-1}(\sin r)$

(B) $\sin^{-1}(\tan r')$

(C) $\sin^{-1}(\tan i)$

(D) $\tan^{-1}(\sin i)$



39. For total internal reflection to take place, the angle of incidence i and the refractive index μ of the medium must satisfy the inequality

(A) $\frac{1}{\sin i} < \mu$ **(B)** $\frac{1}{\sin i} > \mu$

(C) $\sin i < \mu$ **(D)** $\sin i > \mu$

40. Total internal reflection of light is possible when light enters from

(A) Air to glass **(B)** Vacuum to air

(C) Air to water **(D)** Water to air

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41. The radius of curvature for a convex lens is 40 *cm*, for each surface. Its refractive index is 1.5. The focal length will be

(A) 40 *cm* **(B)** 20 *cm*

(C) 80 *cm* **(D)** 30 *cm*

42. A convex lens of focal length f is placed somewhere in between an object and a screen. The distance between the object and the screen is x. If the numerical value of the magnification produced by the lens is m, , then the focal length of the lens is

(A) $\frac{mx}{(m+1)^2}$ **(B)** $\frac{mx}{(m-1)^2}$

(C) $\frac{(m+1)^2}{m}x$ **(D)** $\frac{(m-1)^2}{m}x$

43. A thin lens focal length f_1 and its aperture has diameter d. It forms an image of intensity I. Now the central part of the aperture upto diameter $\frac{d}{2}$ is blocked by an opaque paper. The focal length and image intensity will change to

(A) $\frac{f}{2}$ and $\frac{I}{2}$ **(B)** f and $\frac{I}{4}$

(C) $\frac{3f}{4}$ and $\frac{I}{2}$ **(D)** f and $\frac{3I}{4}$

44. A lens of power + 2 diopters is placed in contact with a lens of power – 1 diopter. The combination will behave like

(A) A convergent lens of focal length 50 *cm*

(B) A divergent lens of focal length 100 *cm*

(C) A convergent lens of focal length 100 *cm*

(D) A convergent lens of focal length 200 *cm*

45. A convex lens of focal length 40 cm is in contact with a concave lens of focal length 25 cm. The power of combination is

(A) – 1.5 *D* **(B)** – 6.5 *D*

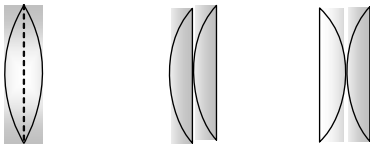
(C) + 6.5 *D* **(D)** + 6.67 *D*

46. Two lenses are placed in contact with each other and the focal length of combination is 80 *cm*. If the focal length of one is 20 *cm*, then the power of the other will be

(A) 1.66 *D* **(B)** 4.00 *D*

(C) –1.00 *D* **(D)** – 3.75 *D*

47. Two similar plano-convex lenses are combined together in three different ways as shown in the adjoining figure. The ratio of the focal lengths in three cases will be



(A) 2 : 2 : 1 **(B)** 1 : 1 : 1

(C) 1 : 2 : 2 **(D)** 2 : 1 : 1

48. Two lenses of power +12 and – 2 diopters are placed in contact. What will the focal length of combination

(A) 10 *cm* **(B)** 12.5 *cm*

(C) 16.6 *cm* **(D)** 8.33 *cm*

49. A concave and convex lens have the same focal length of 20 cm and are put into contact to form a lens combination. The combination is used to view an object of 5 *cm* length kept at 20 cm from the lens combination. As compared to the object, the image will be

(A) Magnified and inverted

(B) Reduced and erect

(C) Of the same size as the object and erect

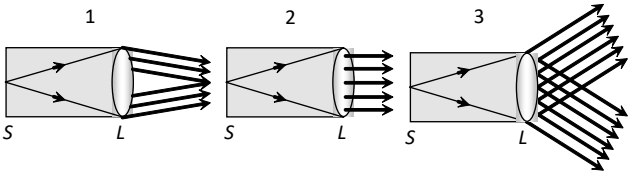
(D) Of the same size as the object but inverted

50. If in a plano-convex lens, the radius of curvature of the convex surface is 10 *cm* and the focal length of the lens is 30 *cm*, then the refractive index of the material of lens will be

(A) 1.5 **(B)** 1.66

(C) 1.33 **(D)** 3

51. The slit of a collimator is illuminated by a source as shown in the adjoining figures. The distance between the slit *S* and the collimating lens *L* is equal to the focal length of the lens. The correct direction of the emergent beam will be as shown in figure



(A) 1 **(B)** 3

(C) 2 **(D)** None of the figures

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52. A converging lens is used to form an image on a screen. When upper half of the lens is covered by an opaque screen

(A) Half the image will disappear

(B) Complete image will be formed of same intensity

(C) Half image will be formed of same intensity

(D) Complete image will be formed of decreased intensity

53. A thin convex lens of focal length 10 *cm* is placed in contact with a concave lens of same material and of same focal length. The focal length of combination will be

(A) Zero **(B)** Infinity

(C) 10 *cm* **(D)** 20 *cm*

54. A convex lens of focal length 84 *cm* is in contact with a concave lens of focal length 12 *cm*. The power of combination (in diopters) is

(A) 25/24 **(B)** 25/18

(C) – 50/7 **(D)** + 50/7

55. A convex lens makes a real image 4 *cm* long on a screen. When the lens is shifted to a new position without disturbing the object, we again get a real image on the screen which is 16 *cm* tall. The length of the object must be

(A) 1/4 *cm* **(B)** 8 *cm*

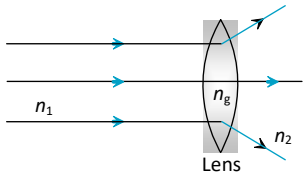
(C) 12 *cm* **(D)** 20 *cm*

56. A glass convex lens $(\mu_g = 1.5)$ has a focal length of 8 cm when placed in air. What would be the focal length of the lens when it is immersed in water $(\mu_w = 1.33)$

(A) 2 *m* **(B)** 4 *cm*

(C) 16 *cm* **(D)** 32 *cm*

57. The ray diagram could be correct



(A) If

(B) If and

(C) If and

(D) Under no circumstances

58. A thin convex lens of refractive index 1.5 has a focal length of 15 *cm* in air. When the lens is placed in liquid of refractive index 4/3 , its focal length will be

(A) 15 *cm* **(B)** 10 *cm*

(C) 30 *cm* **(D)** 60 *cm*

59. A glass lens is placed in a medium in which it is found to behave like a glass plate. Refractive index of the medium will be

(A) Greater than the refractive index of glass

(B) Smaller than the refractive index of glass

(C) Equal to refractive index of glass

(D) No case will be possible from above

60. If I_1 and I_2 be the size of the images respectively for the two positions of lens in the displacement method, then the size of the object is given by

(A) I_1 / I_2 **(B)** $I_1 \times I_2$

(C) $\sqrt{I_1 \times I_2}$ **(D)** $\sqrt{I_1 / I_2}$

61. Which source is associated with a line emission spectrum

(A) Electric fire **(B)** Neon street sign

(C) Red traffic light **(D)** Sun

62. Formula for dispersive power is (where symbols have their usual meanings)

or

If the refractive indices of crown glass for red, yellow and violet colours are respectively μ_r, μ_y and μ_v, then the dispersive power of this glass would be

(A) $\frac{\mu_v - \mu_y}{\mu_r - 1}$ **(B)** $\frac{\mu_v - \mu_r}{\mu_y - 1}$

(C) $\frac{\mu_v - \mu_y}{\mu_y - \mu_r}$ **(D)** $\frac{\mu_v - \mu_r}{\mu_y} - 1$

63. The critical angle between an equilateral prism and air is 45°. If the incident ray is perpendicular to the refracting surface, then

(A) After deviation it will emerge from the second refracting surface

(B) It is totally reflected on the second surface and emerges out perpendicularly from third surface in air

(C) It is totally reflected from the second and third refracting surfaces and finally emerges out from the first surface

(D) It is totally reflected from all the three sides of prism and never emerges out

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64. When white light passes through a glass prism, one gets spectrum on the other side of the prism. In the emergent beam, the ray which is deviating least is or

Deviation by a prism is lowest for

(A) Violet ray **(B)** Green ray

(C) Red ray **(D)** Yellow ray

65. We use flint glass prism to disperse polychromatic light because light of different colours

(A) Travel with same speed

(B) Travel with same speed but deviate differently due to the shape of the prism

(C) Have different anisotropic properties while travelling through the prism

(D) Travel with different speeds

66. A prism $(\mu = 1.5)$ has the refracting angle of 30°. The deviation of a monochromatic ray incident normally on its one surface will be $(\sin 48° 36' = 0.75)$

(A) 18° 36' **(B)** 20° 30'

(C) 18° **(D)** 22°1'

67. Fraunhofer lines are obtained in

(A) Solar spectrum

(B) The spectrum obtained from neon lamp

(C) Spectrum from a discharge tube

(D) None of the above

68. When light rays are incident on a prism at an angle of 45°, the minimum deviation is obtained. If refractive index of the material of prism is $\sqrt{2}$, then the angle of prism will be

(A) 30° **(B)** 40°

(C) 50° **(D)** 60°

69. A spectrum is formed by a prism of dispersive power 'ω'. If the angle of deviation is 'δ', then the angular dispersion is

(A) ω / δ **(B)** δ / ω

(C) $1/\omega\delta$ **(D)** $\omega\delta$

70. Light from sodium lamp is passed through cold sodium vapours, the spectrum of transmitted light consists of

(A) A line at 5890 Å **(B)** A line at 5896 Å

(C) Sodium doublet lines **(D)** No spectral features

71. A far sighted man who has lost his spectacles, reads a book by looking through a small hole (3-4 *mm*) in a sheet of paper. The reason will be

(A) Because the hole produces an image of the letters at a longer distance

(B) Because in doing so, the focal length of the eye lens is effectively increased

(C) Because in doing so, the focal length of the eye lens is effectively decreased

(D) None of these

72. For a normal eye, the least distance of distinct vision is

(A) 0.25 *m* **(B)** 0.50 *m*

(C) 25 *m* **(D)** Infinite

73. For the myopic eye, the defect is cured by

(A) Convex lens **(B)** Concave lens

(C) Cylindrical lens **(D)** Toric lens

74. Lens used to remove long sightedness (hypermetropia) is

or

A person suffering from hypermetropia requires which type of spectacle lenses

(A) Concave lens **(B)** Plano-concave lens

(C) Convexo-concave lens **(D)** Convex lens

75. Substance on the choroid is

(A) Japan black **(B)** Nigrim pigment

(C) Carbon black **(D)** Platinum black

76. Astigmatism (for a human eye) can be removed by using

(A) Concave lens **(B)** Convex lens

(C) Cylindrical lens **(D)** Prismatic lens

77. Circular part in the centre of retina is called

(A) Blind spot **(B)** Yellow spot

(C) Red spot **(D)** None of the above

78. Image formed on the retina is

(A) Real and inverted **(B)** Virtual and erect

(C) Real and erect **(D)** Virtual and inverted

79. If there had been one eye of the man, then

(A) Image of the object would have been inverted

(B) Visible region would have decreased

(C) Image would have not been seen three dimensional

(D) **(B)** and **(C)** both

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80. A person cannot see distinctly at the distance less than one metre. Calculate the power of the lens that he should use to read a book at a distance of 25 *cm*

(A) $+3.0\,D$ **(B)** $+0.125\,D$

(C) $-3.0\,D$ **(D)** $+4.0\,D$

81. The focal lengths of the objective and eye-lens of a microscope are 1 *cm* and 5 *cm* respectively. If the magnifying power for the relaxed eye is 45, then the length of the tube is

(A) 30 *cm* **(B)** 25 *cm*

(C) 15 *cm* **(D)** 12 *cm*

82. In a compound microscope magnification will be large, if the focal length of the eye piece is

(A) Large **(B)** Smaller

(C) Equal to that of objective

(D) Less than that of objective

83. The focal length of the objective lens of a compound microscope is

(A) Equal to the focal length of its eye piece

(B) Less than the focal length of eye piece

(C) Greater than the focal length of eye piece

(D) Any of the above three

84. Microscope is an optical instrument which

(A) Enlarges the object

(B) Increases the visual angle formed by the object at the eye

(C) Decreases the visual angle formed by the object at the eye

(D) Brings the object nearer

85. Magnifying power of a simple microscope is (when final image is formed at $D = 25$ *cm* from eye)

(A) $\frac{D}{f}$ **(B)** $1+\frac{D}{f}$

(C) $1+\frac{f}{D}$ **(D)** $1-\frac{D}{f}$

86. If in compound microscope m_1 and m_2 be the linear magnification of the objective lens and eye lens respectively, then magnifying power of the compound microscope will be

(A) $m_1 - m_2$ **(B)** $\sqrt{m_1 + m_2}$

(C) $(m_1 + m_2)/2$ **(D)** $m_1 \times m_2$

87. For which of the following colour, the magnifying power of a microscope will be maximum

(A) White colour **(B)** Red colour

(C) Violet colour **(D)** Yellow colour

88. The length of the compound microscope is 14 *cm*. The magnifying power for relaxed eye is 25. If the focal length of eye lens is 5 *cm*, then the object distance for objective lens will be

(A) 1.8 *cm* **(B)** 1.5 *cm*

(C) 2.1 *cm* **(D)** 2.4 *cm*

89. If the focal length of objective and eye lens are 1.2 *cm* and 3 *cm* respectively and the object is put 1.25 *cm* away from the objective lens and the final image is formed at infinity. The magnifying power of the microscope is

(A) 150 **(B)** 200

(C) 250 **(D)** 400

90. The focal length of objective and eye lens of a microscope are 4 *cm* and 8 *cm* respectively. If the least distance of distinct vision is 24 *cm* and object distance is 4.5 *cm* from the objective lens, then the magnifying power of the microscope will be

(A) 18 **(B)** 32

(C) 64 **(D)** 20

91. If luminous efficiency of a lamp is 2 lumen/watt and its luminous intensity is 42 candela, then power of the lamp is

(A) 62 *W* **(B)** 76 *W*

(C) 138 *W* **(D)** 264 *W*

92. An electric bulb illuminates a plane surface. The intensity of illumination on the surface at a point 2*m* away from the bulb is 5×10^{-4} phot (*lumen/cm*^{2}). The line joining the bulb to the point makes an angle of 60° with the normal to the surface. The intensity of the bulb in *candela* is

(A) $40\sqrt{3}$ **(B)** 40

(C) 20 **(D)** 40×10^{-4}

93. In a movie hall, the distance between the projector and the screen is increased by 1% illumination on the screen is

(A) Increased by 1% **(B)** Decreased by 1%

(C) Increased by 2% **(D)** Decreased by 2%

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94. Correct exposure for a photographic print is 10 *seconds* at a distance of one metre from a point source of 20 *candela*. For an equal fogging of the print placed at a distance of 2 *m* from a 16 *candela* source, the necessary time for exposure is

(A) 100 *sec* **(B)** 25 *sec*

(C) 50 *sec* **(D)** 75 *sec*

95. A bulb of 100 *watt* is hanging at a height of one meter above the centre of a circular table of diameter 4 *m*. If the intensity at a point on its rim is I_0, then the intensity at the centre of the table will be

(A) I_0 **(B)** $2\sqrt{5}I_0$

(C) $2I_0$ **(D)** $5\sqrt{5}I_0$

96. A movie projector forms an image 3.5*m* long of an object 35 *mm*. Supposing there is negligible absorption of light by aperture then illuminance on slide and screen will be in the ratio of

(A) 100 : 1 **(B)** 10^4 : 1

(C) 1 : 100 **(D)** 1 : 10^4

97. A 60 *watt* bulb is hung over the center of a table 4 *m* × 4 *m* at a height of 3 *m*. The ratio of the intensities of illumination at a point on the centre of the edge and on the corner of the table is

(A) $(17/13)^{3/2}$ **(B)** 2 / 1

(C) 17 / 13 **(D)** 5 / 4

98. "Lux" is a unit of

(A) Luminous intensity of a source

(B) Illuminance on a surface

(C) Transmission coefficient of a surface

(D) Luminous efficiency of source of light

99. Total flux produced by a source of 1 *cd* is

(A) $\frac{1}{4\pi}$ **(B)** 8π

(C) 4π **(D)** $\frac{1}{8\pi}$

100. If the luminous intensity of a 100 *W* unidirectional bulb is 100 candela, then total luminous flux emitted from the bulb is

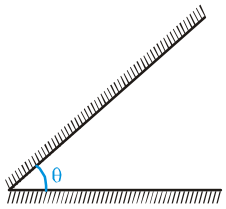
(A) 861 *lumen* **(B)** 986 *lumen*

(C) 1256 *lumen* **(D)** 1561 *lumen*

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Exercise # 2 SINGLE OBJECTIVE AIIMS LEVEL

1. Two mirrors are inclined at an angle θ as shown in the figure. Light ray is incident parallel to one of the mirrors. Light will start retracing its path after third reflection if :



(A) $\theta = 45°$ **(B)** $\theta = 30°$

(C) $\theta = 60°$ **(D)** all three

2. Two plane mirrors are inclined to each other at an angle 60^0. If a ray of light incident on the first mirror is parallel to the second mirror, it is reflected from the second mirror

(A) Perpendicular to the first mirror

(B) Parallel to the first mirror

(C) Parallel to the second mirror

(D) Perpendicular to the second mirror

3. A point object is kept in front of a plane mirror. The plane mirror is performing SHM of amplitude 2 cm. The plane mirror moves along the x-axis and x- axis is normal to the mirror. The amplitude of the mirror is such that the object is always infront of the mirror. The amplitude of SHM of the image is

(A) zero **(B)** 2 cm

(C) 4 cm **(D)** 1 cm

4. An unnumbered wall clock shows time 04: 25: 37, where 1st term represents hours, 2nd represents minutes and the last term represents seconds. What time will its image in a plane mirror show.

(A) 08: 35: 23 **(B)** 07: 35: 23

(C) 07: 34: 23 **(D)** none of these

5. A person's eye is at a height of 1.5 m. He stands infront of a 0.3m long plane mirror which is 0.8 m above the ground. The length of the image he sees of himself is:

(A) 1.5m **(B)** 1.0m

(C) 0.8m **(D)** 0.6m

6. An object of height 1 cm is kept perpendicular to the principal axis of a convex mirror of radius of curvature 20 cm. If the distance of the object from the mirror is 20 cm then the distance (in cm) between heads of the image and the object will be:

(A) $\sqrt{\frac{6404}{9}}$ **(B)** $\sqrt{\frac{6414}{9}}$

(C) $\frac{40}{3}$ **(D)** none of these

7. Two plane mirrors are parallel to each other and spaced 20 cm apart. An object is kept in between them at 15 cm from A. Out of the following at which point(s) image(s) is/are not formed in mirror A (distance measured from mirror A):

(A) 15 cm **(B)** 25 cm

(C) 45 cm **(D)** 55 cm

8. A plane mirror is moving with velocity $4\hat{i} + 5\hat{j} + 8\hat{k}$. A point object in front of the mirror moves with a velocity $3\hat{i} + 4\hat{j} + 5\hat{k}$. Here $\hat{k}$ is along the normal to the plane mirror and facing towards the object. The velocity of the image is :

(A) $-3\hat{i} - 4\hat{j} + 5\hat{k}$ **(B)** $3\hat{i} + 4\hat{j} + 11\hat{k}$

(C) $-3\hat{i} - 4\hat{j} + 11\hat{k}$ **(D)** $7\hat{i} + 9\hat{j} + 11\hat{k}$

9. A point object is kept between a plane mirror and a concave mirror facing each other. The distance between the mirrors is 22.5 cm. Plane mirror is placed perpendicular to principal axis of concave mirror. The radius of curvature of the concave mirror is 20 cm. What should be the distance of the object from the concave mirror so that after two successive reflections the final image is formed on the object itself ? (Consider first reflection from concave mirror)

(A) 5 cm **(B)** 15 cm

(C) 10 cm **(D)** 7.5 cm

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10. A luminous point object is moving along the principal axis of a concave mirror of focal length 12 cm towards it. When its distance from the mirror is 20 cm its velocity is 4 cm/s. The velocity of the image in cm/s at that instant is

(A) 6, towards the mirror

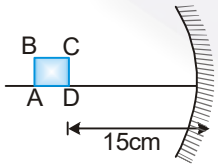
(B) 6, away from the mirror

(C) 9, away from the mirror

(D) 9, towards the mirror.

11. A square ABCD of side 1mm is kept at distance 15 cm infront of the concave mirror as shown in the figure. The focal length of the mirror is 10 cm.

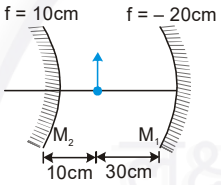
The length of the perimeter of its image will be (nearly):



(A) 8 mm **(B)** 2 mm

(C) 12 mm **(D)** 6 mm

12. In the figure shown find the total magnification after two successive reflections first on M_1 and then on M_2 .



(A) + 1 **(B)** – 2

(C) + 2 **(D)** – 1

13. A point object on the principal axis at a distance 15 cm in front of a concave mirror of radius of curvature 20 cm has velocity 2 mm/s perpendicular to the principal axis. The magnitude of velocity of image at that instant will be:

(A) 2 mm/s **(B)** 4 mm/s

(C) 8 mm/s **(D)** 16 mm/s

14. A particle is moving towards a fixed spherical mirror. The image:

(A) must move away from the mirror

(B) must move towards the mirror

(C) may move towards the mirror

(D) will move towards the mirror, only if the mirror is convex.

15. The distance of an object from the focus of a convex mirror of radius of curvature ' a ' is ' b '. Then the distance of the image from the focus is:

(A) $b^2 / 4a$ **(B)** a / b^2

(C) $a^2 / 4b$ **(D)** $4b / a^2$

16. A point object at 15 cm from a concave mirror of radius of curvature 20 cm is made to oscillate along the principal axis with amplitude 2 mm. The amplitude of its image will be

(A) 2 mm **(B)** 4 mm

(C) 8 mm **(D)** 16 mm

17. The largest distance of the image of a real object from a convex mirror of focal length 20 cm can be:

(A) 20 cm **(B)** infinite

(C) 10 cm

(D) depends on the position of the object

18. I is the image of a point object O formed by spherical mirror, then which of the following statements is incorrect :

(A) If O and I are on same side of the principal axis, then they have to be on opposite sides of the mirror.

(B) If O and I are on opposite side of the principal axis, then they have to be on same side of the mirror.

(C) If O and I are on opposite side of the principal axis, then they can be on opposite side of the mirror as well.

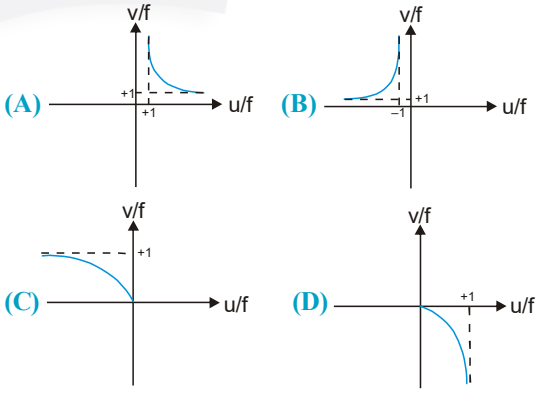
(D) If O is on principal axis then I has to lie on principal axis only.

19. Which of the following can form erect, virtual, diminished image?

(A) plane mirror **(B)** concave mirror

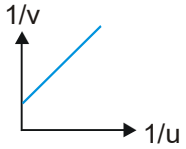
(C) convex mirror **(D)** none of these

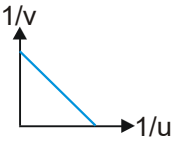
20. A real inverted image in a concave mirror is represented by graph (u, v, f are coordinates)

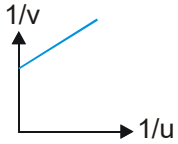


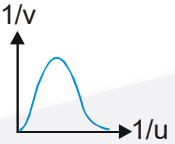
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21. An object is placed at a distance u from a concave mirror and its real image is received on a screen placed at a distance of v from the mirror. If f is the focal length of the mirror, then the graph between $1/v$ versus $1/u$ is

(A) 

(B) 

(C) 

(D) 

22. A ray of light passes from vacuum into a medium of refractive index n. If the angle of incidence is twice the angle of refraction, then the angle of incidence is:

(A) $\cos^{-1}(n/2)$ **(B)** $\sin^{-1}(n/2)$

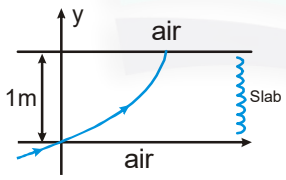
(C) $2\cos^{-1}(n/2)$ **(D)** $2\sin^{-1}(n/2)$

23. The wavelength of light in vacuum is 6000 A° and in a medium it is 4000 A°. The refractive index of the medium is:

(A) 2.4 **(B)** 1.5

(C) 1.2 **(D)** 0.67

24. AZ ray of light travelling in air is incident at grazing incidence on a slab with variable refractive index, $n(y) = [k y^{3/2} + 1]^{1/2}$ where $k = 1\ m^{-3/2}$ and follows path as shown in the figure. What is the total deviation produced by slab when the ray comes out.



(A) 60° **(B)** 53°

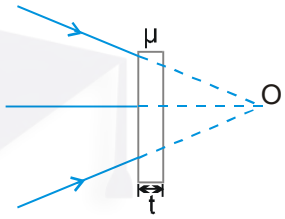
(C) $\sin^{-1}(4/9)$ **(D)** no deviation at all

25. A ray of light is incident on a parallel slab of thickness t and refractive index n. If the angle of incidence θ is small, then the displacement in the incident and emergent ray will be:

(A) $\frac{t\theta(n-1)}{n}$ **(B)** $\frac{t\theta}{n}$

(C) $\frac{t\theta n}{n-1}$ **(D)** none

26. A beam of light is converging towards a point. A plane parallel plate of glass of thickness t, refractive index μ is introduced in the path of the beam as shown in the figure. The convergent point is shifted by (assume near normal incidence):



(A) $t\left(1-\frac{1}{\mu}\right)$ away **(B)** $t\left(1+\frac{1}{\mu}\right)$ away

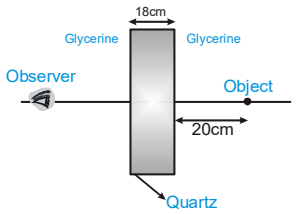
(C) $t\left(1-\frac{1}{\mu}\right)$ nearer **(D)** $t\left(1+\frac{1}{\mu}\right)$ nearer

27. The critical angle of light going from medium A to medium B is θ. The speed of light in medium A is v. The speed of light in medium B is:

(A) $\frac{v}{\sin\theta}$ **(B)** $v\sin\theta$

(C) $v\cot\theta$ **(D)** $v\tan\theta$

28. Given that, velocity of light in quartz = 1.5×10^8 m/s and velocity of light in glycerine = $(9/4) \times 10^8$ m/s. Now a slab made of quartz is placed in glycerine as shown. The shift of the object produced by slab is



(A) 6 cm **(B)** 3.55 cm

(C) 9 cm **(D)** 2 cm

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29. A prism having refractive index $\sqrt{2}$ and refracting angle 30°, has one of the refracting surfaces polished. A beam of light incident on the other refracting surface will retrace its path if the angle of incidence is:

(A) 0° **(B)** 30°

(C) 45° **(D)** 60°

30. A ray of monochromatic light is incident on one refracting face of a prism of angle 75^0. It passes through the prism and is incident on the other face at the critical angle. If the refractive index of the material of the prism is $\sqrt{2}$, the angle of incidence on the first face of the prism is

(A) 30^0 **(B)** 45^0

(C) 60^0 **(D)** 0^0

31. The maximum refractive index of a material, of a prism of apex angle 90°, for which light may be transmitted is:

(A) $\sqrt{3}$ **(B)** 1.5

(C) $\sqrt{2}$ **(D)** None of these

32. A ray of light is incident at angle *i* on a surface of a prism of small angle A and emerges normally from the opposite surface. If the refractive index of the material of the prism is μ, the angle of incidence *i* is nearly equal to :

(A) A/μ **(B)** $A/(2\mu)$

(C) μA **(D)** $\mu A/2$

33. A prism of refractive index $\sqrt{2}$ has refracting angle 60°. Answer the following questions

(A) In order that a ray suffers minimum deviation it should be incident at an angle :

(A) 45^0 **(B)** 90^0

(C) 30^0 **(D)** none

(B) Angle of minimum deviation is :

(A) 45^0 **(B)** 90^0

(C) 30^0 **(D)** none

(C) Angle of maximum deviation is :

(A) 45^0 **(B)** $\sin^{-1}(\sqrt{2}\sin 15^\circ)$

(C) $30^\circ + \sin^{-1}(\sqrt{2}\sin 15^\circ)$ **(D)** none

34. There is a small black dot at the centre C of a solid glass sphere of refractive index μ. When seen from outside, the dot will appear to be located:

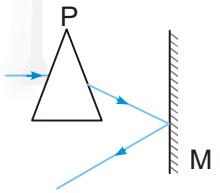
(A) away from C for all values of μ

(B) at C for all values of μ

(C) at C for $\mu = 1.5$, but away from C for $\mu \neq 1.5$

(D) at C only for $\sqrt{2} \leq \mu \leq 1.5$.

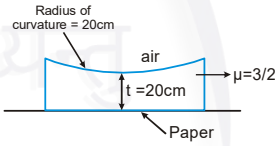
35. A prism having an apex angle of 4^0 and refractive index of 1.50 is located in front of a vertical plane mirror as shown in the figure. A horizontal ray of light is incident on the prism. The total angle through which the ray is deviated is:



(A) 4^0 clockwise **(B)** 178^0 clockwise

(C) 2^0 clockwise **(D)** 8^0 clockwise

36. In the given figure a plano-concave lens is placed on a paper on which a flower is drawn. How far above its actual position does the flower appear to be ?



(A) 10 cm **(B)** 15 cm

(C) 50 cm **(D)** none of these

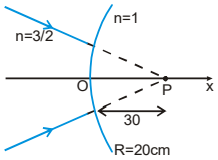
37. The image for the converging beam after refraction through the curved surface (in the given figure) is formed at:

(A) x = 40 cm

(B) $x = \frac{40}{3}$ cm

(C) $x = -\frac{40}{3}$ cm

(D) $x = \frac{180}{7}$ cm



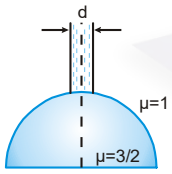
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38. A convexo - concave diverging lens is made of glass of refractive index 1.5 and focal length 24 cm. Radius of curvature for one surface is double that of the other. Then radii of curvature for the two surfaces are (in cm):

(A) 6, 12 **(B)** 12, 24

(C) 3, 6 **(D)** 18, 36

39. A beam of diameter ' d ' is incident on a glass hemisphere as shown in the figure. If the radius of curvature of the hemisphere is very large in comparison to d, then the diameter of the beam at the base of the hemisphere will be:



(A) $\frac{3}{4}$ d **(B)** d

(C) $\frac{d}{3}$ **(D)** $\frac{2}{3}$ d

40. When a lens of power P (in air) made of material of refractive index μ is immersed in liquid of refractive index μ_0. Then the power of lens is:

(A) $\frac{\mu - 1}{\mu - \mu_0}$ P **(B)** $\frac{\mu - \mu_0}{\mu - 1}$ P

(C) $\frac{\mu - \mu_0}{\mu - 1} \cdot \frac{P}{\mu_0}$ **(D)** none of these

41. Two symmetric double convex lenses A and B have same focal length, but the radii of curvature differ so that $R_A = 0.9\ R_B$. If $n_A = 1.63$, find n_B.

(A) 1.7 **(B)** 1.6

(C) 1.5 **(D)** 4/3

42. The diameter of the sun subtends an angle of 0.5^0 at the surface of the earth. A converging lens of focal length 100 cm is used to provide an image of the sun on to a screen. The diameter (in mm) of the image formed is nearly

(A) 1 **(B)** 3

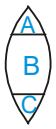
(C) 5 **(D)** 9

43. A lens behaves as a converging lens in air and a diverging lens in water. The refractive index of the material is (refractive index of water = 1.33)

(A) equal to unity **(B)** equal to 1.33

(C) between unity and 1.33 **(D)** greater than 1.33

44. A thin symmetrical double convex lens of power P is cut into three parts, as shown in the figure. Power of A is:



(A) 2 P **(B)** $\frac{P}{2}$

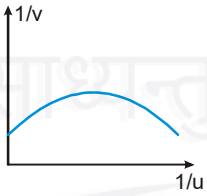
(C) $\frac{P}{3}$ **(D)** P

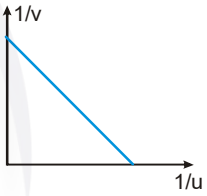
45. A thin lens of focal length f and its aperture diameter d, forms a real image of intensity I. Now the central part of the aperture upto diameter (d/2) is blocked by an opaque paper. The focal length and image intensity would change to :

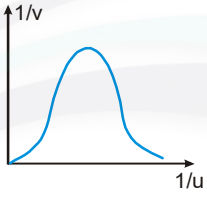
(A) f/2, I/2 **(B)** f, I/4

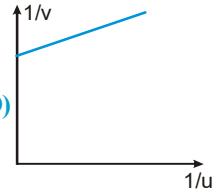
(C) 3f/4, I/2 **(D)** f, 3I/4

46. An object is placed at a distance *u* from a converging lens and its real image is received on a screen placed at a distance of *v* from the lens. If *f* is the focal length of the lens, then the graph between 1/*v* versus 1/*u* is:

(A)


(B)


(C)


(D)


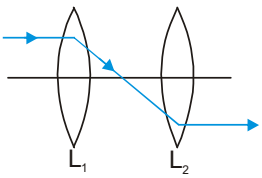
47. In the figure given below, there are two convex lens L_1 and L_2 having focal length of f_1 and f_2 respectively. The distance between L_1 and L_2 will be

(A) f_1

(B) f_2

(C) $f_1 + f_2$

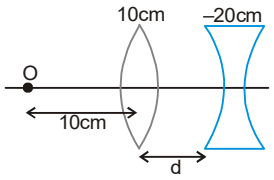
(D) $f_1 - f_2$



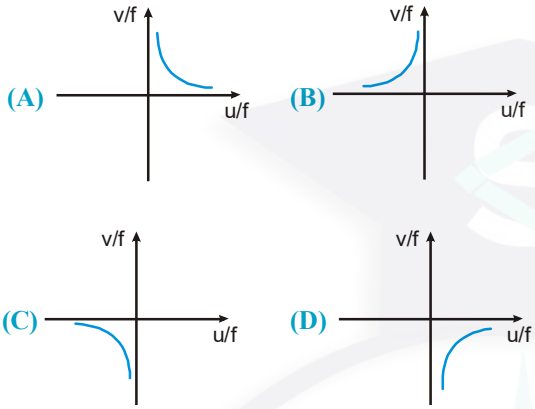
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48. What should be the value of distance d so that final image is formed on the object itself. (focal lengths of the lenses are as given in the figure).

(A) 10 cm
(B) 20 cm
(C) 5 cm
(D) none of these



49. A virtual erect image by a diverging lens is represented by (u, v, f are coordinates)



50. A biconvex lens is used to project a slide on screen. The slide is 2 cm high and placed at 10 cm from the lens. The image is 18 cm high. What is the focal length of the lens?

(A) 9 cm **(B)** 18 cm
(C) 4.5 cm **(D)** 20 cm

51. A thin linear object of size 1 mm is kept along the principal axis of a convex lens of focal length 10 cm. The object is at 15 cm from the lens. The length of the image is:

(A) 1 mm **(B)** 4 mm
(C) 2 mm **(D)** 8 mm

52. Two plano-convex lenses each of focal length 10 cm & refractive index $\frac{3}{2}$ are placed as shown in the figure. In the space left, water $\left(\text{R.I.}=\frac{4}{3}\right)$ is filled. The whole arrangement is in air. The optical power of the system is (in dioptre):

(A) 6.67
(B) - 6.67
(C) 33.3
(D) 20



53. The minimum distance between a real object and its real image formed by a thin converging lens of focal length f is

(A) 4f **(B)** 2f
(C) f **(D)** f/2

54. In the above question the radius of curvature of the curved surface of plano-convex lens is :

(A) $\frac{280}{9}$ cm **(B)** $\frac{180}{7}$ cm
(C) $\frac{39}{3}$ cm **(D)** $\frac{280}{11}$ cm

55. A plano-convex lens, when silvered at its plane surface is equivalent to a concave mirror of focal length 28 cm. When its curved surface is silvered and the plane surface not silvered, it is equivalent to a concave mirror of focal length 10 cm, then the refractive index of the material of the lens is:

(A) 9/14 **(B)** 14/9
(C) 17/9 **(D)** none

56. A convex lens of focal length 25 cm and a concave lens of focal length 20 cm are mounted coaxially separated by a distance d cm. If the power of the combination is zero, *d* is equal to

(A) 45 **(B)** 30
(C) 15 **(D)** 5

57. The focal length of a plano-concave lens is − 10 cm, then its focal length when its plane surface is polished is (n = 3/2):

(A) 20 cm **(B)** − 5 cm
(C) 5 cm **(D)** none of these

58. Critical angle of light passing from glass to air is minimum for

(A) red **(B)** green
(C) yellow **(D)** violet

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59. The dispersion of light in a medium implies that :
(A) lights of different wavelengths travel with different speeds in the medium
(B) lights of different frequencies travel with different speeds in the medium
(C) the refractive index of medium is different for different wavelengths
(D) all of the above.

60 A plane glass slab is placed over various coloured letters. The letter which appears to be raised the least is:
(A) violet **(B)** yellow
(C) red **(D)** green

61. All the listed things below are made of flint glass. Which one of these have greatest dispersive power (ω).
(A) prism **(B)** glass slab
(C) biconvex lens **(D)** all have same ω

62. A medium has $n_v = 1.56$, $n_r = 1.44$. Then its dispersive power is:
(A) 3/50 **(B)** 6/25
(C) 0.03 **(D)** none of these

63. A simple microscope has a focal length of 5 cm. The magnification at the least distance of distinct vision is-
(A) 1 **(B)** 5
(C) 4 **(D)** 6

64. Light of wavelength 4000 Å is incident at small angle on a prism of apex angle 4°. The prism has $n_v = 1.5$ & $n_r = 1.48$. The angle of dispersion produced by the prism in this light is:
(A) 0.2° **(B)** 0.08°
(C) 0.192° **(D)** None of these

65. The resolving power of a telescope is more when its objective lens has
(A) greater focal length **(B)** smaller focal length
(C) greater diameter **(D)** smaller diameter

66. In a compound microscope, the intermediate image is -
(A) virtual, erect and magnified
(B) real, erect and magnified
(C) real, inverted and magnified
(D) virtual, erect and reduced

67. The convex lens is used in-
(A) Microscope **(B)** Telescope
(C) Projector **(D)** All of the above

68. A Galileo telescope has an objective of focal length 100 cm & magnifying power 50. The distance between the two lenses in normal adjustment will be
(A) 150 cm **(B)** 100 cm
(C) 98 cm **(D)** 200 cm

69. The focal length of the objective of a microscope is
(A) arbitrary
(B) less than the focal length of eyepiece
(C) equal to the focal length of eyepiece
(D) greater than the focal length of eyepiece

70. The magnifying power of a simple microscope can be increased if an eyepiece of :
(A) shorter focal length is used
(B) longer focal length is used
(C) shorter diameter is used
(D) longer diameter is used

71. An astronomical telescope has an eyepiece of focal-length 5 cm. If the angular magnification in normal adjustment is 10, when final image is at least distance of distinct vision (25cm) from eye piece, then angular magnification will be :
(A) 10 **(B)** 12
(C) 50 **(D)** 60

72. Resolving power of a microscope depends upon
(A) the focal length and aperture of the eye lens
(B) the focal lengths of the objective and the eye lens
(C) the apertures of the objective and the eye lens
(D) the wavelength of light illuminating the object

73. The focal lengths of the objective and eye-lens of a microscope are 1 cm and 5 cm respectively. If the magnifying power for the relaxed eye is 45, then the length of the tube is :
(A) 30 cm **(B)** 25 cm
(C) 15 cm **(D)** 12 cm

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74. A person with a defective sight is using a lens having a power of +2D. The lens he is using is

(A) concave lens with $f = 0.5$ m

(B) convex lens with $f = 2.0$ m

(C) concave lens with $f = 0.2$ m

(D) convex lens with $f = 0.5$ m

75. An object is placed 30 cm (from the reflecting surface) in front of a block of glass 10 cm thick having its farther side silvered. The final image is formed at 23.2 cm behind the silvered face. The refractive index of glass is :

(A) 1.41 **(B)** 1.46

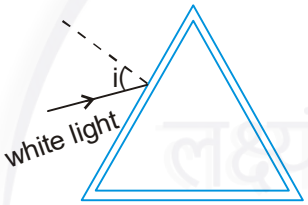
(C) 200/ 132 **(D)** 1.61

76. If the focal length of objective and eye lens are 1.2 cm and 3 cm respectively and the object is put 1.25 cm away from the objective lens and the final image is formed at infinity. The magnifying power of the microscope is :

(A) 150 **(B)** 200

(C) 250 **(D)** 400

77. A beam of white light is incident on hollow prism of glass as shown in figure. Then :



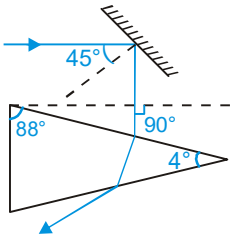
(A) the light emerging from prism gives no dispersion

(B) the light emerging from prism gives spectrum but the bending of all colours is away from base.

(C) the light emerging from prism gives spectrum, all the colours bend towards base, the violet the most and red the least.

(D) the light emerging from prism gives spectrum, all the colours bend towards base, the violet the least and red the most.

78. A ray of light strikes a plane mirror at an angle of incidence 45° as shown in the figure. After reflection, the ray passes through a prism of refractive index 1.50, whose apex angle is 4°. The angle through which the mirror should be rotated if the total deviation of the ray is to be 90° is :



(A) 1^0 clockwise **(B)** 1^0 anticlockwise

(C) 2^0 clockwise **(D)** 2^0 anticlockwise

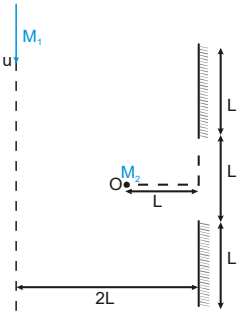
79. Two plane mirrors of length L are separated by distance L and a man M_2 is standing at distance L from the connecting line of mirrors as shown in figure. A man M_1 is walking in a straight line at distance 2 L parallel to mirrors at speed u, then man M_2 at O will be able to see image of M_1 for time:

(A) $\frac{4L}{u}$

(B) $\frac{3L}{u}$

(C) $\frac{6L}{u}$

(D) $\frac{9L}{u}$



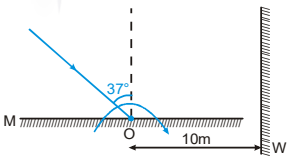
80. A light ray I is incident on a plane mirror M. The mirror is rotated in the direction as shown in the figure by an arrow at frequency $9/\pi$ rps. The light reflected by the mirror is received on the wall W at a distance 10 m from the axis of rotation. When the angle of incidence becomes 37° the speed of the spot (a point) on the wall is:

(A) 10 m/s

(B) 1000 m/s

(C) 500 m/s

(D) None of these



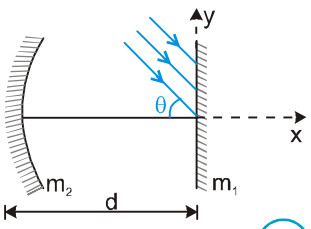
81. In the figure shown a thin parallel beam of light is incident on a plane mirror m_1 at small angle 'θ'. m_2 is a concave mirror of focal length 'f'. After three successive reflections of this beam the x and y coordinates of the image is

(A) $x = f - d, y = f\theta$

(B) $x = d + f, y = f\theta$

(C) $x = f - d, y = -f\theta$

(D) $x = d - f, y = -f\theta$



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82. The distance between an object and its doubly magnified image by a concave mirror is:

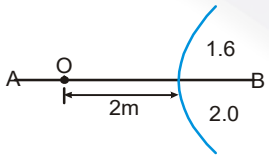
[Assume f = focal length]

(A) 3 f/2 **(B)** 2 f/3

(C) 3 f

(D) depends on whether the image is real or virtual.

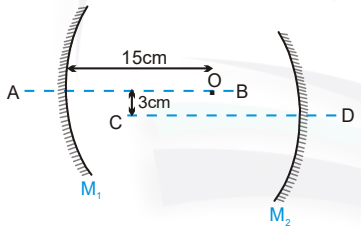
83. In the figure shown a point object O is placed in air. A spherical boundary of radius of curvature 1.0 m separates two media. AB is principal axis. The refractive index above AB is 1.6 and below AB is 2.0. The separation between the images formed due to refraction at spherical surface is:



(A) 12 m **(B)** 20 m

(C) 14 m **(D)** 10 m

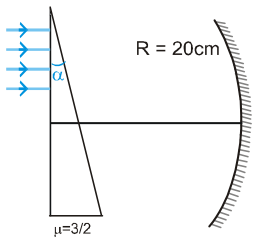
84. In the shown figure M_1 and M_2 are two concave mirrors of the same focal length 10 cm. AB and CD are their principal axes respectively. A point object O is kept on the line AB at a distance 15 cm from M_1. The distance between the mirrors is 20 cm. Considering two successive reflections first on M_1 and then on M_2. The distance of final image from the line AB is:



(A) 3 cm **(B)** 1.5 cm

(C) 4.5 cm **(D)** 1 cm

85. In the given figure a parallel beam of light is incident on the upper part of a prism of angle 1.8° and R.I. 3/2. The light coming out of the prism falls on a concave mirror of radius of curvature 20 cm. The distance of the point (where the rays are focused after reflection from the mirror) from the principal axis is: [use $\pi = 3.14$]



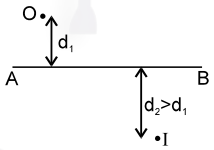
(A) 9 cm

(B) 1.5 7 mm

(C) 3.14 mm

(D) none of these

86. In the figure shown, the image of a real object is formed at point I. AB is the principal axis of the mirror. The mirror must be:

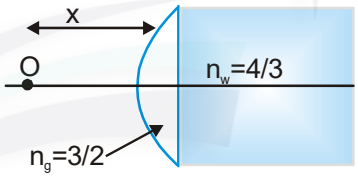


(A) concave and placed towards right of I

(B) concave and placed towards left of O

(C) convex and placed towards right of I

87. In the given figure an object ' O ' is kept in air in front of a thin plano convex lens of radius of curvature 10 cm. It's refractive index is 3/2 and the medium towards right of plane surface is water of refractive index 4/3. What should be the distance ' x ' of the object so that the rays become parallel finally.



(A) 5 cm **(B)** 10 cm

(C) 20 cm **(D)** none of these

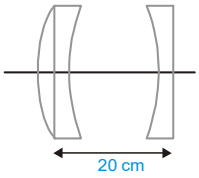
88. For a prism of apex angle 45^0, it is found that the angle of emergence is 45^0 for grazing incidence. Calculate the refractive index of the prism.

(A) $(2)^{1/2}$ **(B)** $(3)^{1/2}$

(C) 2 **(D)** $(5)^{1/2}$

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89. A symmetrical converging convex lens of focal length 10 cm & diverging concave symmetrical lens of focal length – 20 cm are cut from the middle and perpendicularly and symmetrically to their principal axis. The parts thus obtained are arranged as shown in the figure. The focal length of this arrangement will be:



(A) ∞ **(B)** 20 cm

(C) 40 cm **(D)** 80 cm

90. The image (of a real object) formed by a concave mirror is twice the size of the object. The focal length of the mirror is 20 cm. The distance of the object from the mirror is (are)

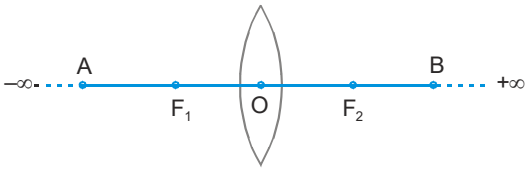
(A) 10 cm **(B)** 30 cm

(C) 25 cm **(D)** 15 cm

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Exercise # 3 PART - 1 MATRIX MATCH COLUMN

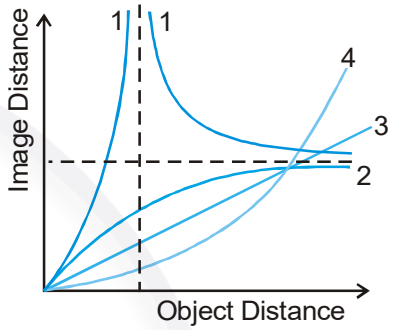
1. Consider the converging lens shown in figure :



Here O is the optic center, F_1 the first principal focus and F_2 the second 0principal focus. ($AF_1 = F_1O$ & $OF_2 = F_2B$)

(A) Object lies between $-\infty$ & F_1	**(J)** Image size is magnified	**(P)** Image lies between O & B
(B) Object lies between A and O	**(K)** Image size is diminished	**(Q)** Image does not lie between O & B
(C) Object lies between F_1 & $+\infty$	**(L)** Image is inverted	**(R)** Image lies between $-\infty$ & F_2
(D) Object does not lie between A and O	**(M)** Image is erect	**(S)** Image lies between F_2 & $+\infty$

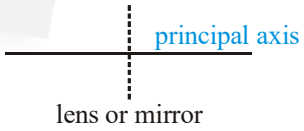
2. A small particle is placed at the pole of a concave mirror and then moved along the principal axis to a large distance. During the motion, the distance between the pole of the mirror and the image is measured. The procedure is then repeated with a convex mirror, a concave lens and a convex lens. The graph is plotted between image distance versus object distance. Match the curves shown in the graph with the mirror or lens that is corresponding to it. (Curve 1 has two segments)



Lens/Mirror	Curve
(A) Converging lens	**(P)** 1
(B) Converging Mirror	**(Q)** 2
(C) Diverging Lens	**(R)** 3
(D) Diverging Mirror	**(S)** 4

3. Column-I gives certain situations regarding a point object and its image formed by an optical instrument. The possible optical instruments are diverging and converging mirrors or lenses as given in Column-II. Same side of principal axis means both image and object should either be above the principal axis or both should be below the principal axis as shown in figure. Same side of optical instrument means both image and object should be either left of the optical instrument or both should be on right of the optical instrument as shown in figure. Match the statements in column-I with the corresponding statements in column-II .

Column I	Column II
(A) If point object and its image are on same side of principal axis and opposite sides of the optical instrument then the optical instrument is	**(P)** Concave mirror
(B) If point object and its image are on opposite side of principal axis and same sides of the optical instrument then the optical instrument is	**(Q)** Convex mirror
(C) If point object and its image are on same side of principal axis and same sides of the optical instrument then the optical instrument is	**(R)** Diverging lens
(D) If point object and its image are on opposite side of principal axis and opposite sides of the optical instrument then the optical instrument is	**(S)** Converging lens



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Exercise # 3 PART - 2 ASSERTION & REASONING

These questions contains, Statement I (assertion) and Statement II (reason).

(A) If both assertion and reason are true and the reason is the correct explanation of the assertion.

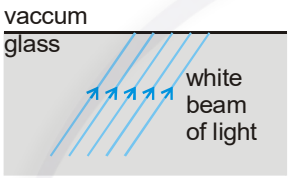
(B) If both assertion and reason are true but reason is not the correct explanation of the assertion.

(C) If assertion is true but reason is false.

(D) If assertion is false but reason is true.

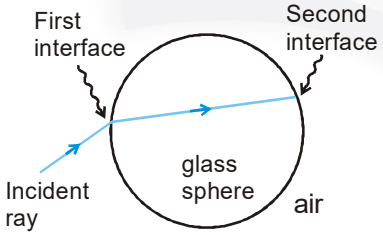
(E) If the assertion and reason both are false.

1. **Assertion :** A white parallel beam of light is incident on a plane glass-vacuum interface as shown. The beam may not undergo dispersion after suffering deviation at the interface (The beam is not incident normally on the interface.)



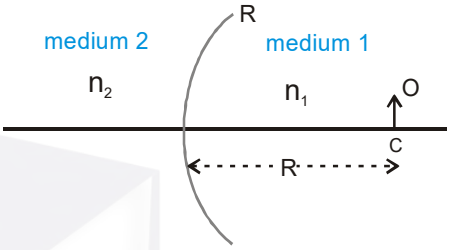
Reason : Vacuum has same refractive index for all colours of white light.

2. **Assertion :** A ray is incident from outside on a glass sphere surrounded by air as shown. This ray may suffer total internal reflection at second interface.



Reason : For a ray going from denser to rarer medium, the ray may suffer total internal reflection.

3. **Assertion :** A spherical surface of radius of curvature R separates two media of refractive index n_1 and n_2 as shown. If an object O (a thin small rod) is placed upright on principal axis at a distance R from pole (i.e., placed at centre of curvature), then the size of image is same as size of object.



Reason : If a point object is placed at centre of curvature of spherical surface separating two media of different refractive index, then the image is also formed at centre of curvature, i.e., image distance is equal to object distance.

4. **Assertion :** A point object moves near the principal axis of a fixed spherical mirror along a straight line. Then the image formed by the spherical mirror also moves along a straight line.

Reason : For an incident ray on a fixed spherical mirror there is a fixed reflected ray. If a point object moves along this incident ray, its image will always lie on the given reflected ray. Further an incident ray can be drawn from the moving point object in its direction of velocity towards the mirror.

5. **Assertion :** When an object is placed between two plane parallel mirrors, then all the images found are of equal intensity.

Reason : In case of plane parallel mirrors, only two images are possible.

6. **Assertion :** The mirrors used in search lights are parabolic and not concave spherical.

Reason : In a concave spherical mirror the image formed is always virtual.

7. **Assertion :** The size of the mirror affect the nature of the image.

Reason : Small mirrors always forms a virtual image.

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8. **Assertion :** Just before setting, the sun may appear to be elliptical. This happens due to refraction.
Reason : Refraction of light ray through the atmosphere may cause different magnification in mutually perpendicular directions.

9. **Assertion :** Critical angle of light passing from glass to air is minimum for violet colour.
Reason : The wavelength of blue light is greater than the light of other colours.

10. **Assertion :** We cannot produce a real image by plane or convex mirrors under any circumstances.
Reason : The focal length of a convex mirror is always taken as positive.

11. **Assertion :** A piece of red glass is heated till it glows in dark. The colour of glowing glass would be orange.
Reason : Red and orange is complementary colours.

12. **Assertion :** Within a glass slab, a double convex air bubble is formed. This air bubble behaves like a converging lens.
Reason : Refractive index of air is more than the refractive index of glass.

13. **Assertion :** The images formed by total internal reflections are much brighter than those formed by mirrors or lenses.
Reason : There is no loss of intensity in total internal reflection.

14. **Assertion :** The focal length of lens does not change when red light is replaced by blue light.
Reason : The focal length of lens does not depends on colour of light used.

15. **Assertion :** There is no dispersion of light refracted through a rectangular glass slab.
Reason : Dispersion of light is the phenomenon of splitting of a beam of white light into its constituent colours.

16. **Assertion :** All the materials always have the same colour, whether viewed by reflected light or through transmitted light.
Reason : The colour of material does not depend on nature of light.

17. **Assertion :** A beam of white light gives a spectrum on passing through a hollow prism.
Reason : Speed of light outside the prism is different from the speed of light inside the prism.

18. **Assertion :** By increasing the diameter of the objective of telescope, we can increase its range.
Reason : The range of a telescope tells us how far away a star of some standard brightness can be spotted by telescope.

19. **Assertion :** For the sensitivity of a camera, its aperture should be reduced.
Reason : Smaller the aperture, image focussing is also sharp.

20. **Assertion :** If objective and eye lenses of a microscope are interchanged then it can work as telescope.
Reason : The objective of telescope has small focal length.

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Exercise # 4 PART - 1 PREVIOUS YEAR (NEET/AIPMT)

1. Rainbows are formed by
(A) reflection and diffraction
(B) refraction and scattering
(C) dispersio and total internal reflection
(D) interference only

2. A man is 6 ft tall. In order to see his entire image, he requires a plane mirror of minimum length equal to

(A) 6 ft **(B)** 12 ft
(C) 2 ft **(D)** 3 ft

3. A planoconvex lens is made of a material of refractive index $\mu = 1.5$. The radius of curvature fo curved surface of the lens is 20 cm. If its plane surface is silvered, the focal length of the silvered lens will be

(A) 10 cm **(B)** 20 cm
(C) 40 cm **(D)** 80 cm

4. A transparent cube contains a small air bubble. Its apparent distance is 2 cm when seen through one face and 5 cm when seen through other face. If the refractive index of the material of the cube is 1.5, the real length of the edge of cube must be

(A) 7 cm **(B)** 7.5 cm
(C) 10.5 cm **(D)** $\frac{14}{3}$ cm

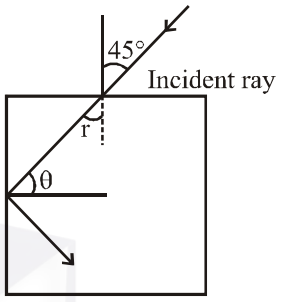
5. Diameter of human eye lens is 2 mm. What will be the minimum distance between two points to resolve them, which are situated at a distance of 50 m from eye? [The wavelength of light is 5000 Å]

(A) 2.32 m **(B)** 4.28 mm
(C) 1.25 cm **(D)** 12.48 cm

6. A body is located on a wall. Its image of equal size is to be obtained on a parallel wall with the help of a convex lens. The lens is placed at a distance d ahead of second wall, then the required focal length will be

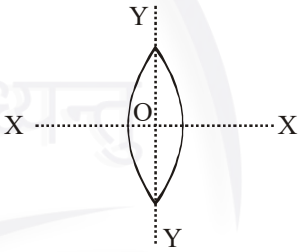
(A) only $\frac{d}{4}$
(B) only $\frac{d}{2}$
(C) more than $\frac{d}{4}$ but less than $\frac{d}{2}$
(D) less than $\frac{d}{4}$

7. For the given incident ray as shown in figure, the condition of total internal reflection of the ray will be satisfied if the refractive index of block will be



(A) $\frac{\sqrt{3}+1}{2}$ **(B)** $\frac{\sqrt{2}+1}{2}$
(C) $\sqrt{\frac{3}{2}}$ **(D)** $\sqrt{\frac{7}{6}}$

8. An equiconvex lens is cut into two halves along (i) XOX′ and (ii) YOY′ as shown in the figure. Let f, f′, f″ be the focal lengths of the complete lens, of each half in case (i), and of each half in case (ii), respectively.



Choose the correct statement from the following

(A) $f' = f, f'' = f$ **(B)** $f' = 2f, f'' = 2f$
(C) $f' = f, f'' = 2f$ **(D)** $f' = 2f, f'' = f$

9. A convex lens is dipped in a liquid whose refractive index is equal to the refractive index of the lens. Then its focal length will

(A) become small, but non-zero
(B) remain unchanged
(C) become zero
(D) become infinite

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10. The refracitive index of the material of a prism is $\sqrt{2}$ and its refracting angle is 30°. One of the refracting surfaces of the prism is made a mirror inwards. A beam of monochromatic light will retrace its path after reflection from the mirrored surface, if its angle of incidence on the prism is

(A) 45° **(B)** 60°
(C) 0° **(D)** 30°

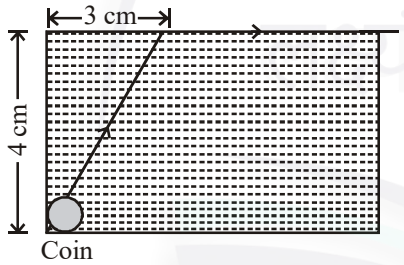
11. A microscope is focussed on a mark on a piece of paper and then a slab of glass of thickness 3 cm and refractive index 1.5 is placed over the mark. How should the microscope be moved to get the mark in focus again?

(A) 1 cm upward **(B)** 4.5 cm downward
(C) 1 cm downward **(D)** 2 cm upward

12. A convex lens and a concave lens, each having same focal length of 25 cm, are put in contact to form a combination of lenses. The power in diopters of the combination is

(A) 25 **(B)** 50
(C) infinite **(D)** zero

13. A small coin is resting on the bottom of a beaker filled the coin travels upto the surface of the liquid and moves along its surface (see figure).



How fast is the light travelling in the liquid?

(A) 1.8×10^8 m/s **(B)** 2.4×10^8 m/s
(C) 3.0×10^8 m/s **(D)** 1.2×10^4 m/s

14. The frequency of a light wave in material is 2×10^{14} Hz and wavelength is 5000 Å. The refractive index of material will be

(A) 1.40 **(B)** 1.50
(C) 3.00 **(D)** 1.33

15. Two thin lenses of focal lengths f_1 and f_2 are in contact and coaxial. The power of the combination is

(A) $\sqrt{\frac{f_1}{f_2}}$ **(B)** $\sqrt{\frac{t_2}{t_1}}$

(C) $\frac{f_1 + f_2}{2}$ **(D)** $\frac{f_1 + f_2}{f_1 f_2}$

16. A boy is trying to start a fire by focusing sunlight ona piece of paper using an equiconvex lens of focal length 10 cm. The diameter of the sun is 1.39×10^9 m and its mean distacne from the earth is 1.5×10^{11} m. What is the diameter of the sun's image on the paper?

(A) 9.2×10^{-4} m **(B)** 6.5×10^{-4} m
(C) 6.5×10^{-5} m **(D)** 12.5×10^{-4} m

17. A lens having focal length f and aperture of diameter d forms an image of intensity I. Aperture of diameter $\frac{d}{2}$ in central region of lens is covered by a black paper. focal length of lens and intensity of image now will be respectively.

(A) f and $\frac{I}{4}$ **(B)** $\frac{3f}{4}$ and $\frac{I}{2}$

(C) f and $\frac{3I}{4}$ **(D)** $\frac{f}{2}$ and $\frac{I}{2}$

18. A ray of light travelling in a transparent medium of refractive index μ falls, on a surface separating the medium from air at an angle of incidence of 45°. For which of the following value of μ the ray can undergo total internal reflection?

(A) $\mu = 1.33$ **(B)** $\mu = 1.40$
(C) $\mu = 1.50$ **(D)** $\mu = 1.25$

19. A biconvex lens has a radius of curvature of magnitude 20 cm. Which one of the following options describe best the image formed of an object of height 2 cm placed 30 cm from the lens?

(A) Virtual, upright, height = 0.5 cm
(B) Real, inverted, height = 4 cm
(C) Real, inverted, height = 1 cm
(D) Virtual, upright, height = 1 cm

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20. The magnitude power of a telescop is 9. When it is adjusted for parallel rays the distance between the objective and eyepiece is 20 cm. The focal length of lenses are

(A) 10 cm, 10 cm

(B) 15 cm, 5 cm

(C) 18 cm, 2 cm

(D) 11 cm, 9 cm

21. A concave mirror of focal length f_1 is placed ata distance of d from a convex lens of focal length f_2. A beam of light coming finfinity and falling on this convex lens - concave mirror combination returns to infinity. The distance d must be equal

(A) $f_1 + f_2$ **(D)** $-f_1 + f_2$

(C) $2f_1 + f_2$ **(D)** $-2f_1 + f_2$

22. A ray of light is incident at an angle of incidence, i, on one face of a prism of angle A (assumed to be small) and emerges normally from the opposite face. If the refractive index of the prism is μ, the angle of incidence i, is nearly equal to

(A) μA **(B)** $\frac{\mu A}{2}$

(C) A/μ **(D)** A/2μ

23. When a biconvex lens of glass having refractive index 1.47 is dipped in a liquid, it acts as a plane sheet of glass. This implies that the liquid must have refractive index

(A) equal to tht of glass

(B) less than one

(C) greater than that of glass

(D) less than that of glass

24. For normal eye, the cornea of eye provides a converging power of the eye lens behind the cornea is 20 D. Using this information, the distance between the retina and the cornea, eye lens can be estinated to be

(A) 5 cm **(B)** 2.5 cm

(C) 1.67 cm **(D)** 1.5 cm

25. A plano-convex lens fits exactly into a plano-concave lens. Their plane surfaces are parallel to each other. If lenses are made of different materials of refractive indices μ_1 and μ_2 and R is the radius of curvature of the curved surface of the lenses, then the focal length of the combination is

(A) $\frac{R}{2(\mu_1 + \mu_2)}$ **(B)** $\frac{R}{2(\mu_1 - \mu_2)}$

(C) $\frac{R}{(\mu_1 - \mu_2)}$ **(D)** $\frac{2R}{(\mu_2 - \mu_1)}$

26. The angle of a prism is A. One of its refracting surfaces is silvered. Light rays falling at an angle of indicence 2A on the first surface returns back through the same path after suffering reflection at the silvered surface. The refractive index μ, of the prism is

(A) 2 sin A **(B)** 2 cos A

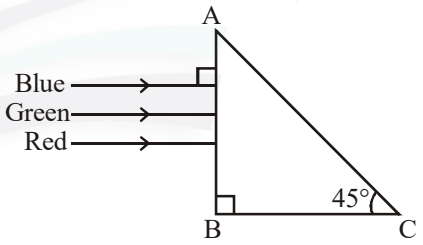
(C) $\frac{1}{2}\cos A$ **(D)** tan A

27. Light with an energy flux of 25×10^4 Wm^{-2} falls on a perfectly reflecting surface at normal incidence. If the surface area is 15 cm^2, the average force exerted on the surface is

(A) 1.25×10^{-6} N **(B)** 2.50×10^{-6} N

(C) 1.20×10^{-6} N **(D)** 3.0×10^{-6} N

28. A beam of light consisting red, green and blue colours is incident on a right angled prism. The refractive index of the material of the prism for the above red, green and blue wavelengths are 1.39, 1.44 and 1.47, respectively.



The prism will

(A) separate the blue colour patt from the red and green colours

(B) separate all the three colours from one another

(C) not separate the three colours at all

(D) separate the red colour part from the green and blue colours

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29. Two identical thin plano-convex glass lenses (frefractive index 1.5) each having radius of curvature of 20 cm are placed with their convex surfaces in contact at the centre. The intervening space is filled with oil of refractive index 1.7. The focal length of the combination is

(A) – 20 cm **(B)** – 25 cm
(C) – 50 **(D)** 50 cm

30. A person can see clearly objects only when they lie between 50 cm and 400 cm from his eye. In order to increase the maximum distance of distinct vision to infinity, the type and power of the correcting lens, the person has to use, will be

(A) convex, + 2.25 diopter
(B) concave, – 0.25 diopter
(C) concave – 0.2 diopter
(D) convex, + 0.15 diopter

31. An air bubble in a glass slab with refractive index 1.5 (near normal incidence) is 5 cm deep when viewed from one surface and 3 cm deep when viewed from the opposite face. The thickness (in cm) of the slab is

(A) 8 **(B)** 10
(C) 12 **(D)** 16

32. Two identical glass ($\mu_g = 3/2$) equi-convex lenses of focal length f each are kept in contact. The space between the two lenses is filled with water ($\mu_w + 4/3$). The focal length of the combination is

(A) f / 3 **(B)** f
(C) $\frac{4f}{3}$ **(D)** $\frac{3f}{4}$

33. The angle of incidence for a ray of light at a refracting surface of a prism is 45°. The angle of prism is 60°. If the ray suffers minimum deviation through the prism, the angle of minimum deviation and refractive index of the material of the prism respectivel, are

(A) $30; \sqrt{2}$ **(B)** $45°; \sqrt{2}$
(C) $30°; \frac{1}{\sqrt{2}}$ **(D)** $45°; \frac{1}{\sqrt{2}}$

34. Match the corresponding entries of Colum 1 with Column 2. [Where m is the magnification produced by the mirror]

	Column 1		Column 2
A.	$m = -2$	a.	Convex mirror
B.	$m = -\frac{1}{2}$	b.	Concave mirror
C.	$m = +2$	c.	Real image
D.	$m = +\frac{1}{2}$	d.	Virtual image

(A) A → a and c; B → a and d; C → a and b; D → c and d
(B) A → a and d; B → b and c; C → b and d; D → b and c
(C) A → c and d ; B → b and d; C → b and c; D → a and d
(D) A → b and c; B → b and c; C → b and d; D → a and d

35. A thin prism having refracting angle 10° is made of glass of refractive index 1.42. This prism is combined with another thin prism of glass of refractive index 1.7. This combination produces dispersion without deviation. The refracting angle of second prism should be

(A) 4° **(B)** 6°
(C) 8° **(D)** 10°

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Exercise # 4 PART - 2 PREVIOUS YEAR (AIIMS)

1. When a ray of light enters a glass slab, then
(A) its frequency and velocity changes
(B) only frequency changes
(C) its frequency and wavelength changes
(D) its frequency does not change.

2. Match the elements of table I and table II.

	Table I		Table II
1.	Myopia	(i)	Bifocal lens
2.	Hypermetropia	(ii)	Cylindrical lens
3.	Presbyopia	(iii)	Concave lens
4.	Astigmatism	(iv)	Convex lens

(A) 1 - iii, 2 - iv, 3 - i, 4 - ii
(B) 1 - iv, 2 - iii, 3 - i, 4 - ii
(C) 1 - i, 2 - ii, 3 - iii, 4 - iv
(D) 1 - ii, 2 - iv, 3 - i, 4 - iii.

3. A light wave moves from air to glass with frequency υ and wavelength λ. Then
(A) υ changes
(B) υ does not change, λ change
(C) λ does not change
(D) υ and λ changes.

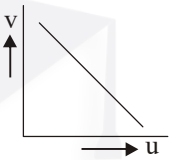
4. A good photographic print is obtained by exposure of 2 second at a distance of 1 m from the lamp. How much time will be required to get equally good result at a distance 2 m from the same lamp ?
(A) 1 second **(B)** 2 second
(C) 4 second **(D)** 8 second

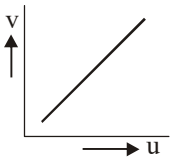
5. The Cauchy's dispersion formula is
(A) $n = 4 + B\lambda^{-2} + C\lambda^{-4}$
(B) $n = A + B\lambda^{-2} + C\lambda^{4}$
(C) $n = A + B\lambda^{2} + C\lambda^{-4}$
(D) $n = A + B\lambda^{2} + C\lambda^{4}$

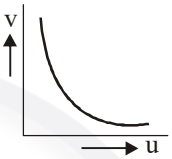
6. Brilliance of diamond is due to
(A) shape
(B) reflection
(C) cutting
(D) total internal reflection.

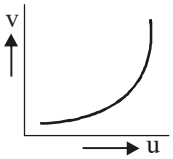
7. When a beam of light is used to determine the position of an object, the maximum accuracy is achieved if the light is
(A) polarised
(B) of longer wavelength
(C) of shorter wavelength
(D) of high intensity.

8. In an experiment to find the focal length of a concave mirror a graph is drawn between the magnitudes of u and v. The graph looks like

(A)


(B)


(C)


(D)


9. An astronaut is looking down on earth's surface from a space shuttle at an altitude of 400 km. Assuming that the astronaut's pupil diameter is 5 mm and the wavelength of visible light is 500 nm, the astronaut will be able to resolve linear objects of the size about
(A) 0.5 m **(B)** 5 m
(C) 50 m **(D)** 500 m

10. Sodium lamps are used in foggy conditions because
(A) yellow light is scattered less by the fog particles
(B) yellow light is scattered more by the fog particles
(C) yellow light is unaffected during its passage through the fog
(D) wavelength of yellow light is the mean of the visible part of the spectrum.

11. An object is immersed in a fluid. In order that the object becomes invisible, it should
(A) behave as a perfect reflector
(B) absorb all light falling on it
(C) have refractive index one
(D) have refractive index exactly matching with that of the surrounding fluid.

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12. An endoscope is employed by a physician to view the internal parts of a body organ. It is based on the principle of

(A) refraction

(B) reflection

(C) total internal reflection

(D) dispersion.

13. What should be the maximum acceptance angle at the air-core interface of an optical fibre if n_1 and n_2 are the refractive indices of the core and the cladding, respectively ?

(A) $\sin^{-1}(n_2/n_1)$ (B) $\sin^{-1}\sqrt{n_1^2 - n_2^2}$

(C) $\left[\tan^{-1}\frac{n_2}{n_1}\right]$ (D) $\left[\tan^{-1}\frac{n_1}{n_2}\right]$

14. A telescope has an objective lens of focal length 200 cm and an eye piece with focal length 2 cm. If this telescope is used to see a 50 meter tall building at a distance of 2 km, what is the height of the image of the building formed by the objective lens ?

(A) 5 cm (B) 10 cm

(C) 1 cm (D) 2 cm

15. The apparent depth of water in cylindrical water tank of diameter 2R cm is reducing at the rate of x cm/minute when water is being drained out at a constant rate. The amount of water drained in c.c. per minute is (n_1 = refractive index of air, n_2 = refractive index of water).

(A) $\frac{x\pi R^2 n_1}{n_2}$ (B) $\frac{x\pi R^2 n_2}{n_1}$

(C) $\frac{2\pi R n_1}{n_2}$ (D) $\pi R^2 x$.

16. In refraction, light waves are bent on passing from one medium to the second medium, because in the second medium

(A) the frequency is different

(B) the coefficient of elasticity is different

(C) the speed id different

(D) the amplitude is smaller.

17. A wire mesh consisting of very small squares is viewed at a distance of 8 cm through a magnifying converging lens of focal length 10 cm, kept close to the eye. The magnification produced by the lens is

(A) 5 (B) 8

(C) 10 (D) 20

18. A lens is made of flint glass (refractive index = 1.5). When the lens is immersed in a liquid of refractive index 1.25, the focal length

(A) increases by a factor of 1.25

(B) increases by a factor of 2.5

(C) increases by a factor of 1.2

(D) decreases by a factor of 1.2

19. Flash light equipped with a new set of batteries, produces bright white light. As the batteries wear out,

(A) the light intensity gets reduced with no change in its colour

(B) light colour changes first to yellow and then red with no change in intensity

(C) it stops working suddenly while giving white light

(D) colour changes to red and also intensity gets reduced.

20. A leaf which contains only green pigments is illuminated by a laser light of wavelength 0.6328 μm. It would appear to be

(A) brown (B) black

(C) red (D) green

21. The camera lens has an aperture of *f* and the exposure time is (1/60) s. What will be the new exposure time if the aperture become 1.4 *f* ?

(A) $\frac{1}{42}$ (B) $\frac{1}{56}$

(C) $\frac{1}{72}$ (D) $\frac{1}{31}$

22. A point source is kept at a distance of 1000 m has an illumination I. To change the illumination to 16I the new distance should become

(A) 250 m (B) 500 m

(C) 750 m (D) 800 m

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23. The focal length of the objective and eye lenses of a microscope are 1.6 cm and 2.5 cm respectively. The distance between the two lenses is 21.7 cm. If the final image is formed at infinity. What is the linear magnification ?

(A) 11 **(B)** 110

(C) 1.1 **(D)** 44

24. A converging lens forms a real image I of an object on its principal axis. A rectangular slab of refractive index μ and thickness x is introduced between I and the lens, I will move

(A) towards the lens $(\mu - 1)x$

(B) towards the lens by $\left(1-\frac{1}{\mu}\right)x$

(C) away from the lens by $(\mu - 1)x$

(D) away from the lens by $\left(1-\frac{1}{\mu}\right)x$.

25. Lumen is the unit of

(A) luminous flux **(B)** luminosity

(C) illumination **(D)** quantity of light

26. When white light passes through a prism, the deviation is maximum for

(A) violet light **(B)** green light

(C) red light **(D)** yellow light

27. An object 5 cm tall is placed 1 m from a concave spherical mirror which has a radius of curvature of 20 cm. The size of the image is

(A) 0.11 cm **(B)** 0.50 cm

(C) 0.55 cm **(D)** 0.60 cm

28. The magnifying power of a compound microscope increases with

(A) the focal length of objective lens is increased and that of eye lens is decreased

(B) the focal length of eye lens is increased and that of objective lens is decreased

(C) focal lengths of both objects and eye-piece are increased

(D) focal lengths of both objects and eye-piece are decreased.

29. A convex lens of refractive index $\frac{3}{2}$ has a power of 2.5 D in air. If it is placed in a liquid of refractive index 2, then the new power of the lens is

(A) – 1.25 D **(B)** – 1.5 D

(C) 1.25 D **(D)** 1.5 D

30. Light with an energy flux of 18 W/cm^2 falls on a non-reflecting surface at normal incidence. The pressure exerted on the surface is

(A) 2 N/m^2 **(B)** 2×10^{-4} N/m^2

(C) 6 N/m^2 **(D)** 6×10^{-4} N/m^2

31. In a concave mirror, an object is placed at a distance d_1 from the focus and the image is formed at a distance d_2 from the focus. Then the focal length of the mirror is

(A) $\sqrt{d, d_2}$ **(B)** $d_1 d_2$

(C) $(d_1 + d_2)/2$ **(D)** $\sqrt{d_1 / d_2}$

32. A short linear object, of length *l*, lies along the axis of a concave mirror, of focal length *f*, at a distance d from the pole of the mirror. The size of the image is then (nearly)

(A) $\frac{lf}{d-f}$ **(B)** $\frac{d-f}{lf}$

(C) $l\frac{f^2}{(d-f)^2}$ **(D)** $\frac{(d-f)^2}{f^2}l$

33. For a person near point of vision is 100 cm. Then the power of lens he must wear so as to have normal vision, should be

(A) +1 D **(B)** – 1D

(C) + 3 D **(D)** – 3 D

34. Two lens of focal lengths – 20 cm and + 10 cm are put in combination, find the power of the combination.

(A) – 1 D **(B)** – 2 D

(C) + 5 D **(D)** + 2 D

35. A far sighted person has his near point 50 cm, find the power of lens he should use to see at 25 cm, clearly.

(A) + 1 D **(B)** + 2 D

(C) – 2 D **(D)** – 1 D

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36. In a convex lens of focal length F, the minimum distance between an object and its real image must be

(A) 3F **(B)** 4F

(C) $\frac{3}{2}$F **(D)** 2F

37. The frequency of a light wave in a material is 2×10^{14} Hz and wavelength is 5000 Å. The refractive index of material will be

(A) 1.50 **(B)** 3.00

(C) 1.33 **(D)** 1.40

38. The length of deviation for a glass prism is equal to its refracting angle. The refractive index of glass is 1.5. Then the angle of prism is

(A) $2\cos^{-1}(3/4)$ **(B)** $\sin^{-1}(3/4)$

(C) $2\sin^{-1}(3/2)$ **(D)** $\cos^{-1}(3/2)$

39. The near point of distinct vision is at 1 m for an elderly person. What power of lens is to be used to bring the near point to the minimum distance of distinct vision (25 cm) ?

(A) 2.5 D **(B)** 3 D

(C) 3.5 D **(D)** 4 D

40. A person uses + 1.5 D glasses to have normal vision from 25 cm onwards. He uses a + 20 D lens as a simple microscope to see an object. What is the maximum magnifying power if the uses the microscope without glasses.

(A) 8 **(B)** 9

(C) 10 **(D)** 11

41. Light wave enters from medium 1 to medium 2. Its velocity in 2nd medium is double from 1st. For total internal reflection the angle of incidence must be greater than

(A) 30° **(B)** 60°

(C) 45° **(D)** 90°

42. A transparent cube of 15 cm edge contains a small air bubble. Its apparent depth when viewed through one face is 6 cm and when viewed through opposite face is 4 cm. The refractive index of material of cube is

(A) 2.0 **(B)** 1.5

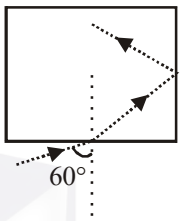
(C) 1.6 **(D)** 2.5

43. Focal length of objective and eye piece of telescope are 200 cm and 4 cm respectively. What is the length of telescope for normal adjustment ?

(A) 196 cm **(B)** 204 cm

(C) 250 cm **(D)** 225 m

44. For a situation shown in figure, find the refrective index of glass so that it will suffer total internal reflection at the vertical surface.



(A) 1.732 **(B)** 1.5

(C) 1.31 **(D)** 1.6

ASSERTION AND REASON

45. **Assertion :** Danger signals are made of red colour.

Reason : Velocity of red light is maximum and thus more visibility is dark.

46. **Assertion :** Endoscopy involves use of optical fibres to study internal organs

Reason : Optical fibres are based on phenomena of total internal reflection.

47. **Assertion :** If a convex lens is kept in water its convergent power decreases.

Reason : Focal length of convex lens in water increases.

48. **Assertion :** The stars twinkle while the planets do not.

Reason : The stars are much bigger in size than the planets.

49. **Assertion :** Owls can move freely during night.

Reason : they have large number of rods on their retina.

50. **Assertion :** A red object appears dark in the yellow light.

Reason : The red colour is scattered less.

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51. **Assertion :** A famous painting was painted by not using brush strokes in the usual manner, but rather a myriad of small colour dots. In this painting the colour you see at any given place on the painting changes as you move away.
Reason : The angular separation of adjacent dots changes with the distance from the painting.

52. **Assertion :** By roughening the surface of a glass sheet its transparency can be reduced.
Reason : Glass sheet with rough surface absorbs more light.

53. **Assertion :** Diamond glitters brilliantly.
Reason : Diamond does not absorb sunlight.

54. **Assertion :** Optical fibres are used for telecommunication
Reason : Optical fibres are based on the phenomenon of total internal reflection.

55. **Assertion :** Goggles have zero power.
Reason : Radius of curvature of both sides of lens is same

56. **Assertion :** The colour of the green flower seen through red appears to be dark.
Reason : Red glass transmits only red light.

57. **Assertion :** A double convex lens ($\mu = 1.5$) has focal length 10 cm. When the lens is immersed in water ($\mu = 4/3$) its focal length becomes 77 cm.
Reason : $\frac{1}{f} = \frac{\mu_v - \mu_m}{\mu_m}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

58. **Assertion :** A total reflecting prism is used to erect the inverted image without deviation.
Reason : Rays of light incident parallel to base of prism emerge out as parallel rays.

59. **Assertion : Assertion :** the edges of the images of white object formed by a concave mirror on the screen appear white.
Reason : concave mirror does not suffer chromatic aberration.

60. **Assertion :** If objective and eye lenses of a microscope are interchanged then it can work as telescope.
Reason : The objective lens of telescope has small focal length.

61. **Assertion :** When white light fall on the compact disc, multicolours are seen after reflection.
Reason : CD disc behaves like a prism.

62. **Assertion :** When a white light is passed through a lens, violet light is more refracted than red light.
Reason : focal length for red light is greater than violet.

63. **Assertion :** Microscope magnifies the image.
Reason : Angular magnification for image is more than object in microscope.

64. **Assertion :** Magnification of a convex mirror is always positive, but that of a concave mirror may be both positive or negative.
Reason : It depends on the sign convention chosen.

65. **Assertion :** A thick lens shows more chromatic aberration.
Reason : Thick lens behave as many thin lenses.

66. **Assertion :** The focal length of objective lens in telescope is much more than that of eye piece.
Reason : Telescope has high resolving power due to large focal length.

67. **Assertion :** if optical density of a substance is more than that of water then the mass density of substance can be less than water.
Reason : Optical density and mass density are not related.

68. **Assertion :** The sun rises some time before the actual sun-rise.
Reason : During sun rises, the refraction takes place through the different layers of atmosphere.

69. **Assertion :** The edges of the images of white object formed by a concave mirror on the screen appear white.
Reason : Concave mirror does not suffer from chromatic aberration.

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70. **Assertion :** In optical fibre, the diameter of the core is kept small.

Reason : The smaller diameter of the core ensures that the fibres should have incident angle more than the critical angle required for total internal reflection.

71. **Assertion :** A secondary rainbow have inverted colours than the primary rainbow.

Reason : the secondary rainbow is formed by single total internal reflection.

72. **Assertion :** When an object is placed between two plane parallel mirrors, then all the images found are of equal intensity.

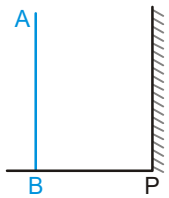
Reason : In case of plane parallel mirrors, only two images are possible.

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MOCK TEST

STRAIGHT OBJECTIVE TYPE

1. In the figure shown a person AB of height 170 cm is standing infront of a plane mirror. His eyes are at height 164 cm. At what distance from P should a hole be made in the mirror so that he cannot see the top of his head.



(A) 167 cm **(B)** 161 cm

(C) 163 cm **(D)** none of these

2. I is the image of a point object O formed by spherical mirror, then which of the following statement is incorrect:

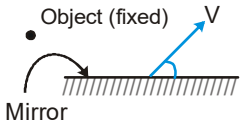
(A) If O and I are on same side of the principal axis, then they have to be on opposite sides of the mirror.

(B) If O and I are on opposite side of the principal axis, then they have to be on same side of the mirror.

(C) If O and I are on opposite side of the principal axis, then they can be on opposite side of the mirror as well.

(D) If O is on principal axis then I has to lie on principal axis only.

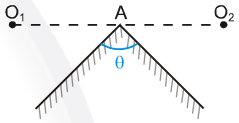
3. An object and a plane mirror are shown in figure. Mirror is moved with velocity V as shown. The velocity of image is :



(A) 2 V sinθ **(B)** 2 V

(C) 2V cosθ **(D)** none of these

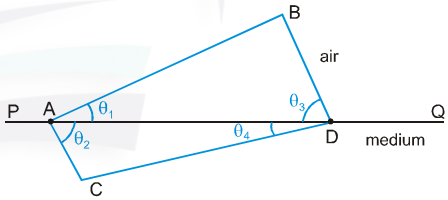
4. Two plane mirrors are joined together as shown in the figure. Two point objects O_1 and O_2 are placed symmetrically such that $AO_1 = AO_2$. The image of the two objects is common if :



(A) θ = 60° **(B)** θ = 90°

(C) θ = 30° **(D)** θ = 45°

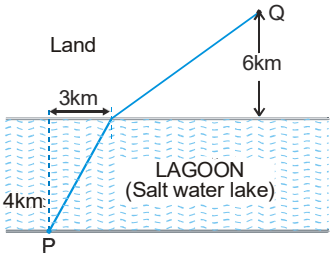
5. The following figure represents a wave front AB which passes from air to another transparent medium and produces a new wave front CD after refraction. The refractive index of the medium is (PQ is the boundary between air and the medium).



(A) $\frac{\cos\theta_1}{\cos\theta_4}$ **(B)** $\frac{\cos\theta_4}{\cos\theta_1}$

(C) $\frac{\sin\theta_1}{\sin\theta_4}$ **(D)** $\frac{\sin\theta_2}{\sin\theta_3}$

6. A man starting from point P crosses a 4 km wide lagoon and reaches point Q in the shortest possible time by the path shown in the figure. If the person swims at a speed of 3 km/hr and walks at a speed of 4 km/hr, then his time of journey is ($\mu_{\text{salt water}} = 4/3$) :



(A) 4hr, 10 min. **(B)** 4 hr and 30 min.

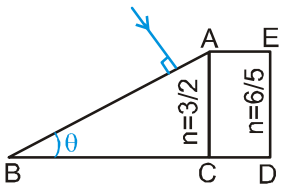
(C) 3 hr and 50 min **(D)** 5 hr and 10 min.

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7. A mango tree is at the bank of a river and one of the branch of tree extends over the river. A tortoise lives in the river . A mango falls just above the tortoise. The acceleration of the mango falling from tree appearing to the tortoise is (Refractive index of water is 4/3 and the tortoise is stationary)

(A) g **(B)** $\frac{3g}{4}$ **(C)** $\frac{4g}{3}$ **(D)** None of these

8. In the figure ABC is the cross section of a right angled prism and ACDE is the cross section of a glass slab. The value of θ so that light incident normally on the face AB does not cross the face AC is



(given $\sin^{-1}(3/5) = 37^\circ$)

(A) $\theta \le 37^\circ$ **(B)** $\theta < 37^\circ$

(C) $\theta \le 53^\circ$ **(D)** $\theta < 53^\circ$

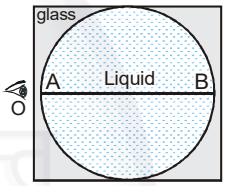
9. Refractive index of a prism is $\sqrt{\frac{7}{3}}$ and the angle of prism is 60°. The minimum angle of incidence of a ray that will be transmitted through the prism is :

(A) 30° **(B)** 45° **(C)** 15° **(D)** 50°

10. For a prism kept in air it is found that for an angle of incidence 60°, the angle of refraction 'A', angle of deviation 'δ' and angle of emergence 'e' become equal. Then the refractive index of the prism is

(A) 1.73 **(B)** 1.15 **(C)** 1.5 **(D)** 1.33

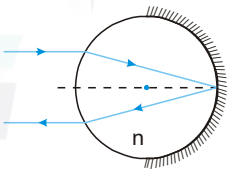
11. As shown in the figure the observer 'O' sees the distance AB as infinitely large. If refractive index of liquid is μ_1 and that of glass is μ_2, then $\frac{\mu_1}{\mu_2}$ is :



(A) 2 **(B)** 1/2

(C) 4 **(D)** None of these

12. A transparent cylinder has its right half polished so as to act as a mirror. A paraxial light ray is incident from left, that is parallel to principal axis, exits parallel to the incident ray as shown in the figure. The refractive index n of the material of the cylinder is :



(A) 1.2 **(B)** 1.5

(C) 1.8 **(D)** 2.0

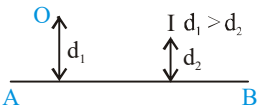
13. In the figure shown, the image of a real object O is formed at point I. AB is the principal axis of the mirror. The mirror must be:

(A) concave & placed towards right of I

(B) concave & placed towards left of I

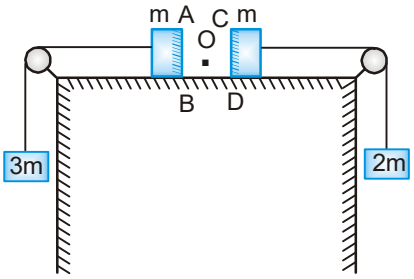
(C) convex & placed towards right of I

(D) convex & placed towards left of I.



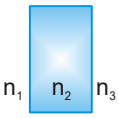
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14. Two blocks each of mass m lie on a smooth table. They are attached to two other masses as shown in the figure. The pulleys and strings are light. An object O is kept at rest on the table. The sides AB & CD of the two blocks are made reflecting. The acceleration of two images formed in those two reflecting surfaces w.r.t. each other is:



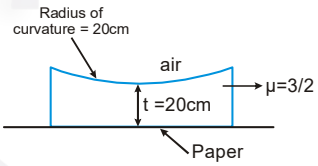
(A) 5g/6 **(B)** 5g/3
(C) g/3 **(D)** 17 g/6

15. The figure shows a parallel slab of refractive index n_2 which is surrounded by media of refractive indices n_1 and n_3. Light is incident on the slab at angle of incidence θ ($\neq 0$). The time taken by the ray to cross the slab is 't_1' if incidence is from 'n_1' and it is 't_2' if the incidence is from 'n_3'. Then assuming that $n_2 > n_1$, $n_2 > n_3$ and $n_3 > n_1$, then value of t_1/t_2.



(A) = 1 **(B)** > 1
(C) < 1 **(D)** cannot be decided

16. A plano concave lens is placed on a paper on which a flower is drawn. How far above its actual position does the flower appear to be?



(A) 10 cm **(B)** 15 cm
(C) 50 cm **(D)** none of these

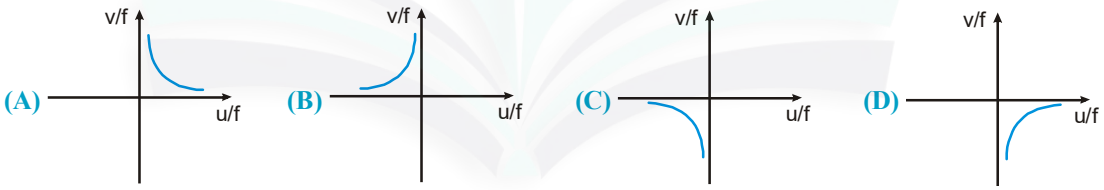
17. Two symmetric double convex lenses A and B have same focal length, but the radii of curvature differ so that $R_A = 0.9\ R_B$. If $n_A = 1.63$, find n_B.

(A) 1.7 **(B)** 1.6 **(C)** 1.5 **(D)** 4/3

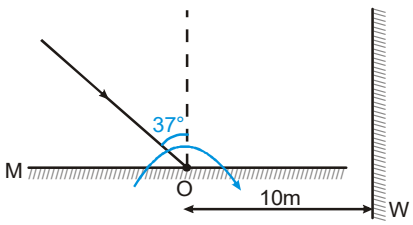
18. The distance between an object and the screen is 100 cm. A lens produces an image on the screen when the lens is placed at either of the positions 40 cm apart. The power of the lens is nearly:

(A) 3 diopters **(B)** 5 diopters **(C)** 2 diopters **(D)** 9 diopters

19. A virtual erect image by a diverging lens is represented by (u, v, f are coordinates)



20. A light ray I is incident on a plane mirror M. The mirror is rotated in the direction as shown in the figure by an arrow at frequency $9/\pi$ rps. The light reflected by the mirror is received on the wall W at a distance 10 m from the axis of rotation. When the angle of incidence becomes 37° the speed of the spot (a point) on the wall is:



(A) 10 m/s **(B)** 1000 m/s **(C)** 500 m/s **(D)** None of these

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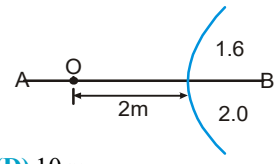
21. If a prism having refractive index $\sqrt{2}$ has angle of minimum deviation equal to the angle of refraction of the prism, then the angle of refraction of the prism is:

(A) 30° **(B)** 45° **(C)** 60° **(D)** 90°

22. A bird is flying up at angle $\sin^{-1}(3/5)$ with the horizontal. A fish in a pond looks at that bird when it is vertically above the fish. The angle at which the bird appears to fly (to the fish) is: [$n_{water} = 4/3$]

(A) $\sin^{-1}(3/5)$ **(B)** $\sin^{-1}(4/5)$ **(C)** 45° **(D)** $\sin^{-1}(9/16)$

23. In the figure shown a point object O is placed in air. A spherical boundary separates two media. AB is principal axis. The refractive index above AB is 1.6 and below AB is 2.0. The separation between the images formed due to refraction at spherical surface is :



(A) 12 m **(B)** 21 m **(C)** 14 m **(D)** 10 m

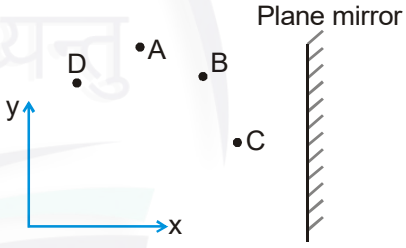
24. Light of wavelength 4000 Å is incident at small angle on a prism of apex angle 4°. The prism has $n_v = 1.5$ & $n_r = 1.48$. The angle of dispersion produced by the prism in this light is :

(A) 0.2° **(B)** 0.08° **(C)** 0.192° **(D)** none of these

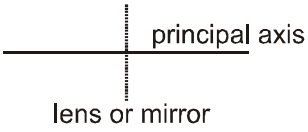
MATRIX - MATCH TYPE

25. Four particles are moving with different velocities in front of stationary plane mirror (lying in y-z plane). At t = 0, velocity of A is $\vec{v}_A = \hat{i}$, velocity of B is $\vec{v}_B = -\hat{i} + 3\hat{j}$, velocity of C is $\vec{v}_C = 5\hat{i} + 6\hat{j}$, velocity of D is $\vec{v}_D = 3\hat{i} - \hat{j}$. Acceleration of particle A is $\vec{a}_A = 2\hat{i} + \hat{j}$ and acceleration of particle C is $\vec{a}_C = 2t\hat{j}$. The particle B and D move with uniform velocity (Assume no collision to take place till t = 2 seconds). All quantities are in S.I. Units. Relative velocity of image of object A with respect to object A is denoted by $\vec{V}_{A',A}$. Velocity of images relative to corresponding objects are given in column I and their values are given in column II at t = 2 second. Match column I with corresponding values in column II.

Column I	Column II
(A) $\vec{V}_{A',A}$	(P) $2\hat{i}$
(B) $\vec{V}_{B',B}$	(Q) $-6\hat{i}$
(C) $\vec{V}_{C',C}$	(R) $-12\hat{i} + 4\hat{j}$
(D) $\vec{V}_{D',D}$	(S) $-10\hat{i}$



26. Column-I gives certain situations regarding a point object and its image formed by an optical instrument. The possible optical instruments are concave and convex mirrors or lenses as given in Column-II. Same side of principal axis means both image and object should either be above the principal axis or both should be below the principal axis as shown in figure. Same side of optical instrument means both image and object should be either left of the optical instrument or both should be on right of the optical instrument as shown in figure. Match the statements in column-I with the corresponding statements in column-II .



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Column I	Column II
(A) If a point object and its image are on same side of principal axis and opposite sides of the optical instrument then the optical instrument is	**(P)** Concave mirror
(B) If a point object and its image are on opposite side of principal axis and same sides of the optical instrument then the optical instrument is	**(Q)** Convex mirror
(C) If a point object and its image are on same side of principal axis and same sides of the optical instrument then the optical instrument is	**(R)** Concave lens
(D) If a point object and its image are on opposite side of principal axis and opposite sides of the optical instrument then the optical instrument is	**(S)** Convex lens

ASSERTION AND REASON TYPE

These questions contains, Statement 1 (assertion) and Statement II (reason).

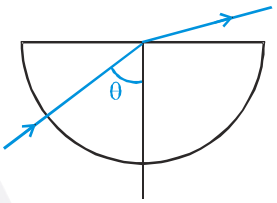
(A) Statement-1 is True, Statement-2 is True; Statement-2 **is** a correct explanation for Statement-1

(B) Statement-1 is True, Statement-2 is True; Statement-2 **is NOT** a correct explanation for Statement-1

(C) Statement-1 is True, Statement-2 is False

(D) Statement-1 is False, Statement-2 is True.

27. **Assertion :** A beam of white light enters the curved surface of a semicircular piece of glass along the normal. The incoming beam is moved clockwise (so that the angle θ increases), such that the beam always enters along the normal to the curved side. Just before the refracted beam disappears, it becomes predominantly red.

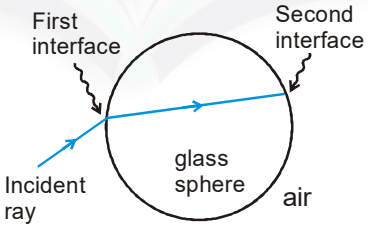


Reason : The index of refraction for light at the red end of the visible spectrum is more than at the violet end.

28. **Assertion :** There exists two angles of incidence for the same magnitude of deviation (except minimum deviation) by a prism kept in air.

Reason : In a prism kept in air, a ray is incident on first surface and emerges out of second surface. Now if another ray is incident on second surface (of prism) along the previous emergent ray, then this ray emerges out of first surface along the previous incident ray. This principle is called principle of reversibility of light.

29. **Assertion :** A ray is incident from outside on a glass sphere surrounded by air as shown. This ray may suffer total internal reflection at second interface.



Reason : For a ray going from denser to rarer medium, the ray may suffer total internal reflection.

30. **Assertion :** Keeping a point object fixed, if a plane mirror is moved, the image will also move.

Reason : In case of a plane mirror, distance of object and its image is equal from any point on the mirror.

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ANSWER KEY

EXERCISE - 1

1. D **2.** B **3.** B **4.** C,D **5.** C **6.** C **7.** D **8.** B **9.** B **10.** C **11.** A **12.** C **13.** D
14. C **15.** A **16.** B **17.** C **18.** B **19.** A **20.** B **21.** D **22.** A **23.** B **24.** A **25.** D **26.** A
27. C **28.** D **29.** C **30.** A **31.** B **32.** C **33.** D **34.** D **35.** C **36.** C **37.** B **38.** C **39.** A
40. D **41.** A **42.** A **43.** D **44.** C **45.** A **46.** D **47.** B **48.** A **49.** C **50.** C **51.** C **52.** D
53. B **54.** C **55.** B **56.** D **57.** C **58.** D **59.** C **60.** C **61.** B **62.** B **63.** B **64.** C **65.** C
66. A **67.** A **68.** D **69.** D **70.** D **71.** C **72.** A **73.** B **74.** D **75.** B **76.** C **77.** B **78.** A
79. D **80.** A **81.** C **82.** B **83.** B **84.** B **85.** B **86.** D **87.** C **88.** A **89.** B **90.** B **91.** D
92. B **93.** D **94.** C **95.** D **96.** B **97.** A **98.** B **99.** C **100.** C

EXERCISE - 2

1. B **2.** B **3.** C **4.** C **5.** D **6.** A **7.** C **8.** B **9.** B **10.** C **11.** C **12.** C **13.** B
14. C **15.** C **16.** C **17.** A **18.** C **19.** C **20.** A **21.** B **22.** C **23.** B **24.** D **25.** A **26.** A
27. A **28.** A **29.** C **30.** B **31.** C **32.** C **33.** A(A),B(C),C(C) **34.** B **35.** B **36.** A **37.** A
38. A **39.** D **40.** C **41.** A **42.** D **43.** C **44.** D **45.** D **46.** B **47.** C **48.** A **49.** D **50.** A
51. B **52.** A **53.** A **54.** A **55.** B **56.** D **57.** C **58.** D **59.** D **60.** C **61.** D **62.** B **63.** D
64. D **65.** C **66.** C **67.** D **68.** C **69.** B **70.** A **71.** B **72.** D **73.** C **74.** D **75.** C **76.** B
77. A **78.** B **79.** C **80.** B **81.** D **82.** A **83.** A **84.** B **85.** B **86.** B **87.** C **88.** D **89.** D
90. A

EXERCISE - 3 : PART # 1

1. A → L, S; B → J, Q ; C → M, R; D → K, P **2.** A → P; B → P ; C → Q ; D → Q
3. A → P, Q ; B → P, Q ; C → R, S ; D → R, S

PART # 2

1. B **2.** D **3.** D **4.** A **5.** D **6.** C **7.** D **8.** A **9.** C **10.** E **11.** D **12.** D **13.** A
14. D **15.** B **16.** D **17.** D **18.** B **19.** C **20.** D

EXERCISE - 4 : PART # 1

1. C **2.** D **3.** B **4.** C **5.** C **6.** B **7.** C **8.** C **9.** D **10.** A **11.** A **12.** D **13.** A
14. C **15.** D **16.** A **17.** C **18.** C **19.** B **20.** C **21.** C **22.** A **23.** A **24.** C **25.** C **26.** B
27. B **28.** D **29.** C **30.** B **31.** C **32.** D **33.** A **34.** D **35.** B

PART # 2

1. D **2.** A **3.** B **4.** D **5.** A **6.** D **7.** C **8.** C **9.** C **10.** A **11.** D **12.** C **13.** B
14. A **15.** B **16.** C **17.** A **18.** B **19.** D **20.** B **21.** D **22.** A **23.** B **24.** D **25.** A **26.** A
27. C **28.** D **29.** A **30.** D **31.** A **32.** C **33.** C **34.** C **35.** B **36.** B **37.** B **38.** A **39.** B
40. B **41.** A **42.** B **43.** B **44.** C **45.** B **46.** A **47.** A **48.** B **49.** A **50.** B **51.** A **52.** C
53. B **54.** A **55.** A **56.** A **57.** A **58.** A **59.** A **60.** D **61.** A **62.** A **63.** A **64.** B **65.** C
66. B **67.** A **68.** A **69.** A **70.** C **71.** C **72.** D

MOCK TEST

1. A **2.** C **3.** A **4.** B **5.** C **6.** A **7.** C **8.** B **9.** A **10.** A **11.** A **12.** D **13.** D
14. D **15.** C **16.** A **17.** A **18.** B **19.** A **20.** B **21.** D **22.** C **23.** A **24.** D
25. A → S; B → P; C → S; D → Q **26.** A → P, Q ; B → P, Q ; C → R, S ; D → R, S
27. C **28.** D **29.** D **30.** D

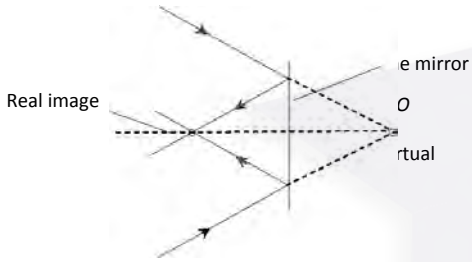
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HINTS & SOLUTIONS

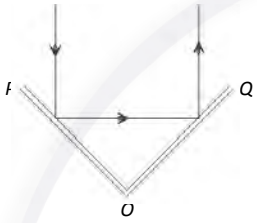
EXERCISE - 1
NEET LEVEL

1. **(D)** $\delta = (360 - 2\theta) = (360 - 2\times 60) = 240^o$

2. **(B)** When converging beam incident on plane mirror, real image is formed as shown



3. **(B)** Incident ray and finally reflected ray are parallel to each other means $\delta = 180^o$

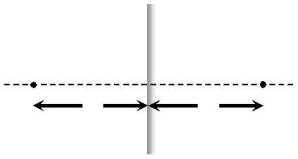


From $\delta = 360 - 2\theta \Rightarrow 180 = 360 - 2\theta \Rightarrow \theta = 90^o$

4. **(C)** By keeping the incident ray is fixed, if plane mirror rotates through an angle θ reflected ray rotates through an angle 2θ.

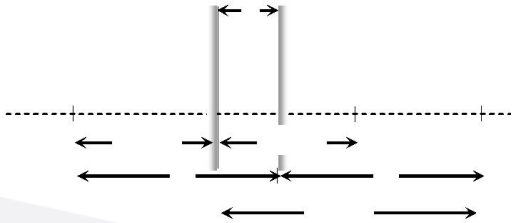


5. **(C)** Suppose at any instant, plane mirror lies at a distance x from object. Image will be formed behind the mirror at the same distance x.



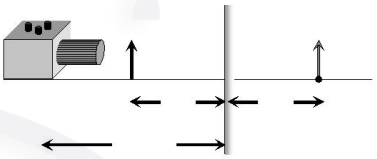
When the mirror shifts towards the object by distance 'y' the image shifts $= x + y - (x - y) = 2y$

So speed of image = 2 × speed of mirror

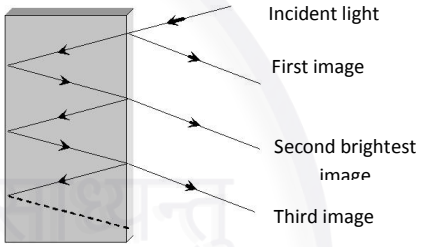


6. **(C)** Number of images $= \left(\frac{360}{\theta} - 1\right) = \left(\frac{360}{60} - 1\right) = 5$

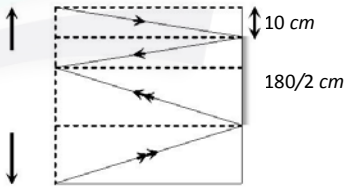
7. **(D)** F_o using distance of image = 4.5 m + 3 m = 7.5 m.



8. **(B)** Several images will be formed but second image will be brightest



9. **(B)** According to the following ray diagram length of mirror $= \frac{1}{2}(10 + 170) = 90\,cm$



10. **(C)** The walls will act as two mirrors inclined to each other at 90^o and so will form $\left(\frac{360}{90} - 1\right) = 4 - 1$ *i.e.* 3 images of the person. Now these images with person will act as objects for the ceiling mirror and so ceiling mirror will form 4 images further. Therefore total number of images formed $= 3 + 3 + 1 = 7$

Note : He can see. 6 images of himself.

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11. (A) $m = +\frac{1}{n} = -\frac{v}{u} \Rightarrow v = -\frac{u}{n}$

By using mirror formula $\frac{1}{f} = \frac{1}{-\frac{u}{n}} + \frac{1}{u} \Rightarrow u = -(n-1)f$

12. (C) **13. (D)**

14. (C) $\frac{I}{O} = \frac{f}{(f-u)} \Rightarrow \frac{I}{+5} = \frac{-10}{-10-(-100)} \Rightarrow I = 0.55\ cm$

15. (A) For real image $m = -2$, so by using $m = \frac{f}{f-u}$

$\Rightarrow -2 = \frac{-50}{-50-u} \Rightarrow u = -75\ cm$

16. (B) By using $\frac{I}{O} = \frac{f}{f-u}$

$\Rightarrow \frac{I}{+(7.5)} = \frac{(25/2)}{\left(\frac{25}{2}\right)-(-40)} \Rightarrow I = 1.78\ cm$

17. (C)

18. (B) $\frac{I}{O} = \frac{f}{f-u}$; where $u = f + x$ $\therefore \frac{I}{O} = -\frac{f}{x}$

19. (A) Image formed by convex mirror is virtual for real object placed anywhere.

20. (B) Given $u = (f + x_1)$ and $v = (f + x_2)$

The focal length $f = \frac{uv}{u+v} = \frac{(f+x_1)(f+x_2)}{(f+x_1)+(f+x_2)}$

On solving, we get $f^2 = x_1x_2$ or $f = \sqrt{x_1x_2}$

21. (D)

22. (A) $\mu_{blue} > \mu_{red}$

23. (B) $\mu \propto \frac{1}{\lambda}, \lambda_r > \lambda_v$

24. (A) $\lambda_{medium} = \frac{\lambda_{air}}{\mu} = \frac{6000}{1.5} = 4000\ \AA$

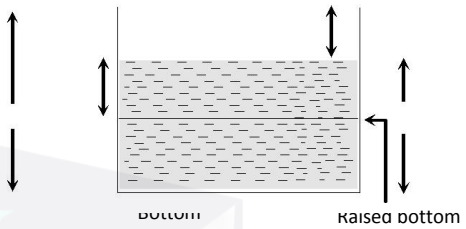
25. (D) Velocity and wavelength change but frequency remains same.

26. (A) $\mu = \frac{c}{v} = \frac{c}{\nu\lambda} = \frac{3\times10^8}{4\times10^{14}\times5\times10^{-7}} = 1.5$

27. (C) To see the container half-filled from top, water should be filled up to height x so that bottom of the container should appear to be raised upto height $(21–x)$.

As shown in figure apparent depth $h' = (21-x)$

Real depth $h = x$



$\therefore \mu = \frac{h}{h'} \Rightarrow \frac{4}{3} = \frac{x}{21-x} \Rightarrow x = 12\ cm$

28. (D) In vacuum, the speed of light is independent of wave length. Thus vacuum (or air) is a non dispersive medium in which all colours travel with the same speed.

29. (C) $\lambda \propto \frac{1}{\mu} \Rightarrow \frac{\lambda_1}{\lambda_2} = \frac{\mu_2}{\mu_1} = \frac{\mu}{1}$

30. (A) $v \propto \frac{1}{\mu}, \mu_{rarer} < \mu_{denser}$

31. (B) Due to high refractive index its critical angle is very small so that most of the light incident on the diamond is total internally reflected repeatedly and diamond sparkles.

32. (C) When incident angle is greater than critical angle, then total internal reflection takes place and will come back in same medium.

33. (D)

34. (D) $_a\mu_g = \frac{1}{\sin C} \Rightarrow \sin C = \frac{1}{_a\mu_g}$

As μ for violet colour is maximum, so $\sin C$ is minimum and hence critical angle C is minimum for voilet colour.

35. (C) The critical angle C is given by

$\sin C = \frac{n_2}{n_1} = \frac{\lambda_1}{\lambda_2} = \frac{3500}{7000} = \frac{1}{2} \Rightarrow C = 30^o$

36. (C) From figure given in question $\theta = 2c = 98°$.

37. (B) $\mu = \frac{1}{\sin C} = \frac{1}{\sin 30} = 2$

$\therefore v = \frac{3\times10^8}{2} = 1.5\times10^8\ m/s$

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38. (C) $_D\mu_R = \frac{\sin i}{\sin r'} \Rightarrow {}_R\mu_D = \frac{\sin r'}{\sin i} = \frac{1}{\sin C}$

$\Rightarrow \sin C = \frac{\sin i}{\sin(90 - r)} = \frac{\sin i}{\cos r} = \frac{\sin i}{\cos i}$ (as $\angle i = \angle r$)

$\Rightarrow \sin C = \tan i \Rightarrow C = \sin^{-1}(\tan i)$

39. (A) For total internal reflection $i > C$

$\Rightarrow \sin i > \sin C \Rightarrow \sin i > \frac{1}{\mu} \Rightarrow \frac{1}{\sin i} < \mu.$

40. (D) For total internal reflection light must travel from denser medium to rarer medium.

41. (A) By formula $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

$= (1.5 - 1)\left(\frac{1}{40} + \frac{1}{40}\right) = 0.5 \times \frac{1}{20} = \frac{1}{40}$

$\therefore \ f = 40 \ cm$

42. (A) $\frac{v}{-u} = -m$ and $v + u = x \Rightarrow u = \frac{x}{1+m}$

$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \Rightarrow f = \frac{mx}{(m+1)^2}.$

43. (D) $I \propto A^2 \Rightarrow \frac{I_2}{I_1} = \left(\frac{A_2}{A_1}\right)^2 = \frac{\pi r^2 - \frac{\pi r^2}{4}}{\pi r^2} = \frac{3}{4}$

$\Rightarrow I_2 = \frac{3}{4} I_1$ and focal length remains unchanged.

44. (C) $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} = \frac{P_1}{100} + \frac{P_2}{100} = \frac{1}{100} \Rightarrow f = 100 \ cm$

$\therefore$ A convergent lens of focal length 100 *cm*.

45. (A) Focal length of the combination can be calculated as

$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \Rightarrow \frac{1}{F} = \frac{1}{(+40)} + \frac{1}{(-25)} \Rightarrow F = -\frac{200}{3} cm$

$\therefore P = \frac{100}{F} = \frac{100}{-200/3} = -1.5 \ D$

46. (D) $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \Rightarrow \frac{1}{80} = \frac{1}{20} + \frac{1}{f_2} \Rightarrow f_2 = -\frac{80}{3}$ cm

$\therefore$ Power of second lens

$P_2 = \frac{100}{f_2} = \frac{100}{-80/3} = -3.75$ D

47. (B) In each case two plane-convex lens are placed close to each other, and $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$.

48. (A) Power of the combination

$P = P_1 + P_2 = 12 - 2 = 10$ D

$\therefore$ Focal length of the combination

$F = \frac{100}{P} = \frac{100}{10} = 10$ cm

49. (C) Resultant focal length = ∞

$\therefore$ It behaves as a plane slab of glass.

50. (C) $f = \frac{R}{(\mu - 1)} \Rightarrow 30 = \frac{10}{(\mu - 1)} \Rightarrow \mu = 1.33$

51. (C) In case of convex lens if rays are coming from the focus, then the emergent rays after refraction are parallel to principal axis.

52. (D) Because to form the complete image only two rays are to be passed through the lens and moreover, since the total amount of light released by the object is not passing through the lens, therefore image is faint (intensity is decreased).

53. (B) $f = \frac{f_1 f_2}{f_1 + f_2} = \frac{10(-10)}{10 + (-10)} = \frac{-100}{10 - 10} =$

54. (C) Focal length of the combination

$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{(+84)} + \frac{1}{(-12)} \Rightarrow F = -14$ cm

$\therefore P = \frac{100}{F} = \frac{100}{-14} = -\frac{50}{7}$ D

55. (B) $O = \sqrt{I_1 I_2} = \sqrt{4 \times 16} = 8$ cm

56. (D) $\frac{f_l}{f_a} = \frac{(_a\mu_g - 1)}{(_l\mu_g - 1)} \Rightarrow \frac{f_w}{f_a} = \frac{(1.5 - 1)}{\left(\frac{1.5}{1.33} - 1\right)} \Rightarrow f_w = 32$ cm

57. (C) If $n_l > n_g$ then the lens will be in more denser medium. Hence its nature will change and the convex lens will behave like a concave lens.

58. (D) $\frac{f_l}{f_a} = \frac{(_a\mu_g - 1)}{(_l\mu_g - 1)} \Rightarrow \frac{f_l}{15} = \frac{(1.5 - 1)}{\left(\frac{1.5}{4/3} - 1\right)} \Rightarrow f_l = 60$ cm

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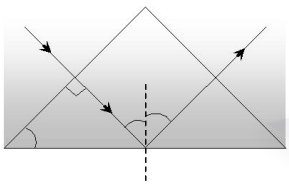
59. (C) $\frac{f_l}{f_a}=\frac{({}_a\mu_g-1)}{({}_l\mu_g-1)} \Rightarrow f_l=\infty$ if ${}_l\mu_g=1 \Rightarrow {}_a\mu_l={}_a\mu_g$

60. (C) $\frac{I_1}{O}=\frac{v}{u}$ and $\frac{I_2}{O}=\frac{u}{v} \Rightarrow O^2=I_1I_2$

61. (B) Neon street sign emits light of specific wavelengths.

62. (B)

63. (B)



64. (C) $\delta \propto (\mu-1) \Rightarrow \mu_R$ is least so δ_R is least.

65. (C)

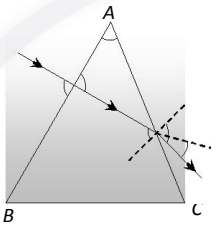
66. (A) For surface $AC \frac{1}{\mu}=\frac{\sin 30^\circ}{\sin e} \Rightarrow \sin e=\mu \sin 30^\circ$

$\Rightarrow \sin e=1.5\times\frac{1}{2}=0.75$

$\Rightarrow e=\sin^{-1}(0.75)=48^\circ 36'$

From figure $\delta = e-30^\circ$

$=48^\circ 36'-30^\circ=18^\circ 36'$



67. (A) The black lines in solar spectrum are called Fraunhoffer lines.

68. (D) $\frac{\sin\frac{A+\delta m}{2}}{\sin\frac{A}{2}}=\mu$, But $\frac{A+\delta_m}{2}=i=45^\circ$

So $\frac{\sin 45^\circ}{\sin(A/2)}=\sqrt{2} \Rightarrow \frac{1}{2}=\sin\frac{A}{2} \Rightarrow A=60^\circ$

69. (D) We know that $\frac{\delta_v-\delta_r}{\delta_{mean}}=\omega$

Angular dispersion $=\delta_v-\delta_r=\theta=\omega\delta_{mean}$

70. (D) According to Kirchhoff's law, a substance in unexcited state will absorb these wavelength which it emits in de-excitation.

71. (C) Man is suffering from hypermetropia. The hole works like a convex lens.

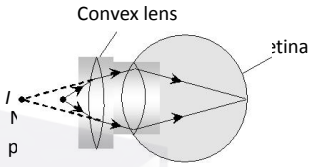
72. (A)

73. (B) In myopia, $u=\infty$, $v=d=$ distance of far point

By $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$, we get $f=-d$

Since f is negative, hence the lens used is concave.

74. (D) Hypermetropia is removed by convex lens.



75. (B)

76. (C) Cylindrical lens are used for removing astigmatism.

77. (B)

78. (A) Image formed at retina is real and inverted.

79. (D) Visible region decreases, so the depth of image will not be seen.

80. (A) $P=\frac{1}{f}=-\frac{1}{v}+\frac{1}{u}=-\frac{1}{100}+\frac{1}{25}=\frac{3}{100}=+3\ D$

81. (C) By using $m_\infty=\frac{(L_\infty-f_o-f_e).D}{f_of_e}$

$\Rightarrow 45=\frac{(L_\infty-1-5)\times 25}{1\times 5} \Rightarrow L_\infty=15\,cm$.

82. (B) For a compound microscope $m\propto\frac{1}{f_of_e}$

83. (B) For a compound microscope $f_{objective} < f_{eye\ piece}$

84. (B) In microscope final image formed is enlarged which in turn increases the visual angle.

85. (B)

86. (D) Magnification of a compound microscope is given by $m=-\frac{v_o}{u_o}\times\frac{D}{u_e} \Rightarrow |m|=m_o\times m_e$.

87. (C) Magnifying power of a microscope $m\propto\frac{1}{f}$

Since $f_{violet} < f_{red}$; $\therefore m_{violet} > m_{red}$

88. (A) $L_\infty=v_o+f_e \Rightarrow 14=v_o+5 \Rightarrow v_o=9\ cm$

Magnifying power of microscope for relaxed eye

$m=\frac{v_o}{u_o}.\frac{D}{f_e}$ or $25=\frac{9}{u_o}.\frac{25}{5}$ or $u_o=\frac{9}{5}=1.8\ cm$

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89. (B) $m_\infty = -\frac{v_o}{u_o} \times \frac{D}{f_e}$

From $\frac{1}{f_o} = \frac{1}{v_o} - \frac{1}{u_o}$

$\Rightarrow \frac{1}{(+1.2)} = \frac{1}{v_o} - \frac{1}{(-1.25)} \Rightarrow v_o = 30\ cm$

$\therefore |m_\infty| = \frac{30}{1.25} \times \frac{25}{3} = 200$

90. (B) For objective lens $\frac{1}{f_o} = \frac{1}{v_o} - \frac{1}{u_o}$

$\Rightarrow \frac{1}{(+4)} = \frac{1}{v_o} - \frac{1}{(-4.5)} \Rightarrow v_o = 36\ cm$

$\therefore |m_D| = \frac{v_o}{u_o}\left(1 + \frac{D}{f_e}\right) = \frac{36}{4.5}\left(1 + \frac{24}{8}\right) = 32$

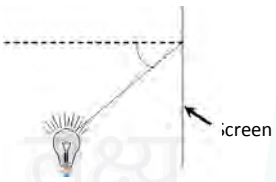
91. (D) Luminous flux $= 4\pi L = 4 \times 3.14 \times 42 = 528\ Lumen$

Power of lamp $= \frac{\text{Luminous flux}}{\text{Luminous efficiency}} = \frac{528}{2} = 264\ W$

92. (B) $I = \frac{L\cos\theta}{r^2}$

$\Rightarrow L = \frac{I \times r^2}{\cos\theta}$

$= \frac{5 \times 10^{-4} \times 10^4 \times 2^2}{\cos 60°} = 40\ Candela$



93. (D) $I = \frac{L}{r^2} \Rightarrow \frac{dI}{I} = -\frac{2dr}{r}$ $(\because L = \text{constant})$

$\Rightarrow \frac{dI}{I} \times 100 = -\frac{2 \times dr}{r} \times 100 = -2 \times 1 = -2\%$

94. (C) For equal fogging $I_2 \times t_2 = I_1 \times t_1$

$\Rightarrow \frac{L_2}{r_2^2} \times t_2 = \frac{L_1}{r_1^2} \times t_1 \Rightarrow \frac{16}{4} \times t_2 = \frac{20}{1} \times 10$

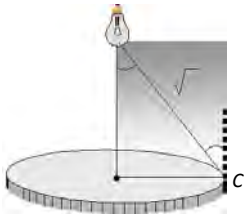
$\Rightarrow t_2 = 50\ \text{sec}.$

95. (D) The illuminance at B

$I_B = \frac{L}{1^2}$ .....(i)

and illuminance at point C

$I_C = \frac{L\cos\theta}{(\sqrt{5})^2} = \frac{L}{(\sqrt{5})^2} \times \frac{1}{\sqrt{5}}$



$\Rightarrow I_C = \frac{L}{5\sqrt{5}}$ ..... (ii)

From equation (i) and (ii) $I_B = 5\sqrt{5}\ I_0$

96. (B) $I \propto \frac{1}{r^2}$ so,

$\frac{\text{Illuminance on slide}}{\text{Illuminance on screen}} = \frac{(\text{Length of image on screen})^2}{(\text{Length of object on slide})^2}$

$= \left(\frac{3.5\ m}{35\ mm}\right)^2 = 10^4 : 1$

97. (A) The illuminance at A is

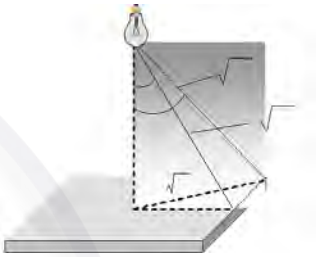
$I_A = \frac{L}{(\sqrt{13})^2} \times \cos\theta_1 = \frac{L}{13} \times \frac{3}{\sqrt{13}} = \frac{3L}{(13)^{3/2}}$

The illuminance at B is

$I_B = \frac{L}{(\sqrt{17})^2} \times \cos\theta_2$

$= \frac{L}{17} \times \frac{3}{\sqrt{17}} = \frac{3L}{(17)^{3/2}}$

$\therefore \frac{I_A}{I_B} = \left(\frac{17}{13}\right)^{3/2}$



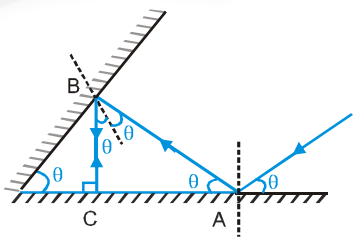
98. (B)

99. (C) Luminous intensity $L = \frac{\phi}{4\pi} \Rightarrow 1 = \frac{\phi}{4\pi} \Rightarrow \phi = 4\pi$.

100.(C) $\phi = 4\pi L = 4 \times 3.14 \times 100 = 1256\ lumen.$

EXERCISE - 2
AIIMS LEVEL

1. (B)



In ΔABC $90° + 3\theta = 180° \Rightarrow \theta = 30°$

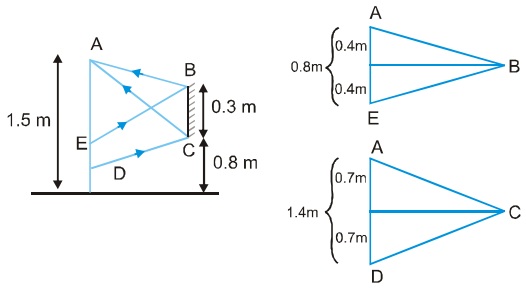
2. (B)

3. (C)

4. (C)

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5. (D)



$ED = AD - AE = 1.4 - 0.8 = 0.6\ m$

6. (A) **7. (C)**

8. (B) $\vec{V}_0 = 3\hat{i} + 4\hat{j} + 5\hat{k}$ $\vec{V}_m = 8\hat{i} + 5\hat{j} + 8\hat{k}$

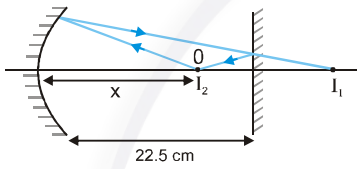
$V_{IZ} = 2V_{mz} - V_{oz} = 2 \times 8 - 5 = 11$

$V_{Ix} = V_{ox} = 3$

$V_{Iy} = V_{oy} = 4$

$\vec{V}_I = 3\hat{i} + 4\hat{j} + 11\hat{k}$

9. (B) I_1 is the image formed by concave mirror.



For reflection by concave mirror

$u = -x, \quad v = -(45 - x), \quad f = -10\ cm,$

$$\frac{1}{-10} = \frac{1}{-(45-x)} + \frac{1}{-x}$$

$$\frac{1}{10} = \frac{x + 45 - x}{x(45-x)} \Rightarrow x^2 - 45x + 450 = 0$$

$\Rightarrow x = 15\ cm, 30\ cm$

but $x = 30$ cm is not acceptable because $x < 22.5$ cm.

10. (C) **11. (C)**

12. (C) For $M_1 : v_1 = \frac{uf}{u-f} = \frac{(-30)\times(-20)}{(-30)-(-20)} = -60$

$\therefore M = -\frac{v_1}{u} = -2.$

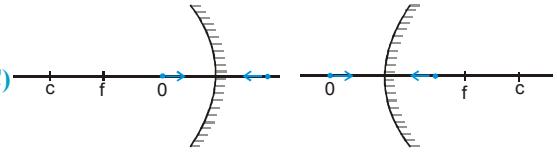
For M_2 : $u = +20.\ f = 10$

$\because \frac{1}{v} + \frac{1}{20} = \frac{1}{10} \Rightarrow v = 20$

$\therefore m_2 = -\frac{20}{20} = -1 \quad \therefore m = m_1 \times m_2 = +2$

13. (B)

14.(C)



only in above two cases image moves towards mirror.

15. (C)

16. (C) Using mirror formula,

$$\frac{1}{-10} = \frac{1}{v} + \frac{1}{-15} \Rightarrow v = -30\ cm.$$

$$|\text{Axial magnification}| = \frac{V^2}{u^2} = \left(\frac{30}{15}\right)^2 = 4$$

amplitude of image $= 4 \times 2 = 8$ mm.

17. (A)

18. (C) $\frac{I}{O} = -\frac{v}{u}$

If O and I are on same sides of PA . $\frac{I}{O}$ will be positive which implies v and u will be of opposite signs.

Similarly if O and I are on opp. sides, $\frac{I}{O}$ will be -ve which implies v and u will have same sign.

If O is on PA, $I = \left(-\frac{V}{u}\right)(O) = 0 \Rightarrow$ I will also be on. P.A.

19. (C)

20. (A) For real inverted image formed by concave mirror.

$v = -ve\ ,\ u = -ve \qquad f = -ve$

Alternative

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{v/f} + \frac{1}{u/f} = 1 \Rightarrow \frac{1}{y} + \frac{1}{x} = 1$$

$\Rightarrow xy = x + y$

$\Rightarrow xy - x - y + 1 = 1 \Rightarrow (x-1)(y-1) = 1$ Hence **(A)**

21. (B)

22. (C) $i = 2r$

$1 \sin i = n \sin r$

$\Rightarrow 2 \sin i/2 \cos i/2 = n \sin i/2$

$\Rightarrow \cos i/2 = (n/2) \Rightarrow i = 2\cos^{-1}(n/2)$

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23. (B)

24. (D) As n varies 'y', parallel slabs can be taken, and we know in parallel slabs

$n_r \sin i_r$ = constant . as $n_1 \sin i_1 = 1 \times \sin 90° = 1$ = constant

$n_{final} = n_{air} = 1$

$\Rightarrow \quad 1 = 1 \times \sin r_{final} \Rightarrow r_{final} = 90°$

$\therefore$ Deviation is zero.

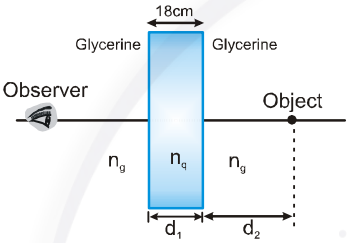
25. (A)

26. (A)

27. (A) $\sin\theta = \frac{1}{\mu} = \frac{C_A}{C_B} \Rightarrow C_B = \frac{V}{\sin\theta}$

28. (A) $n_{quartz} = 2$; $n_{glycerine} = \frac{4}{3}$

$\Rightarrow \frac{n_{quartz}}{n_{glycerine}} = \frac{2}{4/3} = \frac{3}{2} = \mu_{rel}$

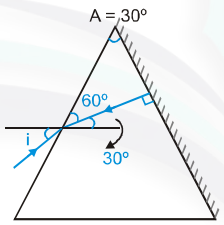


$\text{shift} = t\left(1-\frac{1}{\mu_{rel}}\right) = 18\left(1-\frac{1}{3/2}\right) = 6 \text{ cm}$

29. (C) $\frac{\sin i}{\sin 30°} = \sqrt{2}$

$\Rightarrow \sin i = \sqrt{2} \times \frac{1}{2} = \frac{1}{\sqrt{2}}$

$\Rightarrow i = 45°$.



30 (B)

31. (C) For transmission

$r_2 \le \sin^{-1}(1/\mu)$ & $r_1 \le \sin^{-1}(1/\mu)$

$r_1 + r_2 \le 2\sin^{-1}(1/\mu)$ $A \le 2\sin^{-1}(1/\mu)$

$\sin^{-1}(1/\mu) \ge 45° \Rightarrow \frac{1}{\mu} \ge \frac{1}{\sqrt{2}} \Rightarrow \mu \le \sqrt{2}$.

32. (C)

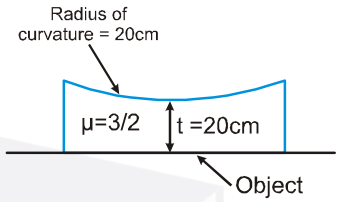
33. (A) (A), (B) (C), (C) (C)

34. (B) $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$ $\frac{\mu_2}{v} - \frac{\mu_1}{-R} = \frac{\mu_2 - \mu_1}{-R}$

$v = -R$ for all values of μ.

35. (B)

36. (A) Considering refraction at the curved surface,



$u = -20$; $\mu_2 = 1$

$\mu_1 = 3/2$; $R = +20$

applying $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R} \Rightarrow \frac{1}{v} - \frac{3/2}{-20}$

$= \frac{1 - 3/2}{20} \Rightarrow v = -10$

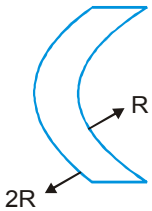
37 (A)

38. (A) $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

$\Rightarrow \frac{1}{-24} = (1.5-1)\left(\frac{1}{2R} - \frac{1}{R}\right)$

$\Rightarrow \frac{1}{-24} = \frac{1}{2}\left(-\frac{1}{2R}\right)$

$R = 6$ cm $\Rightarrow$ $2R = 12$ cm



39. (D)

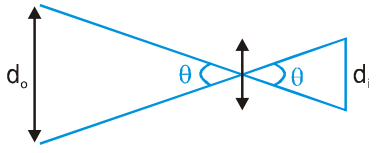
40. (C) $P = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ ....(i)

$P_0 = \left(\frac{\mu}{\mu_o} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ ....(ii)

$\frac{P}{P_0} = \frac{(\mu - 1)\,\mu_0}{(\mu - \mu_0)}$ $P_0 = \frac{P(\mu - \mu_0)}{\mu_0(\mu - 1)}$

41. (A)

42. (D) Image of sun is formed in the focal plane. So,



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Diameter of image $= f\theta = \frac{100 \times 0.5^\circ}{180^\circ} \times \pi \times 10\,\text{mm} = 9.$

43. (C)

44. (D) $f_A = f_B = f_C = f_{net} \Rightarrow P_A = P_B = P_C = P_{net} = P$

45. (D) 46. (B) 47. (C) 48. (A)

49. (D) For vertical erect image by diverging lens.
u, v and f are negative

$\therefore \quad \frac{u}{f} = +\text{ve}$ and $\frac{v}{f} = +\text{ve}$

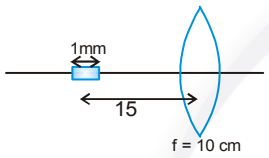
$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad 1 = \frac{f}{v} - \frac{f}{u} \Rightarrow \frac{1}{y} = \frac{1}{x} + 1$

$y = \frac{x}{x+1}$ since x & y are +ve graph lies in first quadrant.

Also, at $x = 0, y = 0$ and at $x = \infty$,, $y = 1$
Hence, **(D)**

50. (A)

51. (B)

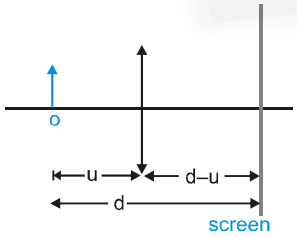


$\frac{1}{10} = \frac{1}{v} - \frac{1}{(-15)} \Rightarrow v = +30\text{ cm}$

for small object $|dv| = \frac{v^2}{u^2} |du| = \left(\frac{30}{15}\right)^2 \times 1 = 4\text{ mm}$

52. (A)

53. (A) $\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{(d-u)} - \frac{1}{(-u)} = \frac{1}{f}$



$\Rightarrow u^2 - du + df = 0 \Rightarrow d = \frac{u^2}{(f-u)}$

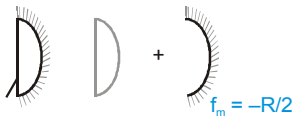
for minimum d, $u = -2f$ Hence, $d_{min.} = 4f$

54. (A)

55. (B) $\frac{1}{-10} = \frac{2}{-R} - \frac{2}{f_1}$

$\frac{2}{R} = \frac{1}{10} - \frac{2}{56} = \frac{56 - 20}{560} = \frac{36}{560}$

$\frac{1}{R} = \frac{18}{560}$



$(\mu - 1)\frac{18}{560} = \frac{1}{56}$

$\mu - 1 = \frac{10}{18}$

$\mu = 1 + \frac{10}{18} = \frac{28}{18} = \frac{14}{9}.$

56. (D) $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2} = 0$

$= \frac{1}{25} + \frac{1}{-20} - \frac{d}{-500} = 0$

$= \frac{20 - 25}{500} = -\frac{d}{500} \quad d = 5\text{ cm.}$

57. (C)

58. $C = \sin^{-1}\left(\frac{1}{\mu}\right)$ μ is greatest for voilet

$\Rightarrow$ C is minimum for voilet.

59. (D) 60. (C) 61. (D)

62. $\omega = \frac{n_v - n_r}{\left(\frac{n_v + n_r}{2}\right) - 1} = \frac{6}{25}.$

63. (D)

64. (D) Dispersion will not occur for a monochromatic light.

65. (C) 66. (C) 67. (D)

68. (C) In normal adjustment

$m = -\frac{f_0}{f_e}$

So $50 = -\frac{100}{f_e} \Rightarrow f_e = -2\text{ cm}$

($\because$ eyepiece is concave lens)

and $L = f_0 + f_e = 100 - 2 = 98\text{ cm}$

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69. (B)

70. $m = 1 + \frac{D}{f}$

71. (B) **72. (D)** **73. (C)**

74. (D) $f = \frac{1}{p} = \frac{1}{2}$ metre

$f = 0.5$ m this is positive so lens is convex lens.

75. (C)

76. (B) $m_\infty = \frac{v_0}{u_0} \times \frac{D}{f_e}$

From $\frac{1}{f_0} = \frac{1}{v_0} - \frac{1}{u_0}$

$\Rightarrow \frac{1}{(+1.2)} = \frac{1}{v_0} - \frac{1}{(-1.25)} \Rightarrow v_0 = 30$ cm

$\therefore |m_\infty| = \frac{30}{1.25} \times \frac{25}{3} = 200$

77. (A)

78. (B) Deviation by prism $= A(\mu - 1) = 4^\circ (1.5 - 1) = 2^\circ$

For 90° total deviation, deviation by mirror

$= 90^\circ - 2^\circ = 88^\circ$

$180^\circ - 2i = 88^\circ$

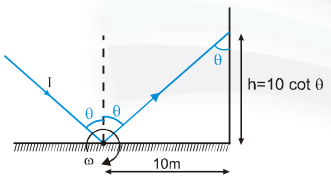
$2i = 92^\circ$

$i = 46^\circ$

Mirror should be rotated 1° anticlockwise.

79. (C)

80. (B)



When mirror is rotated with angular speed ω, the reflected ray rotates with angular speed 2ω (= 36 rad/s)

speed of the spot $= \left|\frac{dh}{dt}\right| = \left|\frac{d}{dt}(10\cot\theta)\right|$

$= \left|-10\operatorname{cosec}^2\theta \frac{d\theta}{dt}\right| = \left|-\frac{10}{(0.6)^2} \times 36\right| = 1000$ m/s.

81. (D)

82. (A) For $m = 2$

$m = -\frac{v}{u} = 2$

$V = -2u$ .....(i)

$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} \Rightarrow \frac{1}{f} = \frac{1}{-2u} + \frac{1}{u}$

$\Rightarrow \frac{1}{f} = \frac{1}{2u} \Rightarrow u = \frac{f}{2}$ & $v = -f$

Distance between object & image $= f + f/2 = 3f/2$

For $m = -2$

$m = -\frac{v}{u} = -2 \Rightarrow v = 2u$

$\Rightarrow \frac{1}{f} = \frac{1}{2u} + \frac{1}{u} \Rightarrow u = \frac{3f}{2}$ & $v = 3f$

Distance between object & image $= 3f - \frac{3f}{2}$.

83. (A) For refraction by upper surface

$\frac{1.6}{v_1} - \frac{1}{-2} = \frac{1.6 - 1}{1} \Rightarrow \frac{1.6}{v_1} = 0.6 - 0.5 = 0.1$

$\Rightarrow v_1 = 16$ m

For refraction by lower surface

$\frac{2}{v_2} - \frac{1}{-2} = \frac{2 - 1}{1} \Rightarrow \frac{2}{v_2} = 1 - 0.5 = 0.5$

$\Rightarrow v_2 = \frac{2}{0.5} = 4$m

Distance between images $= (16 - 4) = 12$m.

84. (B) For M_1

$v = \frac{uf}{u - f} = \frac{-15 \times (-10)}{-15 - (-10)} = -30$ cm

For M_2 $u = 10$ cm

$\therefore v = \frac{10 \times (-10)}{10 - (-10)} = -5$ cm

magnification $m = \frac{-v}{u} = -\left(\frac{-5}{10}\right) = \frac{1}{2}$

so, distance of image from CD $= \frac{1}{2} \times 3 = \frac{3}{2}$ cm

$\therefore$ distance of image from AB $= 3 - \frac{3}{2} = \frac{3}{2}$ cm

85. (B)

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86. (B) **87. (C)**

88. (D) $i=\frac{\pi}{2}$, $e=\frac{\pi}{4}, A=\frac{\pi}{4}$

$$\frac{\sin i}{\sin r_1}=\frac{\sin e}{\sin r_2}=\mu \Rightarrow \sin r_1=\frac{1}{\mu}$$

and $\sin r_2=\frac{1}{\sqrt{2}\,\mu}$

Since $r_1+r_2=A=\frac{\pi}{4} \Rightarrow r_1=\frac{\pi}{4}-r_2$

$\Rightarrow \sin r_1=\frac{1}{\sqrt{2}}\cos r_2-\frac{1}{\sqrt{2}}\sin r_2$

$= \sqrt{2}\sin r_1+\sin r_2=\cos r_2$

$=\frac{\sqrt{2}}{\mu}+\frac{1}{\sqrt{2}\mu}=\sqrt{1-\frac{1}{2\mu^2}}$

$=\frac{1}{\mu^2}\left(2+\frac{1}{2}+2\right)=1-\frac{1}{2\mu^2}$

$=\frac{1}{\mu^2}\left(\frac{9}{2}+\frac{1}{2}\right)=1$

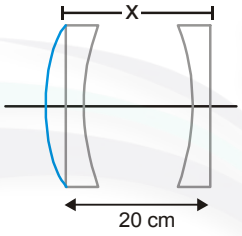
$\mu^2=5 \Rightarrow \mu=\sqrt{5}$.

89. (D) $f_1=\frac{(+20)(-40)}{(20-40)}$ $f_2=-40$

$=40$

$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}-\frac{x}{f_1 f_2}$

$=\frac{1}{40}+\frac{1}{-40}-\frac{20}{40\times(-40)}$



$\frac{1}{f}=\frac{1}{80}$

$f=80$ cm.

90. (A)

EXERCISE - 3

P-1 (Matrix Match)

1. **(A)** l, s **(B)** j, q **(C)** m, r **(D)** k, p

2. **A → P; B → P ; C → Q ; D → Q**

(A) For converging lens (convex lens)

$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$

$u=-x,\ v=y,\ f=d$ (+ ve constant)

$\frac{1}{v}+\frac{1}{x}=\frac{1}{d} \Rightarrow \frac{1}{y}=\frac{1}{d}-\frac{1}{x}$

at $x=0 \quad y=0$

For $x=0$ to $x=d$, $y=-$ ve

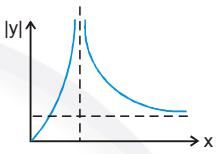
so, if $x\uparrow$ $y\downarrow$ and $|y|\uparrow$

At $x=d, y=\infty$

when $x>d$, $y+$ ve, and

at $x=\infty$, $y=d$

taking magnitude of y, distance graph is shown.



(B) For converging mirror (concave mirror)

$\frac{1}{v}+\frac{1}{u}=\frac{1}{f} \Rightarrow u=-x, f=-\frac{R}{2}, \ v=y$

$\frac{1}{y}-\frac{1}{x}=-\frac{2}{R} \Rightarrow \frac{1}{y}=\frac{1}{x}-\frac{2}{R}$

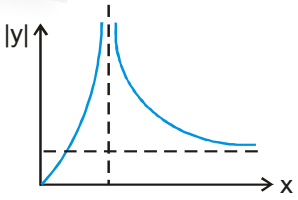
At $x=0, y=0$

for $0<x<\frac{R}{2}$, $y=+$ve

and as x increases $\frac{1}{y}$ decrease so $y\uparrow$ upto $x=\frac{R}{2}$

At $x=\frac{R}{2}$, $y=\infty$

So, graph is (1)



when $x>\frac{R}{2}$ y (–ve)

and as $x\uparrow$, $1/y\downarrow$, $y\uparrow$ so, $|y|\downarrow$

At $x=\infty$, $y=-\frac{R}{2}$

graph breaks so graph is (1)

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(C) For diverging Lens (concave lens)

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$

$u=-x, \quad f=-d \quad v=y$

$$\frac{1}{y}+\frac{1}{x}=-\frac{1}{d}$$

$$\frac{1}{y}=-\frac{1}{x}-\frac{1}{d} \Rightarrow \text{ y is always –ve}$$

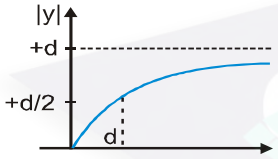
At x = 0, y = 0

As x ↑, y ↓ So, |y| ↑

At $x=d, \ y=\frac{-d}{2}$

or $x=\infty, \ y=-d$

graph is (2)



(D) For diverging Mirror (convex mirror)

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

$$u=-x, \ f=+\frac{R}{2}, \ v=y$$

$$\frac{1}{y}-\frac{1}{x}=\frac{2}{R} \Rightarrow \frac{1}{y}=\frac{1}{x}+\frac{2}{R} \Rightarrow y=+\text{ve}$$

At x = 0 , y = 0

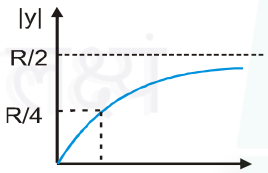
$$\frac{dy}{dx}=\frac{y^2}{x^2}$$

x ↑ , y ↑

At $x=\frac{R}{2}, \ y=\frac{R}{4}$,

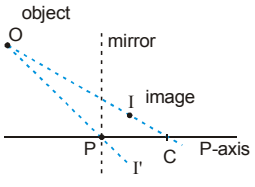
At $x=\infty, \ y=m\frac{R}{2}$

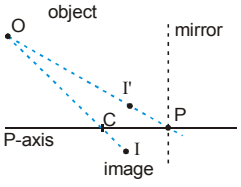
taking magnitude of y distance graph is graph is (2)



3. **A → P, Q ; B → P, Q ; C → R, S ; D → R, S**

For spherical mirror, line joining object and its image crosses principal axis at centre of curvature. The line joining object and image inverted about principal axis cuts the principal axis at the pole. The from figure bellows





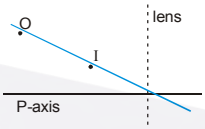
We can conclude

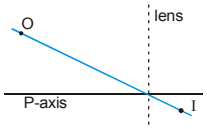
(A) If object and image are on same side of principal axis, they are on opposite side of mirror.

(B) If object and image are on opposite side of principal axis, they are on same side of mirror.

For a lens, the line joining object and image cuts the principal axis at optical centre.

Then from figures below.





We can conclude

(C) If object and image are on same side of principal axis, they are also on same side of lens.

(D) If object and image are on opposite side of principal axis. They are also on opposite side of lens.

EXERCISE - 3

P-2 (Assertion & Reason)

1. **(B)**

2. **(D)** From symmetry the ray shall not suffer TIR at second interface, because the angle of incidence at first interface equals to angle of emergence at second interface. Hence statement 1 is false

3. **(B)**

4. **(C)** Draw an incident ray on the mirror and trace the corresponding reflected ray. If a point object moves along this ray, its image will always lie on the traced reflected ray. Hence when a point object moves near the principal axis of a fixed spherical mirror along a straight line, then its image formed by the spherical mirror also moves along a straight line.Statement-1 is True, Statement-2 is True; Statement-2 is a correct explanation for Statement-1.

5. **(D)**When an object is placed between two plane parallel mirrors, then infinite number of images are formed. Images are formed due to multiple reflections. At each reflection, a part of light energy is absorbed. Therefore, distant images get fainter.

6. **(C)** In search lights, we need an intense parallel beam of light. If a source is placed at the focus of a concave spherical mirror, only paraxial rays are rendered parallel. Due to large aperture of mirror, marginal rays give a divergent beam.

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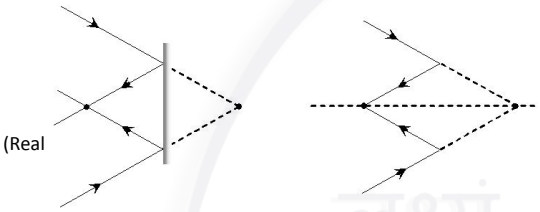
But in case of parabolic mirror, when source is at the focus, beam of light produced over the entire cross-section of the mirror is a parallel beam.

7. **(D)** The size of the mirror does not affect the nature of the image except that a bigger mirror forms a brighter image.

8. **(A)** When the sun is close to setting, refraction will effect the top part of the sun differently from the bottom half. The top half will radiate its image truly, while the bottom portion will send an apparent image. Since the bottom portion of sun is being seen through thicker, more dense atmosphere. The bottom image is being bent intensely and gives the impression of being squashed or "flattened" or elliptical shape.

9. **(C)** $\mu \propto \frac{1}{\lambda} \propto \frac{1}{C}$. λ_V is least so CV is also least. Also the greatest wavelength is for red colour.

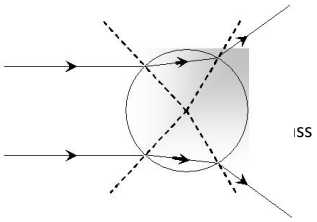
10. **(E)** We can produce a real image by plane or convex mirror.



Focal length of convex mirror is taken positive.

11. **(D)** The colour of glowing red glass in dark will be green as red and green are complimentary colours.

12. **(D)** The air bubble would behave as a diverging lens, because refractive index of air is less than refractive index of glass. However, the geometrical shape of the air bubble shall resemble a double convex lens.



13. **(A)** In total internal reflection, 100% of incident light is reflected back into the same medium, and there is no loss of intensity, while in reflection from mirrors and refraction from lenses, there is always some loss of intensity. Therefore images formed by total internal reflection are much brighter than those formed by mirrors or lenses.

14. **(D)** Focal length of the lens depends upon it's refractive index as $\frac{1}{f} \propto (\mu - 1)$. Since $\mu_b > \mu_r$ so $f_b < f_r$

Therefore, the focal length of a lens decreases when red light is replaced by blue light.

15. **(B)** After refraction at two parallel faces of a glass slab, a ray of light emerges in a direction parallel to the direction of incidence of white light on the slab. As rays of all colours emerge in the same direction (of incidence of white light), hence there is no dispersion, but only lateral displacement.

16. **(D)** It is not necessary for a material to have same colour in reflected and transmitted light. A material may reflect one colour strongly and transmit some other colour. For example, some lubricating oils reflect green colour and transmit red. Therefore, in reflected light, they will appear green and in transmitted light, they will appear red.

17. **(D)** Dispersion of light cannot occur on passing through air contained in a hollow prism. Dispersion take place because the refractive index of medium for different colour is different. Therefore when white light travels from air to air, refractive index remains same and no dispersion occurs.

18. **(B)** The light gathering power (or brightness) of a telescope (diameter)2. So by increasing the objective diameter even far off stars may produce images of optimum brightness.

19. **(C)** Very large apertures gives blurred images because of aberrations. By reducing the aperture the clear image is obtained and thus the sensitivity of camera increases.

Also the focussing of object at different distance is achieved by slightly altering the separation of the lens from the film.

20. **(D)** We cannot interchange the objective and eye lens of a microscope to make a telescope. The reason is that the focal length of lenses in microscope are very small, of the order of mm or a few cm and the difference (f_o - f_e) is very small, while the telescope objective have a very large focal length as compared to eye lens of microscope.

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EXERCISE - 4

P-1 (NEET/AIPMT)

1. **(C)** When white light from sun falls on raindrops, sometimers a band of different colours in form of a circualr arc is seen in the sky. This is called the rainbow.

The reason of origin of rainbow is that the small drops of water behave like a prism for the white sunlight due to which refraction, dispersion and total internal relfection of white light occurs from the water drops.

The rainbow is not seen after every rain, but is seen only when the light rays of particular colour suffer minimum deviation after one or two total internal reflections insdie the small water drops.

2. **(D)** The minimum size of plane mirror required to see full length of a man

$$= \frac{\text{height of man}}{2}$$

Given, height of man = 6 ft

Thus, minimum size of plane mirror $= \frac{6}{2} = 3$ ft

3. **(B)** When a ray falls on convex surface of a planoconvex lens, then it is first refracted and reflected from plane surface and then finally refracted from convex surface. Thus, two refractions and one reflection take place.

Since, refraction takes place two times and reflection takes place one time

So, focal length of planoconvex lens is

$$\frac{1}{F} = \frac{2}{f_l} + \frac{1}{f_m} \qquad ...(i)$$

If plane surface is silivered, so

$$f_m = \frac{R_2}{2} = \frac{\infty}{2} = \infty$$

And from lens maker formula

$$\frac{1}{f_l} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= (\mu - 1)\left(\frac{1}{R} - \frac{1}{\infty}\right) = \frac{(\mu - 1)}{R}$$

$$\therefore \quad \frac{1}{F} = \frac{2(\mu - 1)}{R} + \frac{1}{\infty}$$

$$= \frac{2(\mu - 1)}{R} \qquad ...(ii)$$

or $F = \frac{R}{2(\mu - 1)}$

Given, $R = 20$ cm, $\mu = 1.5$

Hence, $F = \frac{20}{2(1.5 - 1)}$

$$= \frac{20}{2 \times 0.5}$$

$= 20$ cm

4. **(C)** As light travels from denser to rarer medium, so refractive index $(\mu) = \frac{\text{real depth}}{\text{apparent depth}}$

Refractive index $(\mu) = 1.5$

Net apparent depth = 2 + 5 = 7 cm

And real depth = apparent depth × μ

$\therefore$ Real path = 1.5 × 7 = 10.5 cm

5. **(C)** Angular limit of resolution of eye $= \frac{\text{wavelength of ligh}}{\text{diameter of eye lens}}$

i.e. $\theta = \frac{\lambda}{d} \qquad ...(i)$

If y is the minimum distance between two points at distance D from eye, then

Angular limit of resolution of eye

$$\theta = \frac{\lambda}{D} \qquad ...(ii)$$

From Eqs. (i) and (ii), we have

$$\frac{y}{D} = \frac{\lambda}{d}$$

or $y = \frac{\lambda D}{d} \qquad (iii)$

Given, $\lambda = 5000$ Å $= 5 \times 10^{-7}$ m, $D = 50$ m,

$d = 2$ mm $= 2 \times 10^{-3}$ m

Substituting in Eq. (ii), we get

$$y = \frac{5 \times 10^{-7} \times 50}{2 \times 10^{-3}}$$

$= 12.5 \times 10^{-3}$ m $= 1.25$ m

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6. (B) Concept For equal size of image and object, object must be placed of centre of curvature of lens

i.e. $u = v$.

The lens formula can be written as

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \qquad ...(i)$$

Given, $v = d$

For equal sized image,

$$|v| = |u| = d$$

By sign convention,

$$u = -d$$

$$\therefore \quad \frac{1}{f} = \frac{1}{d} + \frac{1}{d} \text{ or } f = \frac{d}{2}$$

7. (C) For total internal reflection to take place,

angle of incidence > critical angle

i.e. $\theta > C$

or $\sin\theta > \sin C$

But for the case of total internal reflection.

$$\sin C = \frac{1}{\mu}$$

and according to question

$$\theta = 90° - r$$

So, $\sin(90° - r) > \frac{1}{\mu}$

i.e. $\mu > \frac{1}{\cos r}$ $[\because \sin(90° - r) = \cos r]$ ...(i)

From Snell's law,

$$\frac{\sin 45°}{\sin r} = \mu$$

$$\Rightarrow \quad \sin r = \frac{1}{\sqrt{2}\mu}$$

$$\therefore \quad \cos r = \sqrt{1 - \sin^2 r} = \sqrt{1 - \frac{1}{2\mu^2}}$$

Thus, Eq. (i) becomes

$$\mu > \frac{1}{\sqrt{1 - \frac{1}{2\mu 2}}}$$

$$\therefore \quad \mu^2 = \frac{1}{1 - \frac{1}{2\mu^2}} \quad \text{or} \quad \mu^2 - \frac{1}{2} = 1 \text{ or } \mu = \sqrt{\frac{3}{2}}$$

8. (C) Initially, the focal length of equiconvex lens is

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(i)$$

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R} - \frac{1}{-R}\right) = \frac{2(\mu - 1)}{R}$$

Case I When lens is cut along XOX′, then each half is agian equiconvex with

$$R_1 = R, R_2 = -R$$

Thus, $\frac{1}{f} = (\mu - 1)\left[\frac{1}{R} - \frac{1}{(-R)}\right]$

$$= (\mu - 1)\left[\frac{1}{R} + \frac{1}{R}\right]$$

$$= (\mu - 1)\frac{2}{R} = \frac{1}{f'}$$

$$\Rightarrow \quad f' = f$$

Case II When lens is cut along YOY′, then each half becomes planoconvex with

$$R_1 = R, \quad R_2 = \infty$$

Thus, $\frac{1}{f''} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

$$= (\mu - 1)\left(\frac{1}{R} - \frac{1}{\infty}\right)$$

$$= \frac{(\mu - 1)}{R} = \frac{1}{2f}$$

Hence, $f' = f, \quad f'' = 1f$

Note : When we cut a convex lens along principal axis both the lens formed are convex lens of same focal length as that of original.

9. (D) From lens maker's formula

$$\frac{1}{f} = (\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(i)$$

When convex lens is dipped in a liquid of refractive index (μ_l), then its focal length becomes

$$\frac{1}{f_l} = \left(\frac{\mu_g}{\mu_l} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

or $\frac{1}{f_l} = \frac{(\mu_g - \mu_l)}{\mu_l}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ ...(ii)

Dividing Eq. (i) by Eq. (ii), we get

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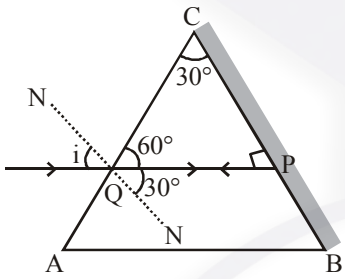
$$\frac{f_1}{f} = \frac{(\mu_g - 1)\mu_1}{(\mu_g - \mu_1)} \qquad ...(iii)$$

But it is given that refractive index of lens is equal to refractive index of liquid i.e. $\mu_g = \mu_1$.

Hence, Eq. (iii) gives,

$$\frac{f_1}{f} = \frac{(\mu_g - 1)\mu_1}{0} = \infty \qquad \text{(infinity)}$$

10. **(A)** According to the given condition, the beam of light will retrace its path after reflection from BC.



So, $\angle CPQ = 90°$

Thus, angle of refraction at surface AC

$$\angle PQN = \angle r = 90° - 60° = 30°$$

By Snell's law

$$\mu = \frac{\sin i}{\sin r} \Rightarrow \sqrt{2} = \frac{\sin i}{\sin 30°}$$

$$\therefore \sqrt{2} \times \sin 30° = \sin i$$

$$\Rightarrow \sqrt{2} \times \frac{1}{2} = \sin i$$

$$\Rightarrow \sin i = \frac{1}{\sqrt{2}} = \sin 45°$$

$$\therefore i = 45°$$

11. **(A)** Apparent depth of mark as seen through a glass slab of thickness x and refractive index μ is

$$\text{Apparent depth} = \frac{\text{real depth}}{\text{refractive index}}$$

$$\text{or} \quad x' = \frac{x}{\mu} = \frac{3}{1.5} = 2 \text{ cm}$$

As image appears to be raised by 1 cm, therefore, microscope must be moved upward by 1 cm.

12. **(D)** Focal length of combination of lenses placed in contact is

$$\frac{1}{F} = \frac{1}{f_1} = \frac{1}{f_2}$$

For convex lens, $f_1 = 25$ cm

For concave lens, $f_2 = -25$ cm

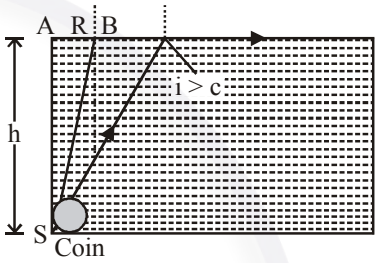
Hence, $$\frac{1}{F} = \frac{1}{25} + \frac{1}{-25} = \frac{1}{25} - \frac{1}{25} = 0$$

$$\therefore \quad F = \frac{1}{0} = \infty$$

Hence, power of combination,

$$P = \frac{1}{F} = 0 \text{ D}$$

13. **(A)** As shown in figure, a light ray from the coin will not emerge out of liquid, if $i > C$.



Therefore, minimum radius R corresponds to $i = C$.

In ΔSAB,

$$\frac{R}{h} = \tan C$$

$$\text{or} \quad R = h \tan C$$

$$\text{or} \quad R = \frac{h}{\sqrt{\mu^2 - 1}}$$

Given, $R = 3$ cm, $h = 4$ cm

Hence, $$\frac{3}{4} = \frac{1}{\sqrt{\mu^2 - 1}}$$

$$\text{or} \quad \mu^2 = \frac{25}{9} \quad \text{or} \quad v = \frac{c}{\mu}$$

$$\text{but} \quad \mu^2 = \frac{c}{v} \quad \text{or} \quad v = \frac{c}{\mu}$$

$$= \frac{3 \times 10^8}{5/3}$$

$$= 1.8 \times 10^8 \text{ m/s}$$

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14. (C) Velocity of light waves in material is

$$v = v\lambda \qquad ...(i)$$

Refractive index of material is

$$\mu = \frac{c}{v} \qquad ...(ii)$$

where, c is speed of light in vacuum or air.

$$\text{or} \quad \mu = \frac{c}{v\lambda} \qquad ...(iii)$$

Given, $v = 2 \times 10^{14}$ Hz

$\lambda = 5000$ Å $= 5000 \times 10^{-10}$ m,

and $c = 3 \times 10^8$ m/s

Hence, from Eq. (iii), we get

$$\mu = \frac{3\times10^8}{2\times10^{14}\times5000\times10^{-10}} = 3.00$$

15. (D) As and we know that $P_{eq} = P_1 + P_2$

$$\frac{1}{F_{eq}} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\therefore \quad F_{eq} = \frac{f_1 f_2}{f_1 + f_2}$$

As $P = \frac{1}{F}$

$$\therefore \quad P_{eq} = \frac{f_1 + f_2}{f_1 f_2}$$

16. (A) The diameter of the sun, $O = 1.39 \times 10^9$ m and its image is I. As the distance of sun from lens $m = 1.5 \times 10^{11}$ m and from paper is $v = 0.1$ m.

Then by using relation

$$\frac{I}{O} = \frac{v}{u}$$

$$\Rightarrow \quad \frac{I}{1.39\times10^9} = \frac{0.1}{1.5\times10^{11}}$$

we get $I = 9.2 \times 10^{-4}$ m

17. (C) As we know that,

Intensity, $I \propto A$ (Area exposed)

$$\Rightarrow \quad \frac{I_2}{I_1} = \left[\frac{A_2}{A_1}\right] = \frac{\frac{\pi d^2}{4} - \frac{\pi d^2/4}{4}}{\frac{\pi d^2}{4}} = \frac{3}{4}$$

$$\Rightarrow \quad I_2 = \frac{3}{4} I_1$$

and focal length remains unchanged.

18. (C) For total internal reflection, i > c (initial angle)

So, $\sin i > \sin c$

$$\Rightarrow \quad \sin 45° > \frac{1}{\mu}$$

$$\Rightarrow \quad \mu > \sqrt{2}$$

$$\Rightarrow \quad \mu > 14$$

19. (B) Given, $R = 20$ cm

$h_0 = 2$ cm and $u = -30$ cm

In general we have assumed $\mu = 1.5$

$$\text{As} \quad \frac{1}{f} = (1.5-1)\times\frac{2}{20} = \frac{1}{20}$$

So, $f = 20$ cm

Now, as $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

$$\frac{1}{20} = \frac{1}{v} + \frac{1}{30}$$

$$\frac{1}{v} = \frac{1}{20} = \frac{1}{30} = \frac{10}{600}$$

$$\therefore \quad v = 60 \text{ cm}$$

As $m = \frac{v}{u} = \frac{60}{-30} = -2$

$$\Rightarrow \quad m = \frac{h_i}{h_o} = -2$$

$$\therefore \quad hi = -2 \times 2 = -4 \text{ cm}$$

20. (C) Given,

Magnification $= \frac{f_o}{f_e} = 9$ and $f_o + f_e = 20$

$$f_o = 9\, f_e$$

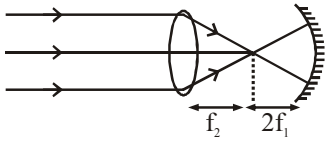
So, $9\, f_e + f_e = 20$

$$f_e = 2 \text{ cm}$$

$$\therefore \quad f_o = 9 \times 2$$

$$f_o = 18 \text{ cm}$$

21. (C) According to question, the ray diagram will be



So, distance d between convex lens and concave mirror is given by

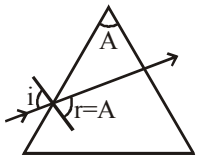
$$d = 2f_1 + f_2$$

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22. (A) Refractive index

$$\mu = \frac{\sin i}{\sin r}, \mu = \frac{\sin i}{\sin A}$$

In case of small angle, $\sin i \approx i$ and $\sin A \approx A$



$$\mu = \frac{i}{A}$$

$$i = \mu A$$

23. (A) If biconvex lens behaves like a plane sheet of glass, ray will pass undeviated through it only when medium has same refractive index as that of biconvex lens.

24. (C) Given, power $(P_1) = 40$ D and power $(P_2) = 20$ D

We have $P_{eq} = P_1 + P_2$

$= 40 + 20 = 60$ D

So, $\frac{1}{f_{eq}} = \frac{1}{f_1} = \frac{1}{f_2}$

$\Rightarrow f_{eq} = \frac{100}{P_{eq}} = \frac{100}{60} = 1.67$ cm

25. (C) Focal length of the combination

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} \quad ...(i)$$

We have $\frac{1}{f_1} = (\mu_1 - 1)\left(\frac{1}{\infty} - \frac{1}{-R}\right) = \frac{\mu_1 - 1}{R}$

and $\frac{1}{f_2} = (\mu_2 - 1)\left(\frac{1}{-R} - \frac{1}{\infty}\right) = -\frac{(\mu_2 - 1)}{R}$

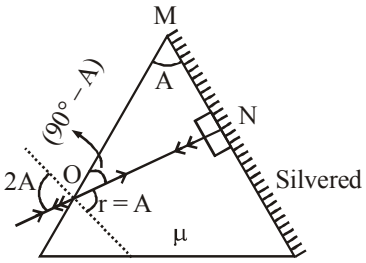
Putting these values of $\frac{1}{f_1}$ and $\frac{1}{f_2}$ in Eq. (i)

$$\frac{1}{f_1} = \frac{(\mu_1 - 1)}{R} - \frac{(\mu_2 - 1)}{R}$$

$$= \frac{[\mu_1 - 1 - \mu_2 + 1]}{R} = \frac{\mu_1 - \mu_2}{R}$$

$$f = \frac{R}{\mu_1 - \mu_2}$$

26. (B) According to question, diagram is shown below.



So, $\angle MON = 90° - A$

and $\angle r = 90° - (90° - A)$

$\Rightarrow \angle r = A$

By Snell's law, $\frac{\sin i}{\sin r} = \mu$

$$\frac{\sin(2A)}{\sin(A)} = \mu$$

$$\frac{2\sin A \cos A}{\sin A} = \mu$$

$\Rightarrow \mu = 2\cos A$

27. (B) $F_{average} = \frac{2IA}{c}$

where, I = energy flux of light $= 25 \times 10^4$ Wm^{-2}

A = Surface area of reflecting surface

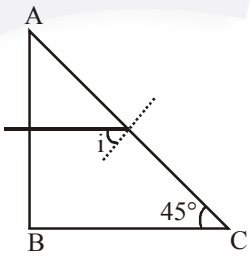
and c = speed of light $= 3 \times 10^8$ m/s

$\therefore F_{average} = \frac{2 \times 25 \times 10^4 \times 15 \times 10^{-4}}{3 \times 10^8}$

$= 2.50 \times 10^{-6}$ N

28. (D) For refractive index of a index,

$$\mu = \frac{1}{\sin i_c} = \frac{1}{\sin 45°} = \sqrt{2}$$



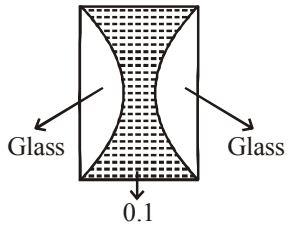
As, $\mu_{red} = 1.39$, $\mu_{green} = 1.44$ and $\mu_{blue} = 1.47$

$\therefore (\mu_{red} = 1.39) < \mu, \mu_{green} > \mu, \mu_{blue} > \mu$

Thus, only red colour do not suffer total internal reflection.

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29. (C) Given $\mu_g = 1.5$



$\mu_{oil} = 1.7 \Rightarrow R = 20\,cm$

From Lens Maker's formula for the plano convex lens

$$\frac{1}{f} = (m-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

Here, $R_1 = R$

and for plane surface $R_2 = \infty$

$$\therefore \quad \frac{1}{f_{lens}} = (1.5-1)\left(\frac{1}{R} - 0\right) \Rightarrow \frac{1}{f_{lens}} = \frac{0.5}{R}$$

When the intervening medium is filled with oil, then focal lengthof the concave lens formed by the oil

$$\frac{1}{f_{concave}} = (1.7-1)\left(-\frac{1}{R} - \frac{1}{R}\right)$$

$$= -0.7 \times \frac{2}{R} = \frac{-14}{R}$$

Here, we have two concave surfaces

So, $$\frac{1}{f_{eq}} = 2 \times \frac{1}{f} + \frac{1}{f}$$

$$= 2 \times \frac{0.5}{R} + \left(\frac{-1.4}{R}\right) = \frac{1}{R} - \frac{14}{R} = -\frac{0.4}{R}$$

$$\therefore \quad f_{eq} = -\frac{R}{0.4} = -\frac{20}{0.4} = -50\ cm$$

30. (B) Key Idea Image of object at ∞ must lie within distance upto which person can view clearly.

Image distane, $v = 400\ cm = 4\ m \Rightarrow u = \infty$

Using lens equation,

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

$$\Rightarrow \quad \frac{1}{-4} - \frac{1}{\infty} = \frac{1}{f}$$

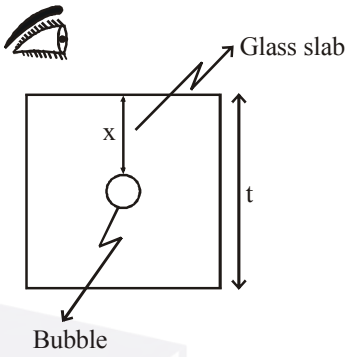
$$\Rightarrow \quad f = -4\ m$$

Now power of the required lens is,

$$P = \frac{1}{f} = \frac{1}{-4} = -0.25\,D$$

Thus, the person require a concave lens of power – 0.25 D.

31. (C) Let thickness of the given slab is t. According to the question, when viewed from both the surfaces



$$\frac{x}{\mu} + \frac{t+x}{\mu} = 3+5$$

$$\Rightarrow \quad \frac{t}{\mu} = 8\,cm$$

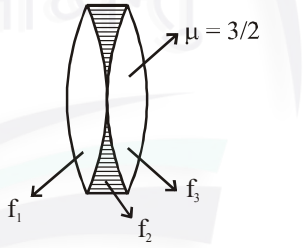
$$\Rightarrow \quad t = 8 \times \mu$$

$$\Rightarrow \quad t = 8 \times \frac{8}{2} = 12\,cm$$

32. (D) Consider the situation shown is figure. Let radius of curvature of lens surfaces is R. The combination is equivalent to three lenses in contact.

$$\therefore \quad \frac{1}{f_{eq}} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3}$$

$$= \frac{2}{f_1} + \frac{1}{f_2} \qquad (\because f_1 = f_3)$$



Now $$\frac{1}{f_1} = \frac{1}{f_3} = (\mu-1)\left(\frac{2}{R}\right) = \frac{1}{f}$$

$$\frac{1}{f_2} = (\mu_w - 1)\left(-\frac{2}{R}\right) = \left(\frac{4}{3} - 1\right)\left(\frac{-2}{R}\right)$$

$$= \left(\frac{1}{3}\right)\left(-\frac{2}{R}\right) = \left(-\frac{2}{3}\right)\left(\frac{1}{2(\mu-1)}\right)$$

$$\Rightarrow \quad \frac{1}{f_2} = \left(-\frac{1}{3}\right)\left(\frac{1}{\frac{3}{2}-1}\right)\left(\frac{1}{f}\right) = -\frac{2}{3} \times \frac{1}{f}$$

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$$\therefore \quad \frac{1}{f_{eq}} = \frac{2}{f} - \frac{2}{3} \times \frac{1}{f} = \frac{6-2}{3f} = \frac{4}{3f} \Rightarrow f_{eq} = \frac{3f}{4}$$

33. **(A)** Consider a ray of light PQ incident an the surface AB and moves along RS, after passing through the prism ABC.

It is given that the incident ray suffers minimum deviation. Therefore, the ray inside the prism must be parallel to the base BC of the prism.

From the geometry of the prism and the ray diagram, it is clear that angle of incidence, $i = 45°$

angle of refraction $r = r' = 30°$

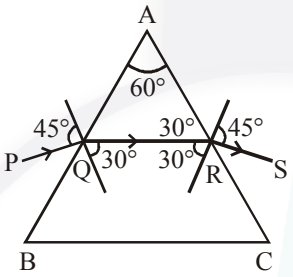
angle of emergence, $e = 45°$

Therefore, minimum deviation suffered by the ray is

$$\delta_{min} = i + e - (r + r') = 90° - 60° = 30°$$

Also we know that

$$\mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\frac{A}{2}}$$



where, μ = refractive index of the material of the prism.

A = angle of prism = 60°

$$\therefore \quad \mu = \frac{\sin\left(\frac{60° + 30°}{2}\right)}{\sin\frac{60°}{2}} = \frac{\sin 45°}{\sin 30°}$$

$$= \frac{1/\sqrt{2}}{1/\sqrt{2}} = \frac{2}{\sqrt{2}} = \sqrt{2}$$

34. **(D)** A concave mirror forms real and virtual images, whose magnification can be negative or positive depending upon the position of the object.

If object is placed between focus and pole the image obtained will be virtual and its magnification will be positive. In all other cases concave mirror forms real images whose magnification will be negative.

A convex mirror always forms a virtual image whose magnification will always be positive.

35. **(B) Thinking Process** For dispersion without deviation, net deviation produced by the combination of prisms must be zero.

Let, prism angle of the first and second prisms are A_1 and A_2 respectively. Similarly, their refractive indices are μ_1 and μ_2.

$$\delta_1 - \delta_2 = 0$$

$$\Rightarrow \quad (\mu_1 - 1)A_1 - (\mu_2 - 1)A_2 = 0$$

$$\Rightarrow \quad A_2 = \left(\frac{\mu_1 - 1}{\mu_2 - 1}\right)$$

$$\Rightarrow \quad A_1 = \left(\frac{1.42 - 1}{1.7 - 1}\right)(10°)$$

$$\Rightarrow \quad A_2 = 6°$$

EXERCISE - 4

P-2 (AIIMS)

1. **(D)** When a ray of light enters a glass slab, it is assumed that its energy does not change except in specific cases. As energy is $h\upsilon$, υ is assumed to be a constant. The refractive index is related to the wavelength.

2. **(A)** For myopia (shortsightedness) a concave lens is used. For hypermetropia, we need convex lens for the ray of light to be focused on the retina. For presbyopia bifocal lens is used and astigmatism is cleared with cylindrical lenses. Therefore the correct alternative is (a).

3. **(B)** υ does not change, λ changes. When a ray of light enters a glass slab, it is assumed that its energy does not change except in specific cases. As energy is $h\upsilon$, υ is assumed to be a constant. The refractive index is related to the wavelength.

4. **(D)** For photoprint of same quality total amount of light energy falling per unit area on the photograph must be same i.e.

$$E_1 t_1 = E_2 t_2 \text{ or } \frac{I_1}{r_1^2} t_1 = \frac{I_2 t_2}{r_2^2}$$

For the same intensity $\frac{t_1}{r_1^2} = \frac{t_2}{r_2^2}$, $\frac{2}{1^2} = \frac{t^2}{2^2}$

or $t_2 = 8$ sec.

5. **(A)** The Cauchy's dispersion formula represents the dispersion of most of the substances with considerable accuracy. Also from the Cauchy's dispersion formula if n is refractive index and A, B and C are constants, then $n = A + B\lambda^{-2+} C\lambda^{-4}$.

6. **(D)** Total internal reflection can occur only when a ray is incident on the surface of a medium whose refractive index is smaller than that of the medium in which the ray is travelling. Since the refractive index of air is 1.00029 and that of diamond is 2.42, therefore brilliance of diamond is due to total internal reflection.

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7. **(C)** For maximum accuracy in finding the position of an object using a light beam is achieved, when the light beam used is of shorter wavelength, because if the wavelength is longer, the spread in the wave will be more.

8. **(C)** For a concave mirror, $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$

$\frac{v+u}{vu}=\frac{1}{f}$ or $u+v=(\text{constant }\frac{1}{f})\,vu$

The curve is depicted in (c).

9. **(C)** The resolving power of the eye is given by

$R=1.22\frac{\lambda}{b}\times D$

where λ is wavelength of light, b is the diameter of the eye lens and D is the distance from the lens at which light is focused.

$D=400\text{ km}=400000\text{ m}, d=5\text{ mm}=5\times10^{-3}\text{ m}$

$\lambda=500\text{ mm}=500\times10^{-9}\text{ m}$

$\therefore\quad R=1.22\times\frac{500\times10^{-9}\times4\times10^{5}}{5\times10^{-3}}=48.8\approx50\text{ m}.$

10. **(A)** Sodium lamp light emits monochromatic light i.e. it is comprised of only one wavelength (deep yellow). This colour is scattered less in the foggy condition while other light sources produce light at many different discrete wavelengths and all provide some degree of colour rendering. Also sodium lamps emit light very near to the peak sensitivity of the human eye under normal viewing conditions.

11. **(D)** If the refractive index of two media are same, the surface of separation does not produce refraction or reflection which helps in visibility.

12. **(C)** This is made of optical fibres whose interior is coated with a refractive index greater than that of the outer cover, glass.

13. **(B)** Core of acceptance angle $\theta=\sin^{-1}\sqrt{n_1^2-n_2^2}$.

14. **(A)** For objective lens, $f_0=200$ cm,

$u_0=-2\times10^5$ cm

$\therefore\quad \frac{1}{v_0}-\frac{1}{u_0}=\frac{1}{f_0}$, for a lens

$\therefore\quad \frac{1}{v_0}-\frac{1}{f_0}=\frac{1}{u_0}=\frac{1}{200}-\frac{1}{2\times10^5}=\frac{999}{2\times10^5}$

or $\quad v_0=\frac{2\times10^5}{999}$ cm

Consider magnification due to objective lens

$\therefore\quad \frac{\text{size of image}}{\text{size of object}}=\left|\frac{v_0}{u_0}\right|$

$\therefore\quad$ Size of image = size of object $\times\left|\frac{v_0}{u_0}\right|$

$=(50\times100)\times\frac{2\times10^5}{999}\times\frac{1}{2\times10^5}=\frac{5000}{999}\approx5$ cm.

15. **(B)** $\frac{n_2}{n_1}=\frac{\text{real depth}}{\text{apparent depth}}$ or $\frac{n_2}{n_1}=\frac{h}{x}$

Differentiating with respect to time, $\frac{n_2}{n_1}=\frac{dh/dt}{dx/dt}$

Change in real depth $=\frac{n_2}{n_1}\times$ change in apparent depth

$\frac{dh}{dt}=\frac{n_2}{n_1}x$ cm/min.

The amount of water drained in c.c. per minute

$=\frac{dh}{dt}\times\pi R^2\times x\,\pi R^2\frac{n_2}{n_1}.$

16. **(C)** The speed of light is different in different media. This given rise to refraction phenomenon.

17. **(A)** $u=-8$ cm, $f=+10$ cm

As, $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$,

$\therefore\quad \frac{1}{v}=\frac{1}{f}+\frac{1}{u}=\frac{1}{10}+\frac{1}{-8}=\frac{1}{10}-\frac{1}{8}=\frac{4-5}{40}=\frac{-1}{40}$

or, $\quad v=-40$ cm.

Magnification produced by the lens, $m=\frac{v}{u}=\frac{-40}{-8}=5.$

This is a virtual image, erect and on the same side as the object.

18. **(B)** Let f be focal length of lens.

$\frac{1}{f}=({}^{a}\mu_g-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)=(1.5-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

or, $\quad \frac{1}{f}=0.5\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$ or $\frac{1}{R_1}-\frac{1}{R_2}=\frac{1}{0.5f}$ ...(i)

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Let f' be focal length of the lens when immersed in a liquid.

$$\frac{1}{f'}=({}^{L}\mu_g-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)=\left(\frac{1.5}{1.25}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$=\left(\frac{0.25}{1.25}\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)=\frac{0.25}{1.25}\times\frac{1}{0.5f}\ \text{(using(i))}$$

$$\frac{1}{f'}=\frac{1}{2.5f}\ \text{or,}\ f'=2.5f.$$

i.e. focal length of lens when immersed in a liquid is increased by a factor of 2.5.

19. (D) If the voltage is not sufficient to heat it to white hot temperature, the filament will become red. But the intensity will be very much reduced because of low voltage. But if the voltage is only reduced a little, only intensity will be reduced. It can be (a) also.

20. (B) A green leaf reflects green light and so it appears to be green. It absorbs other wavelengths of incident light.

When incident light has no wavelength corresponding to green, the leaf will reflect no colour and appear black. This happens when incident light is laser light of wavelength 0.6328 μm. Wavelength of green colour in much less than 0.6328 μm. Wavelength of green colour is much less than 0.6328.

The leaf absorbs the incident laser light, reflects no colour and appears black.

21. (D) Time of exposure $\propto f^2$

$$\frac{1}{60}\times\frac{1}{1}=\frac{t}{1.4^2}\Rightarrow t=\frac{1}{31}\text{s}.$$

22. (A) For a point source, illuminance at a distance r is given by

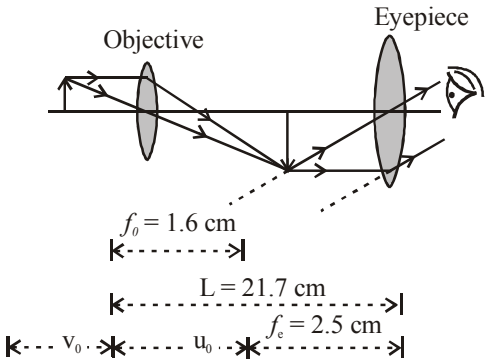
$$\text{Illuminance } I=\frac{\text{luminous flux, }\phi}{4\pi r^2}$$

$$\therefore\quad \frac{I}{I'}=\left(\frac{r'}{r}\right)^2,\quad \frac{I}{16I}=\frac{r'^2}{(1000\,\text{m})^2}$$

$$\text{or}\quad r'^2=\frac{(1000\,\text{m})^2}{16}\quad\text{or}\quad r'=\frac{(1000\,\text{m})}{4}$$

$$r'=250\,\text{m}$$

23. (B)



Here $v_0 = L - f_e = 21.7\,\text{cm} - 2.5 = +19.2\,\text{cm}$

for a objective lens $\quad \frac{1}{v_0}-\frac{1}{u_0}=\frac{1}{f_0}$

$$\therefore\quad \frac{-1}{u_0}=\frac{1}{f_0}-\frac{1}{v_0}\qquad \therefore\quad \frac{1}{u_0}=\frac{1}{(+1.6)}-\frac{1}{(+19.2)}$$

$$\frac{-1}{u_0}=\frac{19.2-1.6}{(1.6)(19.2)}\qquad \text{or}\quad u_0=-1.745\,\text{cm}$$

When the image is formed at infinity, the magnification is given by

$$m=\left(\frac{v_0}{u_0}\right)\left(\frac{D}{f_e}\right)$$

where D is the distance of distinct vision.

$$\therefore\quad m=\left(\frac{19.2\,\text{cm}}{1.745\,\text{cm}}\right)\left(\frac{25\,\text{cm}}{2.5\,\text{cm}}\right)=110.$$

24. (D) Due to insertion of slab, the optical path increases by x/μ, where x is thickness of slab.

Therefore the converging point will shift away by

$$\left[x-\frac{x}{\mu}\right]=x\left(1-\frac{1}{\mu}\right).$$

25. (A) Lumen is the S.I. unit of luminous flux.

26. (A) Since the wavelength of violet light is the smallest, therefore maximum deviation will occur for violet light.

27. (C) $h_0 = 5$ cm, $h_i = ?$

$u = -100$ cm, $R = -20$ cm. $\quad\therefore\quad f = -10$ cm

Using mirror formula,

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}\Rightarrow\frac{1}{v}+\frac{1}{100}=-\frac{1}{10}$$

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$$\frac{1}{v}=\frac{1}{100}-\frac{1}{10}=\frac{1-10}{100}=-\frac{9}{100}$$

$$\therefore \quad v=-\frac{100}{9}\ \text{cm.}$$

$$\frac{h_i}{h_0}=\frac{v}{u} \Rightarrow \frac{h_i}{5\ \text{cm}}=\frac{(100/9)}{100}=\frac{1}{9}$$

$$\therefore \quad h_i = 5/9 = 0.55\ \text{cm.}$$

28. (D) Magnifying power of compound microscope

$$M=-\frac{v_0}{u_0}\left(1+\frac{D}{f_e}\right)=-\frac{L}{f_0}\left(1+\frac{D}{f_e}\right)$$

29. (A) Focal length of a convex lens having power 2.5D,

$$=\frac{1}{2.5}\text{m}$$

Also focal length of a lens in a medium of refractive index μ is given by

$$\frac{1}{f}=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$\Rightarrow \quad 2.5=\frac{1}{f}=\left(\frac{3}{2}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \quad \text{....(i)} \quad \text{(in air)}$$

$$\Rightarrow \quad \frac{1}{f'}=\left(\frac{3}{4}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \quad \text{....(ii)} \quad [\because {}^{l}\mu_g=\frac{3}{4}]$$

(in liquid)

Dividing the two, $2.5\ f'=\dfrac{0.5}{-0.25}$

$$\Rightarrow \quad \frac{1}{f'}=\frac{-5}{25\times 0.25}=-1.25\ \text{D}$$

30. (D) Radiation pressure P_{rad} due to light falling on a non-reflecting surface at normal incidence is given by

$$P_{rad}=\frac{\text{Energy flux}}{\text{Speed of light}}=\frac{18\text{W/cm}^2}{3\times10^8\text{m/s}}$$

$$=\frac{18\times10^4\text{W/m}^2}{3\times10^8\text{m/s}}=6\times10^{-4}\text{N/m}^2$$

31. (A) Using $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$

Given $u=f+d_1 \qquad v=f+d_2$

$$f=\frac{uv}{u+v}=\frac{(f+d_1)(f+d_2)}{(f+d_1)+(f+d_2)}$$

On solving $f=\sqrt{d_1d_2}$

32. (C) use $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$

Find v_1, when u = d and v_2, when u = d + l

$$\text{Size of image} = v_1 - v_2 = l\left(\frac{f}{d-f}\right)^2$$

33. (C) The power of lens

$$P=\frac{1}{f}=\frac{1}{v}-\frac{1}{u}=\left[\frac{1}{25}-\frac{1}{\text{N.P.}}\right]$$ Where N.P. = Near point of vision

$$P=\left[\frac{1}{25}-\frac{1}{100}\right]$$

$$P=\frac{4-1}{100}=\frac{3}{100\ \text{cm}}=\frac{3}{1\ \text{m}}=3\ \text{D}$$

34. (C) Here $f_1=-20$ cm, $f_2=+10$ cm

Focal length of combination is,

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{-20}+\frac{1}{10}$$

$$\frac{1}{F}=\frac{1}{20} \Rightarrow F=20\ \text{cm}$$

Power of the combination,

$$P=\frac{100}{F}=\frac{100}{20}=+5\text{D}$$

35. (B) Here u = – 25 cm, v = – 50 cm

We have $\frac{1}{f}=\frac{1}{-u}+\frac{1}{v}$

i.e, $\frac{1}{f}=\frac{1}{25}+\frac{1}{50}$ or $f=50$ cm

Power of lens he should use,

$$P=\frac{100}{f}=\frac{100}{50}=+2\text{D}$$

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36. (B) Let L is the distance between a real object and its real image formed by a convex lens, then as

$L = (|u| + |v|)$

$= (\sqrt{u} - \sqrt{v})^2 + 2\sqrt{uv}$ ....(i)

L will be minimum, when

$(\sqrt{u} - \sqrt{v})^2 = 0$

i.e., $u = v$

Putting, $u = -u$ and $v = +u$ in lens formula,

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{F}$$

$$\frac{1}{u} - \frac{1}{-u} = \frac{1}{F}$$

$u = 2F$

$\therefore \quad (L)_{min} = 2\sqrt{2F \times 2F} = 4F$ (Using (i))

37. (B) Using, $\mu = \frac{c}{v}$

Here, $c = 3 \times 10^8 \text{ m s}^{-1}$

$v = \upsilon\lambda = 2 \times 10^{14} \text{ Hz} \times 5000 \times 10^{-10} \text{ m}$

$= 1 \times 10^8 \text{ m s}^{-1}$

$$\therefore \quad \mu = \frac{3 \times 10^8 \text{ m s}^{-1}}{1 \times 10^8 \text{ m s}^{-1}} = 3$$

38. (B) Here, $\delta_m = A, \mu = 1.5$

$$\therefore \quad \mu = \frac{\sin\frac{(A + \delta_m)}{2}}{\sin\frac{A}{2}} = \frac{\sin\frac{(A + A)}{2}}{\sin\frac{A}{2}}$$

$$= \frac{2\sin\left(\frac{A}{2}\right)\cos\left(\frac{A}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

$$\frac{3}{2} = 2\cos\frac{A}{2} \qquad \left(\because \mu = 1.5 = \frac{3}{2}\right)$$

$$\cos\frac{A}{2} = \frac{3}{4} \text{ or } \frac{A}{2} = \cos^{-1}\left(\frac{3}{4}\right) \text{ or } A = 2\cos^{-1}\left(\frac{3}{4}\right)$$

39. (B) Here, $u = -25 \text{ cm}$ $v = -1 \text{ m} = -100 \text{ cm}$

$$\therefore \quad \frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-100} + \frac{1}{25} = \frac{3}{100}$$

$$\text{or } f = \frac{100}{3}\text{cm} = \frac{1}{3}\text{m}$$

Therefore, required power,

$$P = \frac{1}{f(\text{m})} = \frac{1}{1/3} = 3 \text{ D}$$

40. (B) Let d be the distance of near point of the person without glasses.

Focal length of glasses,

$$f_1 = \frac{100}{P_1} = \frac{100}{1.5} = \frac{200}{3}\text{cm}$$

Now $u = -25 \text{ cm}$; $v = ?$

From lens formula, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f_1}$

$$\text{or } \frac{1}{v} = \frac{1}{f_1} + \frac{1}{u} = \frac{3}{200} - \frac{1}{25} = -\frac{5}{200}$$

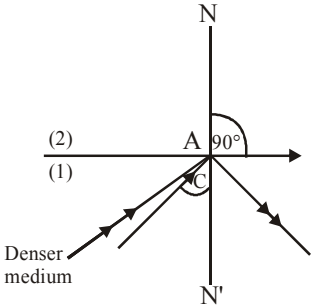
$$\therefore \quad v = -\frac{200}{5} = -40 \text{ cm}$$

Therefore, the near point of the person is 40 cm. Focal length of microscope,

$$f_2 = \frac{100}{P_2} = \frac{100}{20} = 5 \text{ cm}$$

$$\therefore \quad M = 1 + \left|\frac{d}{f_2}\right| = 1 + \frac{40}{5} = 9$$

41. (A) Total internal reflection occurs when the angle of incidence is greater than critical angle (C) in the denser medium.



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$${}^{1}\mu 2 = \frac{\text{Velocity of light in medium '1'}}{\text{Velocity of light in medium '2'}}$$

$${}^{1}\mu 2 = \frac{v}{2v} = \frac{1}{2}.$$ Medium '1' is denser.

or $\sin C = \sin 30°$ or $C = 30°$.

42. **(B)** Here, real depth, x = 15 cm

apparent depth, y = 6 + 4 = 10 cm

$$\mu = \frac{x}{y} = \frac{15}{10} = 1.5$$

43. **(B)** In normal adjustment,

$L = f_0 + f_e = 200\text{ cm} = 4\text{ cm} = 204\text{ cm}$

44. **(C)** Clearly $r + i_c = 90°$

$r = 90 - i_c$

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin 60°}{\sin(90 - i_c)}$$

$$\mu = \frac{\sqrt{3}}{2\cos i_c} \quad \text{....(i)}$$

$\because$ $$\mu = \frac{1}{\sin i_c} \quad \text{....(ii)}$$

From eqns (i) and (ii)

$$\sin i_c = \frac{2\cos i_c}{\sqrt{3}} \Rightarrow \tan i_c = \frac{2}{\sqrt{3}}$$

or $i_c \approx 49°\ 11' \approx 50°$

$$\Rightarrow \mu = \frac{1}{\sin i_c} = \frac{1}{\sin 50°} = 1.31$$

45. **(B)** Red colour is always used for danger signals, because as red colour is having the longest wavelength, it is the least scattered. So, this signal can be seen from a very long distance.

46. **(A)** The assertion is true. The reason is true. It explains the assertion. An endoscope is made of optical fibres. Its core is made of optically rarer material. It is based on total internal reflection.

47. **(A)** The focal length of a lens in a medium of refractive index μ_m is given by

$$\frac{1}{f_m} = \left(\frac{\mu - \mu_m}{\mu_m}\right)\left(\frac{1}{R_1}\frac{1}{R_2}\right)$$ where μ is the refractive index of glass.

In air $$\frac{1}{f_a} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

From these two expressions it is clear that $f_m > f_a$. That is the focal length of the convex lens in water increases thereby reducing its convergent power.

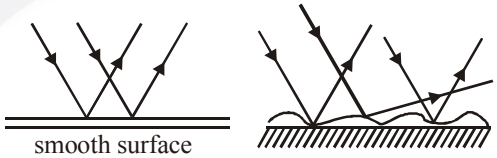
48. **(B)** This is true that the stars are much bigger in size than the planets. But this is not the reason why the stars twinkle but the planets do not. Actually the planets do not have their own light to twinkle. As the stars have their own light, and as they are very much for away from us, the light coming from the stars has to travel a very long distance and for a very long time to arrive us. And so the light coming from the stars is found to change their intensities continuously and hence the stars are seen to be twinkling.

49. **(A)** There are two types of receptors in the eyes. One is called rods and other is cones. The rods are sensitive for dark light. As the owl has large number of rods in its retina and so the owl can move freely in the dark.

50. **(B)** A red object reflects only red light and absorbs the remaining colours and so it appears red. When yellow light is incident on red object, the object absorbs yellow and reflects nil. It therefore appears black.

51. **(A)** For the human eye, the resolving power or angular separation of objects changes as distance from the object changes. Thus when we are close to the painting our eyes can pick out the separate colours of dots. But when we move away from the painting, our eyes blend the dots and we see different colours.

52. **(C)** When glass surface is made rough then the light falling on it is scattered in different direction due to which its transparency decreases.



53. **(B) :** Diamond glitters brilliantly because light enters in diamond suffers total internal reflection. All the light entering in it comes out of diamond after number of reflections and no light is absorbed by it.

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54. **(A)** Optical fibers are used in communication and it is because the phenomenon of total internal reflection, taking place inside the fiber for the signal incident. Both the statements are correct and the reason given is the right explanation.

55. **(A)** Assertion : goggles have zero power. True The focal length is given by $\frac{1}{f}=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$. For goggles lenses, both sides are curved the same way. R_1 and R_2 are positive. If they are the same, $\frac{1}{f}=0$ i.e. power is zero.

56. **(A)**

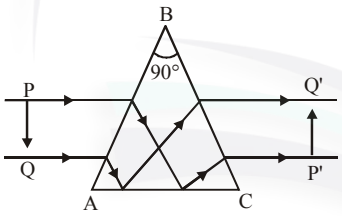
57. **(A)** $\frac{1}{f}=({}^{a}\mu_g-1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]=\left(\frac{\mu_g}{\mu_w}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

$$\frac{1}{f}=\left(\frac{\mu_g-\mu_w}{\mu_w}\right)\cdot\left[\frac{1}{R_1}-\frac{1}{R_2}\right]=\left(\frac{1.5-1.33}{1.33}\right)\cdot\left[\frac{1}{20}+\frac{1}{20}\right]$$

$$\frac{1}{f}=\frac{0.13\times 2}{20}\quad\Rightarrow\quad f=\frac{20}{0.26}$$

$\therefore\quad f=76.92$ cm.

58. **(A)** Beam of light incident on face AB, suffers refraction fro air to glass and strikes the face AC suffering total internal reflection.



The beam now strikes the face BC of the prism at an angle of incidence less than the critical angle hence it suffers refraction from glass to air and bend away from the normal. The beam emerges out parallel to the base. As a result of refraction, on emergence the rays are inverted.

59. **(A)** The rays or all colours incident on a concave mirror at the same angle are reflected at the same angle. Hence image formed by reflection does not suffer chromatic aberration.

60. **(D)** We cannot interchange the objective and eye lenses of a microscope to make a telescope. The reason is that the focal length of lenses in microscope are very small, of the order of mm or a few cm and the difference (f_0-f_e) is very small, while the telescope objective have a very large focal length as compared to eye lens of microscope.

61. **(A)** The CD acts like a prism because the narrow grooves are so close to each other that you cannot see the separation. But, white light fall on the CD will be separated by multicolours by grooves.

62. **(A)** When white light is passed through a lens, violet light is more refracted than red light because wavelength of violet is less than red light and therefore focal length for red light is greater then violet.

63. **(A)** Microscope is an optical instrument which forms a magnified image of a small nearby object and thus, increases the visual angle subtended by the image at the eye so that the object is seen to be bigger and distinct. Therefore angular magnification for image is more than object.

64. **(B)** The sign of magnification depend on the sign convention chosen. According to the new Cartesian sign conventions, magnification for a convex mirror is positive because image formed by a convex mirror is always virtual or erect images and also real, inverted images. In the latter case, its magnification becomes negative. The reason though correct does not explain the assertion properly.

65. **(C)** Lenses have different refractive index for different wavelengths of light. The refractive index decreases with increasing wavelength. So red light will bend least and violet the most. This will result is slight dispersion which will be seen as chromatic aberration.

66. **(B)** In telescope to have a large magnifying power, focal length of objective lens is kept large. To increase the magnifying power and resolving power, aperture of the objective lens is made large.

67. **(A)** Optical density and mass density are not related to each other mass density is mass per unit volume. It is not possible that mass density of an optically denser medium may be less than that of an optically rarer medium (optical density is the ratio of the speed of light in two media). e.g., turpentine and water. Mass density of turpentine is less than that of water but is optical density is higher.

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68. **(A)** This is because refraction through the different layers of atmosphere.

69. **(A)** The rays of all colours incident on a concave mirror at the same angle are reflected at the same angle. As there is no chromatic aberration, the reflected image is white.

70. **(C)** Diameter of a single mode optical fibre lies between 8 to 10.5 μm.

Critical angle for total internal reflection does not depend on width of media.

71. **(C)** In the formation of secondary rainbow, light suffers two total internal reflections instead of one. In this, ray undergoes two internal partial reflections having a maximum deviation of about 50° for red and 54° for violet. Also secondary rainbow will sometimes be formed with inverted colours. Secondary rainbow is fainter than the primary for two reason (i) the light has undergone two internal reflections and has thereby becomes weakened, (ii) there is greater angular dispersion in this rainbow than in the primary.

72. **(D)** When an object is placed between two plane parallel mirrors, then infinite number of images are formed. Images are formed due to multiple reflections. At each reflection, a part of light energy is absorbed. Therefore, distant images get fainter.

MOCK TEST

1. **(A)**

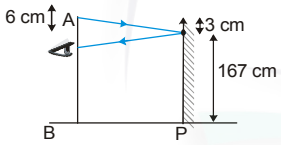


Figure in self explanatory.

2. **(C)** $\frac{I}{O} = -\frac{V}{u}$

If O and I are on same sides of PA . $\frac{I}{O}$ will be positive which implies v and u will be of opposite signs.

Similarly if O and I are on opposite sides, $\frac{I}{O}$ will be -ve which implies v and u will have same sign.

If O is on PA, $I = \left(-\frac{V}{u}\right)(O) \Rightarrow$ I will also be on. P.A.

3. **(A)** $\vec{V}_I m = \vec{V}_0 m$ (normal to plane mirror)

$\Rightarrow \vec{v}_I - \vec{v}_m = -(\vec{V}_0 - \vec{V}_m)$

$\vec{V}_I - V\sin\theta = -(0 - V\sin\theta)$

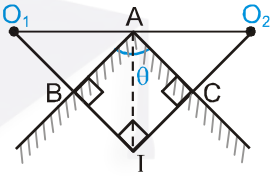
$V_I = 2V\sin\theta$

4. **(B)** As AB is common and $O_1B = BI$

$\Delta O,BA$ and ΔBAI are congruent

By symmetry AI is perpendicular to O_1 to O_2

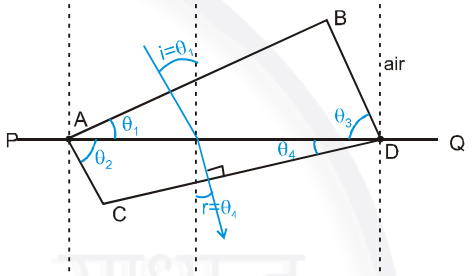
and $\angle O_1AB = \angle BAI$



$\therefore$ BAI = 45°

and $\angle BAC = 90°$

5. **(C)** By snell's law :

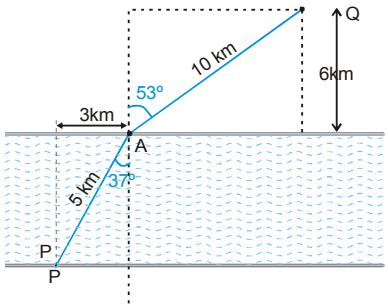


$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$

for $i = \theta_1$, $r = \theta_4$ and $\mu_1 = 1$. $\mu_2 = \frac{\sin\theta_1}{\sin\theta_4}$.

6. **(A)** As we know that light travels in a path such as to reach from one point to another in shortest possible time.

Therefore, the man must travel along that path on which light would have travelled in moving from P to Q.



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By Snell's law ;

$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} \Rightarrow \sin r = \frac{\mu_1}{\mu_2} . \sin i$

$\sin r = \frac{3}{5} . \frac{4}{3} = \frac{4}{5} \Rightarrow r = 53^\circ$

$\therefore$ AQ = 10 Km.

From P to A :

$t_1 = \frac{5}{3}$

From A to Q :

$t_2 = \frac{10}{4} = \frac{5}{2}$

$T = t_1 + t_2 = \frac{5}{3} + \frac{5}{2} = \frac{25}{6}$ hr. $= \left(\frac{24}{6} + \frac{1}{6}\right)$ hr

$= \left(4\text{hr} + \frac{1}{6}\text{hr}\right) = 4\text{hr} + 10$ minutes

7. **(C)** $\frac{x}{1} = \frac{x_{rel}}{\mu}$ $x_{rel} = \mu x$

$\frac{d^2x_{rel}}{dt^2} = \mu \frac{d^2x}{dt^2} \Rightarrow a_{rel} = \mu g$

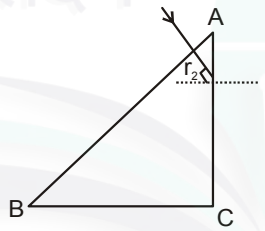
8. **(B)** $A = 90^\circ - \theta$

$r_2 = A = 90^\circ - \theta > \theta_C$

$\cos\theta > \sin\theta_C = \frac{6/5}{3/2} = \frac{4}{5}$

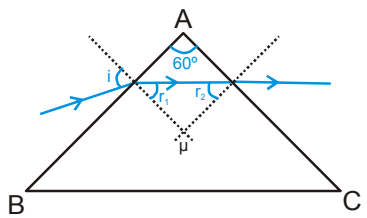
(θ_C is critical angle)

$\Rightarrow \theta < \cos^{-1}\frac{4}{5} = 37^\circ$.



9. **(A)** $r_2 < \theta_C$; $A - r_1 < \theta_C$; $r_1 > A - \theta_C$

$\Rightarrow \sin r_1 > \sin(A - \theta_C) \Rightarrow \frac{\sin i}{\mu} > \sin(A - \theta_C)$



$\Rightarrow \sin i > \mu(\sin A \cos\theta_C - \sin\theta_C \cos A)$

$= \sqrt{\frac{7}{3}}\left(\frac{\sqrt{3}}{2}\sqrt{1-\frac{3}{7}} - \sqrt{\frac{3}{7}}.\frac{1}{2}\right) = 1 - \frac{1}{2} = \frac{1}{2}$

$\Rightarrow \sin i > \frac{1}{2}$ or $i > 30^0$.

10. **(A)** Given $i = 60^\circ$ $A = \delta = e$

$\delta = i + e - A \Rightarrow \delta = i$ ($\because e = A$) and $\delta = i = e$

$\mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\frac{A}{2}}$

Here angle of deviation is minimum ($\because i = e$)

$\mu = \frac{\sin\left(\frac{60^\circ + 60^\circ}{2}\right)}{\sin(60^\circ/2)} = \sqrt{3}$ Ans.

11. **(A)** Using formula of spherical surface taking 'B' as object

$\frac{\mu_2}{\infty} - \frac{\mu_1}{(-2R)} = \frac{\mu_2 - \mu_1}{-R}$

(R being the radius of the curved surface)

$\Rightarrow \frac{\mu_1}{\mu_2} = 2$

12. **(D)** For spherical surface

using $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$

$\Rightarrow \frac{n}{2R} - \frac{1}{\infty} = \frac{n-1}{R}$

$\Rightarrow n = 2n - 2 \Rightarrow n = 2.$

13. **(D)** The image is erect hence, mirror must be between object & image. Virtual image of real object is diminished, hence mirror is convex.

14. **(D)** Acceleration of block AB $= \frac{3mg}{3m + m} = \frac{3}{4}g$;

acceleration of block CD $= \frac{2mg}{2m + m} = \frac{2g}{3}$

Acceleration of image in mirror AB

= 2 acceleration of mirror

$= 2.\left(\frac{-3g}{4}\right) = \frac{-3}{2}g$

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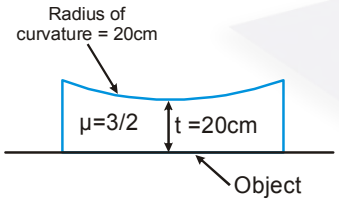
Acceleration of image in mirror CD = $2.\left(\frac{2g}{3}\right) = \frac{4g}{3}$

$\therefore$ Acceleration of the two image w.r.t. each other

$= \frac{4g}{3} - \left(\frac{-3g}{2}\right) = \frac{17g}{6}$.

15. (C) In the first case the distance travelled in the slab < distance travelled in the slab in the 2nd case.

16. (A) Considering refraction at the curved surface,



$u = -21\sqrt{3}$; $\mu_2 = 1$ $\mu_1 = 3/2$; $R = +20$

applying $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$

$\Rightarrow \frac{1}{v} - \frac{3/2}{-20} = \frac{1-3/2}{20} \Rightarrow v = -10$

i.e. 10 cm below the curved surface

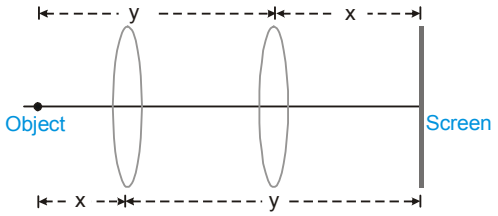
or 10 cm above the actual position of flower.

17. (A) $\left(\frac{n_A - 1}{1}\right)\frac{2}{R_A} = \left(\frac{n_B - 1}{1}\right)\frac{2}{R_B}$

or $\frac{0.63}{R_A} = \frac{n_B - 1}{R_B}$

or $n_B = 1.7$

18. (B) At first position of lens, let the distance of lens from object and screen be x and y respectively.



$\therefore$ $x + y = 100$ .....(1)

$\therefore$ At second position of lens the distance of lens from object and screen shall be y and x respectively.

$\therefore$ $y - x = 40$ .....(2)

solving equation (1) and (2) we get

$y = 70\text{ cm} = \frac{70}{100}$ m

and $x = 30\text{ cm} = \frac{30}{100}$ m

$\therefore$ The power of lens is

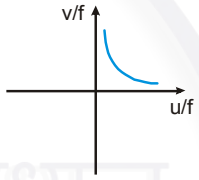
$\frac{1}{f} = \frac{1}{y} + \frac{1}{x} = \frac{100}{70} + \left(\frac{100}{30}\right) = \frac{100}{21} \approx 5$ diopters

19. (A) $\frac{1}{V} - \frac{1}{u} = \frac{1}{f}$

$\frac{f}{v} - \frac{f}{u} = 1$ or $\frac{1}{y} - \frac{1}{x} = 1$

or $y = \frac{x}{x+1}$

Hence, a virtual erect image by a diverging lens is represented by

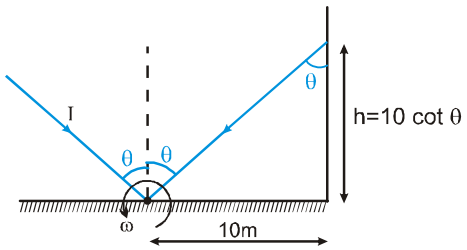


20. (B) When mirror is rotated with angular speed ω, then the reflected ray rotates with angular speed

$2\omega (= 36\text{ rad/s})$

speed of the spot $= \left|\frac{dh}{dt}\right| = \left|\frac{d}{dt}(10\cot\theta)\right|$

$= \left|-10\,\text{cosec}^2\theta\,\frac{d\theta}{dt}\right|$



$= \left|-\frac{10}{(0.6)^2} \times 36\right| = 1000$ m/s.

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21. **(A)** Put $A = \delta_{min}$ and $\mu = \sqrt{2}$

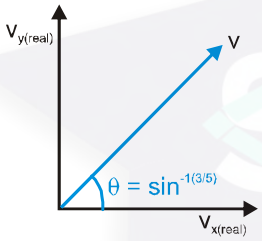
$A = \delta_{min}$ $\mu = \sqrt{2}$

The relation $\mu = \dfrac{\sin\left(\dfrac{A+\delta_{min}}{2}\right)}{\sin\left(\dfrac{A}{2}\right)}$ and solve for A

22. **(C)** Let y-axis be vertically upwards and x-axis be horizontal.

$$V_y(\text{app.}) = \frac{V_y(\text{real})}{\left(\frac{1}{\mu}\right)}$$

$$V_x(\text{app.}) = V_x(\text{real})$$



$$\tan\phi = \frac{V_y(\text{app})}{V_x(\text{app})} = \frac{4}{3}\tan\theta = \frac{4}{3}\times\frac{3}{4} = 1$$

23. **(A)** Use refraction formulae separately that is for air and $\mu = 1.6$ and for air and $\mu = 2.0$ and find the positions of the two images.

24. **(A)** Dispersion will not occur for a light of single wave length $\lambda = 4000$ Å.

25. **A → S; B → P; C → S; D → Q**

(A) $\vec{v}_A = \hat{i} + \vec{a}\,t = \hat{i} + (2\hat{i} + \hat{j})(2) = 5\hat{i} + 2\hat{j}$

$\vec{v}_{A'} = -5\hat{i} + 2\hat{j}$

$\vec{v}_{A',A} = \vec{v}_{A'} - \vec{v}_A = -10\hat{i}$

$\vec{v}_B = (-\hat{i} + 3\hat{j})$, $\vec{v}_{B'} = \hat{i} + 3\hat{j}$ So $\vec{v}_{B',B} = 2\hat{i}$

For particle C

$\dfrac{dv_y}{dt} = 2t \Rightarrow v_y - 6 = t^2 \Rightarrow v_y = 6 + 4 = 10$

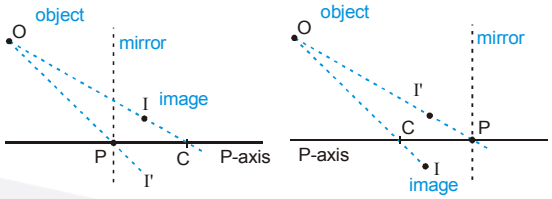
$\vec{v}_C = 5\hat{i} + 10\hat{j}$, $\vec{v}_{C'} = -5\hat{i} + 10\hat{j}$

So $\vec{v}_{C',C} = -10\hat{i}$

$\vec{v}_D = 3\hat{i} - \hat{j}$, $\vec{v}_{D'} = -3\hat{i} - \hat{j}$, $\vec{v}_{D',D} = -6\hat{i}$

26. **A → P, Q ; B → P, Q ; C → R, S ; D → R, S**

For a spherical mirror, line joining object and its image crosses principal axis at centre of curvature. The line joining object and image inverted about principal axis cuts the principal axis at the pole. Then from figure below.



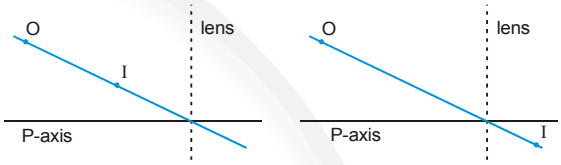
We can conclude

(A) If object and image are on same side of principal axis, they are on opposite side of mirror.

(B) If object and image are on opposite side of principal axis, they are on same side of mirror.

For a lens, the line joining object and image cuts the principal axis at optical centre.

Then from figures below.



We can conclude

(C) If object and image are on same side of principal axis, they are also on same side of lens.

(D) If object and image are on opposite side of principal axis. They are also on opposite side of lens.

27. **(C)** The index of refraction for light at the red end of the visible spectrum is lesser than at the violet end. Hence statement -2 is false

28. **(D)** Statement-2 is correct explanation of statement-1.

29. **(D)** From symmetry the ray shall not suffer TIR at second interface, because the angle of incidence at first interface equals to angle of emergence at second interface. Hence statement 1 is false

30. **(D)** If the mirror is shifted parallel to itself such that the velocity of the mirror is parallel to its surface, the image shall not shift. Hence statement 1 is false.

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CHAPTER 08

WAVE OPTICS

A rainbow is the product of physics working for your appreciation of beauty.

"KYLE HILL"

INTRODUCTION

The dutch physicist Christiaan Huygens, in 1678 put forward the wave theory of light – it is this wave model of light that we will discuss in this chpater. As we will see, the wave model could satisfactorily explain the phenomena of reflection and refraction; however, it predicted that on refraction if the wave bends towards the normal then the speed of light would be less in the second medium. This is in contradiction to the prediction made by using the corpuscular model of light. It was much later confirmed by experiments where it was shown that the speed of light in water is less than the speed in air confirming the prediction of the wave model; Foucault carried out this experiment in 1850.

The wave theory was not readily accepted primarily because of Newton's authority and also because light could travel through vacuum and it was felt that a wave would always require a medium to propagate from one point to the other. However, when Thomas Young performed his famous interference experiment in 1801, it was firmly established that light is indeed a wave phenomenone. The wavelength of visible light was measured and found to be extremely small; for example, the wavelength of yellow light is about 0.5 μm. Because of the smallness of the wavelength of visible light (in comparison to the dimensions of typical mirrors and lenses), light can be assumed to approximately travel in straight lines. This is the field of geometrical optics, and a ray is defined as the path of energy propagation in the limit of wavelength tending to zero.

LIGHT

The physical cause, with the help of which our eyes experience the sensation of vision, is known as light or the form of energy, which excites our retina and produce the sensation of vision, is known as light.

PROPERTIES OF VISIBLE LIGHT

(i) No material medium is required for the propagation of light energy i.e. it travels even in vacuum.

(ii) Its velocity is constant in all inertial frames i.e. it is an absolute constant. It is independent of the relative velocity between source and the observer.

(iii) Its velocity in vacuum is maximum whose value is 3×10^8 m/s.

(iv) It lies in the visible region of electromagnetic spectrum whose wavelength range is from 4000 Å to 8000 Å.

(v) Its energy is of the order of eV.

(vi) It propagates in straight line.

(vii) It exhibits the phenomena of reflection, refraction, interference, diffraction, polarisation and double refraction.

(viii) It can emit electrons from metal surface i.e. it can produce photoelectric effect.

(ix) It produces thermal effect and exerts pressure when incident upon a surface. It proves that light has momentum and energy.

(x) Its velocity is different in different media. In rarer medium it is more and in denser medium it is less.

(xi) Light energy propagates via two processes.

(a) The particles of the medium carry energy from one point of the medium to another.

(b) The particles transmit energy to the neighbouring particles and in this way energy propagates in the form of a disturbance.

DIFFERENT THEORIES OF LIGHT

1. Newton's corpuscular theory of light.
2. Hygen's wave theory of light.
3. Maxwell's electromagnetic theory of light.
4. Plank's Quantum theory of light.
5. De-Broglie's dual theory of light.

1. Newton's corpuscular theory of light

This theory was enuciated by Newton.

(i) Characteristics of the theory

(a) Extremely minute, very light and elastic particles are being constantly emitted by all luminous bodies (light sources) in all directions

(b) These corpuscles travel with the speed of light..

(c) When these corpuscles strike the retina of our eye then they produce the sensation of vision.

(d) The velocity of these corpuscles in vacuum is 3×10^8 m/s.

(e) The different colours of light are due to different size of these corpuscles.

(f) The rest mass of these corpuscles is zero.

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(g) The velocity of these corpuscles in an isotropic medium is same in all directions but it changes with the change of medium.

(h) These corpuscles travel in straight lines.

(i) These corpuscles are invisible.

(ii) The phenomena explained by this theory

(a) Reflection and refraction of light.

(b) Rectilinear propagation of light.

(c) Existence of energy in light.

(iii) The phenomena not explained by this theory

(a) Interference, diffraction, polarisation, double refraction and total internal reflection.

(b) Velocity of light being greater in rarer medium than that in a denser medium.

(c) Photoelectric effect and Compton effect.

2. WAVE THEORY OF LIGHT

This theory was enunciated by Hygen in a hypothetical medium known as luminiferrous ether.

Ether is that imaginary medium which prevails in all space, in isotropic, perfectly elastic and massless.

The different colours of light are due to different wave lengths of these waves.

The velocity of light in a medium is constant but changes with change of medium.

This theory is valid for all types of waves.

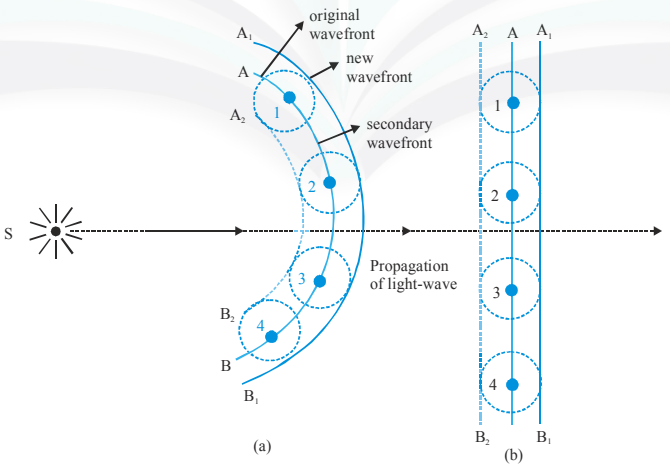
(i) The locus of all ether particles vibrating in same phase is known as wavefront.

(ii) Light travels in the medium in the form of wavefront.

(iii) When light travels in a medium then the particles of medium start vibrating and consequently a disturbance is created in the medium.

(iv) Every point on the wave front becomes the source of secondary wavelets. It emits secondary wavelets in all directions which travel with the speed of light **(v)**,

The tangent plane to these secondary wavelets represents the new position of wave front.



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The phenomena explained by this theory

(i) Reflection, refraction, interference, diffraction, polarisation and double refraction.

(ii) Rectilinear propagation of light.

(iii) Velocity of light in rarer medium being grater than that in denser medium.

Phenomena not explained by this theory

(i) Photoelectric effect, Compton effect and Raman effect.

(ii) Backward propagation of light.

WAVE FRONT, VARIOUS TYPES OF WAVE FRONT AND RAYS

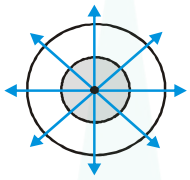
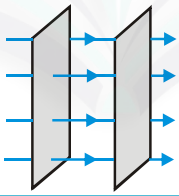
(a) Wavefront

The locus of all the particles vibrating in the same phase is known as wavefront.

(b) Types of wavefront

The shape of wavefront depends upon the shape of the light source originating that wavefront. On the basis of there are three types of wavefront.

Comparative study of three types of wavefront

S.No.	Wavefront	Shape of light source	Diagram of shape of wavefront	Variation of amplitude with distance	Variation of intensity with distance
1.	Spherical	Point source		$A \propto \frac{1}{d}$ or $A \propto \frac{1}{r}$	$I \propto \frac{1}{r^2}$
2.	cylindrical	Linear or slit		$A \propto \frac{1}{\sqrt{d}}$ or $A \propto \frac{1}{\sqrt{r}}$	$I \propto \frac{1}{r}$
3.	Plane	Extended large source situated at very large distance		A = constant	I = constant

Characteristic of Wavefront

(a) The phase difference between various particles on the wavefront is zero.
(b) These wavefronts travel with the speed of light in all directions in an isotropic medium.
(c) A point source of light always gives rise to a spherical wavefront in an isotropic medium.
(d) In an anisotropic medium it travels with different velocities in different directions.
(e) Normal to the wavefront represents a ray of light.
(f) It always travels in the forward direction of the medium.

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PRINCIPLE OF SUPERPOSITION

When two or more waves simultaneously pass through a point, the disturbance of the point is given by the sum of the disturbances each wave would produce in absence of the other wave(s). In case of wave on string disturbance means displacement, in case of sound wave it means pressure change, in case of Electromagnetic Waves. it is electric field or magnetic field. Superposition of two light travelling in almost same direction results in modification in the distribution of intensity of light in the region of superposition. This phenomenon is called *interference*.

Superposition of two sinusoidal waves

Consider superposition of two sinusoidal waves (having same frequency), at a particular point.

Let, $x_1(t) = a_1 \sin \omega t$

and, $x_2(t) = a_2 \sin(\omega t + \phi)$

represent the displacement produced by each of the disturbances. Here we are assuming the displacements to be in the same direction. Now according to superposition principle, the resultant displacement will be given by,

$$x(t) = x_1(t) + x_2(t)$$
$$= a_1 \sin \omega t + a_2 \sin(\omega t + \phi)$$
$$= A \sin(\omega t + \phi_0)$$

where $A^2 = a_1^2 + a_2^2 + 2a_1 . a_2 \cos \phi$ ..... **(1.1)**

and $$\tan \phi_0 = \frac{a_2 \sin \phi}{a_1 + a_2 \cos \phi}$$ .....**(1.2)**

Ex. S_1 and S_2 are two sources of light which produce individually disturbance at point P given by $E_1 = 3\sin \omega t$, $E_2 = 4 \cos \omega t$. Assuming $\vec{E}_1$ & $\vec{E}_2$ to be along the same line, find the resultant after their superposition.

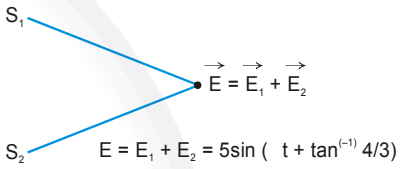


Figure 1.1

Sol.: $E = 3\sin\omega t + 4\sin(\omega t + \frac{\pi}{2}) \Rightarrow A^2 = 3^2 + 4^2 + 2(3)(4)\cos\frac{\pi}{2} = 5^2$

$$\tan\phi_0 = \frac{4\sin\frac{\pi}{2}}{3 + 4\cos\frac{\pi}{2}} = \frac{4}{3} \Rightarrow \phi_0 = 53^\circ \Rightarrow E = 5\sin[\omega t + 53^\circ]$$

Superposition of progressive waves; path difference :

Let S_1 and S_2 be two sources producing progressive waves (disturbance travelling in space given by y_1 and y_2)

At point P,

$y_1 = a_1 \sin(\omega t - kx_1 + \theta_1)$

$y_2 = a_2 \sin(\omega t - kx_2 + \theta_2)$

$y = y_1 + y_2 = A\sin(\omega t + \Delta\phi)$

Here, the phase difference,

$\Delta\phi = (\omega t - kx_1 + \theta_1) - (\omega t - kx_2 + \theta_2)$

$= k(x_2 - x_1) + (\theta_1 - \theta_2) = k\Delta p - \Delta\theta$ where $\Delta\theta = \theta_2 - \theta_1$

Here $\Delta p = \Delta x$ is the path difference

Clearly, phase difference due to path difference = k (path difference)

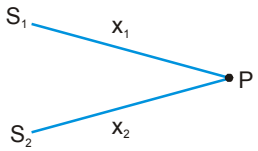


Figure: 1.3

where $k = \frac{2\pi}{\lambda}$

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$\Rightarrow \quad \Delta\phi = k\Delta p = \frac{2\pi}{\lambda}\Delta x$ ..... **(1.3)**

For Constructive Interference :

$\Delta\phi = 2n\pi, \quad n = 0, 1, 2 .....$

or, $\Delta x = n\lambda$

$A_{max} = A_1 + A_2$

Intensity, $\sqrt{I_{max}} = \sqrt{I_1} + \sqrt{I_2} \quad \Rightarrow \quad I_{max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$ ..... **(1.4)**

For Destructive interference :

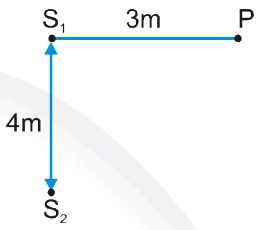
$\Delta\phi = (2n+1)\pi, \quad n = 0, 1, 2 .....$

or, $\Delta x = (2n+1)\lambda/2$

$A_{min} = |A_1 - A_2|$

Intensity, $\sqrt{I}_{min} = \sqrt{I_1} - \sqrt{I_2} \quad \Rightarrow \quad I_{min.} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2$ ..... **(1.5)**

Ex. S_1 and S_2 are two coherent sources of frequency 'f' each. ($\theta_1 = \theta_2 = 0^\circ$)
$V_{sound} = 330$m/s.
(i) so that constructive interference at 'p'
(ii) so that destructive interference at 'p'



Sol. For constructive interference

$K\Delta x = 2n\pi$

$\frac{2\pi}{\lambda} \times 2 = 2n\pi \quad \Rightarrow \quad \lambda = \frac{2}{n} \quad \Rightarrow \quad V = \lambda f \quad \Rightarrow \quad V = \frac{2}{n} f \quad \Rightarrow \quad f = \frac{330}{2} \times n$

For destructive interference

$K\Delta x = (2n+1)\pi$

$\frac{2\pi}{\lambda} . 2 = (2n+1)\pi \quad \Rightarrow \quad \frac{1}{\lambda} = \frac{(2n+1)}{4} \quad \Rightarrow \quad f = \frac{V}{\lambda} = \frac{330 \times (2n+1)}{4}$

Ex. Light from two sources, each of same frequency and travelling in same direction, but with intensity in the ratio 4 : 1 interfere. Find ratio of maximum to minimum intensity.

Sol. : $\frac{I_{max}}{I_{min}} = \left(\frac{\sqrt{I_1} + \sqrt{I_2}}{\sqrt{I_1} - \sqrt{I_2}}\right)^2 = \left(\frac{\sqrt{\frac{I_1}{I_2}} + 1}{\sqrt{\frac{I_1}{I_2}} - 1}\right)^2 = \left(\frac{2+1}{2-1}\right)^2 = 9 : 1.$

INTERFERENCE OF LIGHT

When two light waves of same frequency with zero initial phase difference or constant phase difference superimpose over each other, then the resultant amplitude (or intensity) in the region of superimposition is different from the amplitude (or intensity) of individual waves.

This modification in intensity in the region of superposition is called interference.

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(a) Constructive interference

When resultant intensity is greater than the sum of two individual wave intensities [$I > (I_1 + I_2)$], then the interference is said to be constructive.

(b) Destructive interference

When the resultant intensity is less than the sum of two individual wave intensities [$I < (I_1 + I_2)$], then the interference is said to destructive.

There is no violation of the law of conservation of energy in interference. Here, the energy from the points of minimum energy is shifted to the points of maximum energy.

TYPES OF SOURCES

(i) Coherent source

Two sources are said to be coherent if they emit light waves of the same wavelength and start with same phase or have a constant phase difference.

Note : Laser is a source of monochromatic light waves of high degree of coherence.

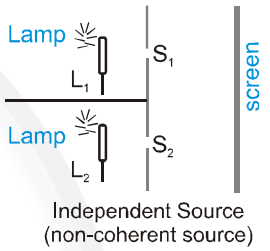
Main points

1. They are obtained from the same single source.
2. Their state of polarization is the same

(ii) Incoherent source

Two independent monochromatic sources, emit waves of same wavelength.

But the waves are not in phase. So they are incoherent. This is because, atoms cannot emit light waves in same phase and these sources are said to be incoherent sources. By using two independent laser beams it has been possible to record the interference pattern.

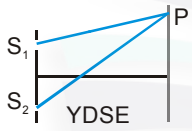


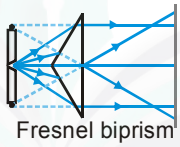
METHOD FOR OBTAINING COHERENT SOURCE

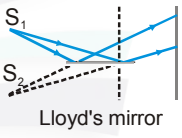
(i) Division of wave front

In this method, the wavefront is divided into two or more parts by use of mirrors, lenses or prisms.

Ex. : Young's double slit experiment. Fresnel's Biprism and Lloyd's single mirror method.



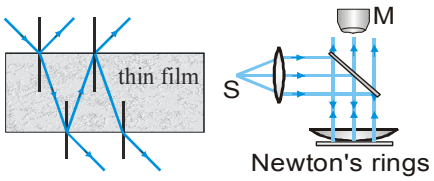




(ii) Division of amplitude

The amplitude of incoming beam is divided into two or more parts by partial reflection or refraction. These divided parts travel different paths and are finally brought together to produce interference.

Ex. : The brilliant colour seen in a thin film of transparent material like soap film, oil film, Michelson's Interferro Meter, Newtons' ring etc.



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Condition for Sustained Interference

To obtain the stationary interference pattern, the following conditions must be fulfilled :

(a) The two sources should be coherent, i.e., they should vibrate in the same phase or there should be a constant phase difference between them.

(b) The two sources must emit continuously waves of same wavelength and frequency.

(c) The separation between two coherent sources should be small.

(d) The distance of the screen from the two sources should be small.

(e) For good contrast between maxima and minima, the amplitude of two interfering waves should be as nearly equal as possible and the background should be dark.

(f) For a large number of fringes in the field of view, the sources should be narrow and monochromatic.

ANALYSIS OF INTERFERENCE OF LIGHT

When two light waves having same frequency and equal or nearly equal amplitude are moving in the same direction, They superimpose each other, at some point the intensity of light is maximum and at some point it is minimum this phenomenon is known as interference of light.

Let two waves having amplitude a_1 and a_2 and same frequency, same phase difference ϕ superpose. Let their displacement are : $y_1 = a_1 \sin \omega t$ and $y_2 = a_2 \sin (\omega t + \phi)$

By principle of superposition.

$y = y_1 + y_2 = a_1 \sin \omega t + a_2 \sin (\omega t + \phi) = a_1 \sin \omega t + a_2 [\sin \omega t \cos \phi + \cos \omega t \sin \phi]$

$= \sin \omega t (a_1 + a_2 \cos \phi) + a_2 \cos \omega t \sin \phi$

Let, $a_1 + a_2 \cos \phi = A \cos \theta$ and $a_2 \sin \phi = A \sin \theta$

Hence $y = A \sin \omega t \cos \theta + A \cos \omega t \sin \theta = A \sin (\omega t + \theta)$

Resultant amplitude $A = \sqrt{a_1^2 + a_2^2 + 2a_1 a_2 \cos\phi}$ and Phase angle $\theta = \tan^{-1} \dfrac{a_2 \sin \phi}{a_1 + a_2 \cos \phi}$

Intensity $\propto$ (Amplitude)^2 $\Rightarrow I \propto A^2 \Rightarrow I = KA^2$ So $I_1 = Ka_1^2$ & $I_2 = Ka_2^2$ $\therefore I = I_1 + I_2 + 2\sqrt{I_1}\sqrt{I_2} \cos \phi$

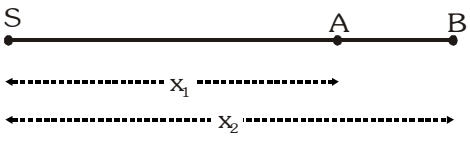
Here, $2\sqrt{I_1}\sqrt{I_2} \cos \phi$ is known as interference factor.

- If the distance of a source from two points A and B is x_1 and x_2 then

Path difference $\delta = x_2 - x_1$

Phase difference $\phi = \dfrac{2\pi}{\lambda}(x_2 - x_1) \Rightarrow \phi = \dfrac{2\pi}{\lambda}\delta$

Time difference $\Delta t = \dfrac{\phi}{2\pi} t$



$$\frac{\text{Phase difference}}{2\pi} = \frac{\text{Path difference}}{\lambda} = \frac{\text{Time difference}}{T} \Rightarrow \frac{\phi}{2\pi} = \frac{\delta}{\lambda} = \frac{\Delta t}{T}$$

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TYPES OF INTERFERENCE

(i) Constructive Interference

When both waves are in same phase. So phase difference is an even multiple of $\pi \Rightarrow \phi = 2\,n\pi$; $n = 0,1,2 \ldots$

(a) When path difference is an even multiple of $\frac{\lambda}{2}$

$\because \frac{\phi}{2\pi} = \frac{\delta}{\lambda} \Rightarrow \frac{2n\pi}{2\pi} = \frac{\delta}{\lambda} \Rightarrow \delta = 2n\left(\frac{\lambda}{2}\right) \Rightarrow \delta = n\lambda$ (where $n = 0,1,2\ldots$)

(b) When time difference is an even multiple of $\frac{T}{2}$ $\quad \therefore \Delta t = 2n\left(\frac{T}{2}\right)$

(c) In this condition the resultant amplitude and Intensity will be maximum.

$$A_{max} = (a_1 + a_2) \Rightarrow I_{max} = I_1 + I_2 + 2\sqrt{I_1}\sqrt{I_2} = (\sqrt{I_1} + \sqrt{I_2})^2$$

(ii) Destructive Interference

When both the waves are in opposite phase. So phase difference is an odd multiple of π.

$\phi = (2n-1)\pi$; $n = 1, 2 \ldots$

(a) When path difference is an odd multiple of $\frac{\lambda}{2}$, $\delta = (2n-1)\frac{\lambda}{2}$, $n = 1, 2 \ldots$

(b) When time difference is an odd multiple of $\frac{T}{2}$, $\Delta t = (2n-1)\frac{T}{2}$, $(n=1,2\ldots)$

In this condition the resultant amplitude and intensity of wave will be minimum.

$$A_{min} = (a_1 - a_2) \Rightarrow I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2$$

(i) Interference follows law of conservation of energy.

(ii) Average Intensity $I_{av} = \frac{I_{max} + I_{min}}{2} = I_1 + I_2 = a_1^2 + a_2^2$

(iii) Intensity $\propto$ width of slit $\propto$ (amplitude)$^2 \Rightarrow I \propto w \propto a^2 \Rightarrow \frac{I_1}{I_2} = \frac{w_1}{w_2} = \frac{a_1^2}{a_2^2}$

(iv) $\frac{I_{max}}{I_{min}} = \left[\frac{\sqrt{I_1} + \sqrt{I_2}}{\sqrt{I_1} - \sqrt{I_2}}\right]^2 = \left[\frac{a_1 + a_2}{a_1 - a_2}\right]^2 = \left[\frac{a_{max}}{a_{min}}\right]^2$

(v) Fringe visibility $V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \times 100\%$ when $I_{min} = 0$ then fringe visibility is maximum

i.e. when both slits are of equal width the fringe visibility is the best and equal to 100%.

Ex. If two waves represented by $y_1 = 4 \sin \omega t$ and $y_2 = 3 \sin\left(\omega t + \frac{\pi}{3}\right)$ interfere at a point. Find out the amplitude of the resulting wave.

Sol. Resultant amplitude $A = \sqrt{a_1^2 + a_2^2 + 2a_1a_2\cos\phi} = \sqrt{(4)^2 + (3)^2 + 2.(4)(3)\cos\frac{\pi}{3}} \Rightarrow A \simeq 6$

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Ex. Two beams of light having intensities I and 4I interferer to produce a fringe pattern on a screen. The phase difference between the beam is $\frac{\pi}{2}$ at point A and 2π at point B. Then find out the difference between the resultant intensities at A and B.

Sol. Resultant intensity $I = I_1 + I_2 + 2\sqrt{I_1}\sqrt{I_2}\cos\phi$

Resultant intensity at point A is $I_A = I + 4I + 2\sqrt{I}\sqrt{4I}\cos\frac{\pi}{2} = 5I$

Resultant intensity at point B, $I_B = I + 4I + 2\sqrt{I}\sqrt{4I}\cos 2\pi = 9I$ $(\because \cos 2\pi = 1)$ $\therefore I_B - I_A = 9I - 5I \Rightarrow 4I$

Ex. In interference pattern, if the slit widths are in the ratio 1:9. Then find out the ratio of minimum and maximum intensity.

Sol. Slit width ratio

$$\frac{w_1}{w_2} = \frac{1}{9} \because \frac{I_1}{I_2} = \frac{w_1}{w_2} = \frac{a_1^2}{a_2^2} = \frac{1}{9} \Rightarrow \frac{a_1}{a_2} = \frac{1}{3} \Rightarrow 3a_1 = a_2 \therefore \frac{I_{min}}{I_{max}} = \frac{(a_1 - a_2)^2}{(a_1 + a_2)^2} = \frac{(a_1 - 3a_1)^2}{(a_1 + 3a_1)^2} = \frac{4}{16} = 1:4$$

Ex. The intensity variation in the interference pattern obtained with the help of two coherent source is 5% of the average intensity. Find out the ratio of intensities of two sources.

Sol. $$\frac{I_{max}}{I_{min}} = \frac{105}{95} = \frac{21}{19} \Rightarrow \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2} = \frac{21}{19} \Rightarrow \frac{a_1 + a_2}{a_1 - a_2} = \sqrt{\frac{21}{19}} = 1.05 \Rightarrow a_1 + a_2 = 1.05\, a_1 - 1.05\, a_2$$

$$0.05\, a_1 = 2.05\, a_2 \Rightarrow \frac{a_1}{a_2} = \frac{2.05}{0.05} = \frac{41}{1} \therefore \frac{I_1}{I_2} = \frac{a_1^2}{a_2} = \frac{1680}{1}$$

Ex. Waves emitted by two identical sources produces intensity of K unit at a point on screen where path difference between these waves is λ, calculate the intensity at that point on screen at which path difference is $\frac{\lambda}{4}$.

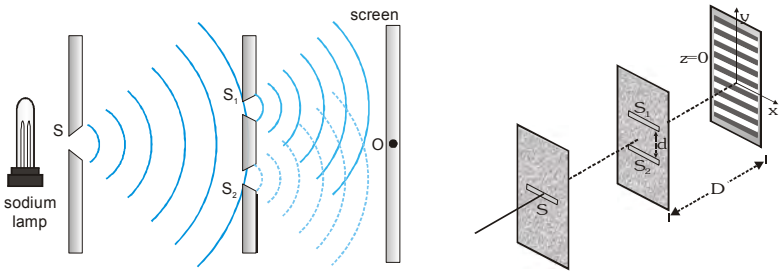
Sol. $\phi_1 = \frac{2\pi\delta}{\lambda} \Rightarrow \frac{2\pi}{\lambda} \times \lambda = 2\pi$ and $\phi_2 = \frac{2\pi}{\lambda} \times \frac{\lambda}{4} = \frac{\pi}{2}$, $I_1 = I_0 + I_0 + 2\sqrt{I_0}\sqrt{I_0}\cos 2\pi = 4I_0$

and $I_2 = I_0 + I_0 + 2\sqrt{I_0}\sqrt{I_0}\cos\frac{\pi}{2} = 2I_0$ $\therefore \frac{I_1}{I_2} = \frac{4I_0}{2I_0} = 2 \Rightarrow I_2 = \frac{I_1}{2} = \frac{K}{2}$ unit $[\because I_1 = K \text{ unit}]$

YOUNG'S DOUBLE SLIT EXPERIMENT (YDSE)

According to Huygen, light is a wave. It is proved experimentally by YDSE.

S is a narrow slit illuminated by a monochromatic source of light sends wave fronts in all directions. Slits S_1 and S_2 become the source of secondary wavelets which are in phase and of same frequency. These waves are superimposed on each other gave rise to interference. Alternate dark and bright bands are obtained on a screen (calledinterference fringes) placed certain distance from the plane of slit S_1 and S_2. Central fringe is always bright (due to path from S_1O and S_2O centre is equal) called central maxima.



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Energy is conserved in interference. This indicated that energy is redistributed from destructive interference region to the constructive interference region .

(i) If one of the two slit is closed. The interference pattern disappears. It shows that two coherent sources are required to produce interference pattern.

(ii) If white light is used as parent source, then the fringes will be coloured and of unequal width.

(a) Central fringe will be white.

(b) As the wave length of violet colour is least, so fringe nearest to either side of the central white fringe is violet and the fringe farthest from the central white fringe is red.

CONDITION FOR BRIGHT AND DARK FRINGES

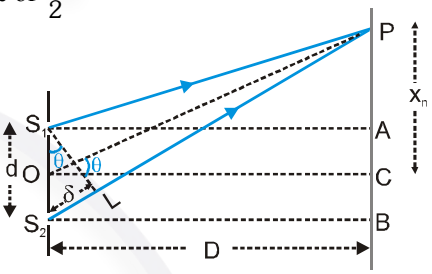
(i) Bright Fringe

D = distance between slit and screen, d = distance between slit S_1 and S_2

Bright fringe occurs due to constructive interference.

$\because$ For constructive interference path difference should be even multiple of $\frac{\lambda}{2}$

$\therefore$ Path difference $\delta = PS_2 - PS_1 = S_2L = (2n)\frac{\lambda}{2}$



In ΔPCO $\tan\theta = \frac{x_n}{D}$; In ΔS_1S_2L $\sin\theta = \frac{\delta}{d}$

$\delta = n\lambda$ for bright fringes

If θ is small then $\tan\theta \simeq \sin\theta \Rightarrow \frac{x_n}{D} = \frac{\delta}{d}$

The distance of n^{th} bright fringe from the central bright fringe $x_n = n\frac{D\lambda}{d}$

(ii) Dark Fringe

Dark fringe occurs due to destructive interference.

$\because$ For destructive interference path difference should be odd multiple of $\frac{\lambda}{2}$.

$\therefore$ Path difference $\delta = (2m-1)\frac{\lambda}{2}$

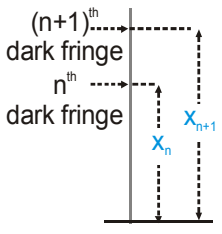
The distance of the m^{th} dark fringe from the central bright fringe $x_m = \frac{(2m-1)D\lambda}{2d}$

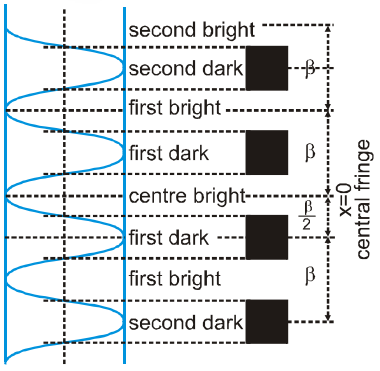
(iii) Fringe Width

The distance between two successive bright or dark fringe is known as fringe width.

$$\beta = x_{n+1} - x_n = \frac{(n+1)D\lambda}{d} - \frac{nD\lambda}{d}$$

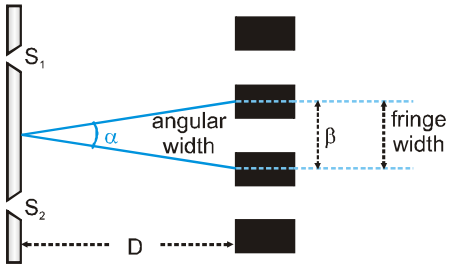
Fringe Width $\beta = \frac{D\lambda}{d}$





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(iv) Angular Fringe width



Angular Fringe Width $\alpha = \frac{\beta}{D}$, $\alpha = \frac{\lambda}{d}$ $\left[\because \frac{\beta}{D} = \frac{\lambda}{d}\right]$

(a) The distance of n^{th} bright fringe from the central bright fringe $x_n = \frac{n\lambda D}{d} = n\beta$

(b) The distance between n_1 and n_2 bright fringe $x_{n_2} - x_{n_1} = n_2\frac{\lambda D}{d} - n_1\frac{\lambda D}{d} = (n_2 - n_1)\beta$

(c) The distance of m^{th} dark fringe from central fringe $x_m = \frac{(2m-1)D\lambda}{2d} = \frac{(2m-1)\beta}{2}$

(d) The distance of n^{th} bright fringe from m^{th} dark fringe $x_n - x_m = n\frac{D\lambda}{d} - \frac{(2m-1)D\lambda}{2d} = n\beta - \frac{(2m-1)\beta}{2}$

$$x_n - x_m = \left[n - \frac{(2m-1)}{2}\right]\beta$$

(i) If the whole apparatus is immersed in a liquid of refractive index μ, then wavelength of light $\lambda' = \frac{\lambda}{\mu}$ since $\mu > 1$ so $\lambda' < \lambda \Rightarrow$ wavelength will decrease. Hence fringe width ($\beta \propto \lambda$) will decrease $\Rightarrow$ fringe width in liquid $\beta' = \beta/\mu$ angular width will also decrease.

(ii) With increase in distance between slit and screen D, angular width of maxima does not change, fringe width β increase linearly with D but the intensity of fringes decreases.

(iii) If an additional phase difference of π is created in one of the wave then the central fringe become dark.

(iv) When wavelength λ_1 is used to obtain a fringe n_1. At the same point wavelength λ_2 is required to obtain a fringe n_2 then $n_1\lambda_1 = n_2\lambda_2$

(v) When waves from two coherent sources S_1 and S_2 interfere in space the shape of the fringe is hyperbolic with foci at S_1 and S_2.

Ex. Laser light of wavelength 630 nm incident on a pair of slits produces an interference pattern in which the bright fringes are separated by 8.1 mm. A second light produces an interference pattern in which the fringes are separated by 7.2 mm. Calculate the wavelength of the second light.

Sol. Fringe separation is given by $\beta = \frac{\lambda D}{d}$ i.e. $\frac{\beta_2}{\beta_1} = \frac{\lambda_2}{\lambda_1} \Rightarrow \lambda_2 = \frac{\beta_2}{\beta_1} \times \lambda_1 = \frac{7.2}{8.1} \times 630 = 560$ nm

Ex. A double slit is illuminated by light of wave length 6000Å. The slit are 0.1 cm apart and the screen is placed one metre away. Calculate :

(i) The angular position of the 10^{th} maximum in radian and

(ii) Separation of the two adjacent minima.

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Sol. **(i)** $\lambda = 6000\ \text{Å} = 6\times 10^{-7}\ \text{m},\ d = 0.1\ \text{cm} = 1\times 10^{-3}\ \text{m},\ D = 1\text{m},\ n = 10$

Angular position $\theta_n = \dfrac{n\lambda}{d} = \dfrac{10\times 6\times 10^{-7}}{10^{-3}} = 6\times 10^{-3}\ \text{rad.}$

(ii) Separation between two adjacent minima = fringe width β

$$\beta = \frac{\lambda D}{d} = \frac{6\times 10^{-7}\times 1}{1\times 10^{-3}} = 6\times 10^{-4}\text{m} = 0.6\ \text{mm}$$

Ex. In Young's double slit experiment the fringes are formed at a distance of 1m from double slit of separation 0.12 mm. Calculate

(i) The distance of 3rd dark band from the centre of the screen.

(ii) The distance of 3rd bright band from the centre of the screen, given $\lambda = 6000$Å

Sol. **(i)** For m^{th} dark fringe $x'_m = (2m-1)\dfrac{D\lambda}{2d}$ given, $D = 1\text{m} = 100\ \text{cm},\ d = 0.12\ \text{mm} = 0.012\ \text{cm}$

$$x'_3 = \frac{(2\times 3-1)\times 100\times 6\times 10^{-7}}{2\times 0.012} = 1.25\ \text{cm}\ [\because\ m = 3 \text{ and } \lambda = 6\times 10^{-7}\ \text{m}]$$

(ii) For n^{th} bright fringe $x_n = \dfrac{nD\lambda}{d} \Rightarrow x_3 = \dfrac{3\times 100\times 6\times 10^{-7}}{0.012} = 1.5\times 10^{-2}\text{m} = 1.5\ \text{cm}\quad [\because n = 3]$

Ex. In Young's double slit experiment the two slits are illuminated by light of wavelength 5890Å and the distance between the fringes obtained on the screen is 0.2°. The whole apparatus is immersed in water, then find out angular fringe width, (refractive index of water = $\dfrac{4}{3}$).

Sol. $\alpha_{air} = \dfrac{\lambda}{d} \Rightarrow \alpha_{air} = 0.2° \Rightarrow \alpha \propto \lambda \Rightarrow \dfrac{\alpha_w}{\alpha_{air}} = \dfrac{\lambda_w}{\lambda_{air}} \Rightarrow \lambda_w = \dfrac{\lambda_{air}}{\mu} \Rightarrow \alpha_w = \dfrac{\alpha_{air}\,\lambda}{\mu.\lambda} = \dfrac{0.2\times 3}{4} = 0.15$

Ex. The path difference between two interfering waves at a point on screen is 171.5 times the wavelength. If the path difference is 0.01029 cm. Find the wavelength.

Sol. Path difference = $171.5\,\lambda = \dfrac{343}{2}\lambda$ = odd multiple of half wavelength . It means dark fringe is observed

According to question $0.01029 = \dfrac{343}{2}\lambda \Rightarrow \lambda = \dfrac{0.01029\times 2}{343} = 6\times 10^{-5}\ \text{cm} \Rightarrow \lambda = 6000\ \text{Å}$

Ex. In young's double slit interference experiment, the distance between two sources is $0.1/\pi$ mm. The distance of the screen from the source is 25 cm. Wavelength of light used is 5000Å. Then what is the angular position of the first dark fringe ?

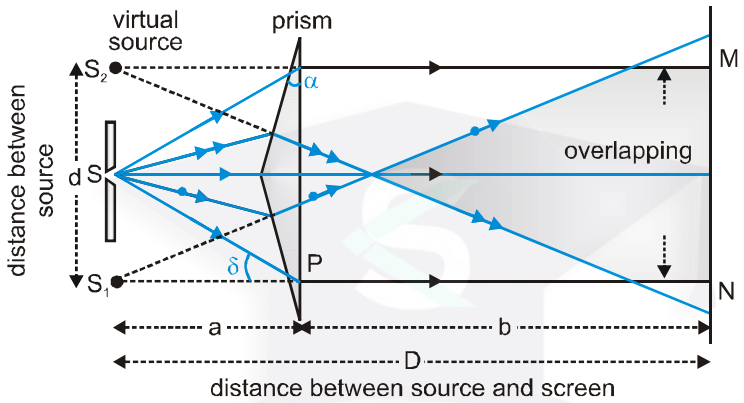
Sol. The angular position $\theta = \dfrac{\beta}{D} = \dfrac{\lambda}{d}$ $\left(\because\ \beta = \dfrac{\lambda D}{d}\right)$ The first dark fringe will be at half the fringe width from the mid point of central maximum. Thus the angular position of first dark fringe will be-

$$\alpha = \frac{\theta}{2} = \frac{1}{2}\left[\frac{\lambda}{d}\right] = \frac{1}{2}\left[\frac{5000\times\pi}{.1\times 10^{-3}}\times 10^{-10}\right]\frac{180}{\pi} = 0.45°.$$

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FRESNEL'S BIPRISM

It is an optical device to obtain two coherent sources by refraction of light. It is prepared by rubbing an optically pure glass plate slightly on two sides so that each angle of prism is generally $\frac{1^\circ}{2}$ or 1°. The fringes of equal width are observed in the limited region MN due to superposition.



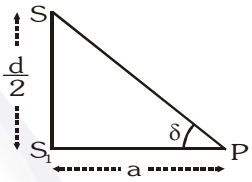
Distance between source and biprism = a

Distance between biprism and eye piece (screen) = b

The distance between source and screen D = a + b

Refracting angle = α , refractive index of the material of prism = μ

The distance between two coherent source = d



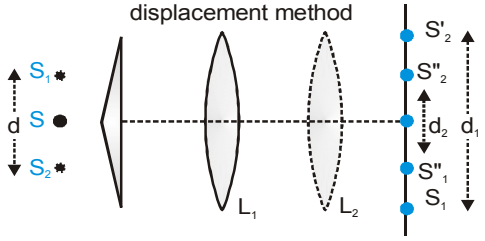
From ΔSS_1P $\tan\delta = \frac{d/2}{a}$ for very-very small δ hence $\tan\delta = \delta$ so $\delta = \frac{d}{2a} \Rightarrow d = 2a\delta$

For prism $\delta = (\mu - 1)\alpha$ $\therefore$ $d = 2a(\mu - 1)\alpha$, Fringe width $\beta = \frac{\lambda D}{d}$ $\therefore$ $\beta = \frac{(a+b)\lambda}{2a(\mu-1)\alpha}$

- **To calculate the value of d by displacement method**

In this method a convex lens is placed between prism and screen. The lens is adjusted in two position L_1 and L_2 and image is obtained on screen. Let d_1 an d_2 be the real image in these two cases.

The distance d between the virtual source $d = \sqrt{d_1 d_2}$ Fringe width $\beta = \frac{(a+b)\lambda}{\sqrt{d_1 d_2}}$



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(i) If the fresnel biprism experiment is performed in water instead of air then

(i) Fringe width in water increases $\left[\beta_w = \frac{\mu_g - 1}{\mu_g - \mu_w}\beta_{air}\right]$ $\beta_w = 3\,\beta_{air}\left[\because \mu_g = \frac{3}{2}, \mu_w = \frac{4}{3}\right]$

(ii) Separation between the two virtual sources decreases.

(but in Young's double slit experiment it does not change.)

$\because d_{air} = 2a(\mu_g - 1)\alpha \therefore d_w = 2a({}_w\mu_g - 1)\alpha \Rightarrow d_w = 2a\left[\frac{\mu_g}{\mu_w} - 1\right]\alpha$

$\therefore \frac{d_w}{d_{air}} = \frac{\frac{\mu_g}{\mu_w} - 1}{\mu_g - 1} = \frac{\frac{3/2}{4/3} - 1}{3/2 - 1} = \frac{1}{4} \Rightarrow d_w = \frac{1}{4}\,d_{air}$

(ii) If we use white light instead of monochromatic light then coloured fringes of different width are obtained. Central fringe is white.

(iii) With the help of this experiment the wavelength of monochromatic light, thickness of thin films and their refractive index and distance between apparent coherent sources can be determined.

Ex. Fringes are obtained with the help of a biprism in the focal plane of an eyepiece distant 1m from the slit. A convex lens produces images of the slit in two position between biprism and eyepiece. The distances between two images of the slit in two positions are 4.05×10^{-3} m and 2.9×10^{-3} m respectively. Calculate the distance between the slits.

Sol. $d = \sqrt{d_1 d_2} = \sqrt{4.05 \times 10^{-3} \times 2.9 \times 10^{-3}} = 3.43 \times 10^{-3}$ m

Ex. In fresnel's biprism experiment a mica sheet of refractive index 1.5 and thickness 6×10^{-6} m is placed in the path of one of interfering beams as a result of which the central fringe gets shifted through five fringe widths. Then calculate the wavelength of light.

Sol. $x = \frac{(\mu - 1)t\beta}{\lambda} = \frac{(1.5 - 1)t\beta}{\lambda}$ but, $t = 5\beta$ $\therefore 5\beta = \frac{0.5\ t\beta}{\lambda} \Rightarrow \lambda = \frac{t}{10} = \frac{6 \times 10^{-6}}{10} = 6000\text{Å}$

Ex. A whole biprism experiment is immersed in water. If the fringe width in air is β_a and refractive index of biprism material and water are 1.5 and 1.33 respectively. Find the value of the fringe width.

Sol. $\beta_w = \frac{\mu_g - 1}{\mu_g - \mu_w}\beta_a = \frac{\frac{3}{2} - 1}{\frac{3}{2} - \frac{4}{2}} = 3\beta_a$

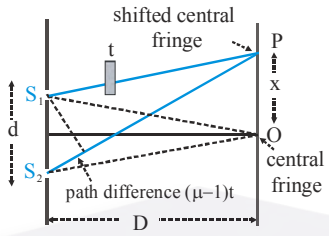
Ex. In fresnel's biprism experiment the distance between the source and the screen is 1m and that between the source and biprism is 10 cm. The wavelength of light used is 6000Å. The fringe width obtained is 0.03 cm and the refracting angle of biprism is 1°. Then calculate the refractive index of the material of biprism.

Sol. $\beta = \frac{D\lambda}{2a(\mu - 1)\alpha}$ $\therefore (\mu - 1) = \frac{D\lambda}{2a\beta_\alpha} = \frac{1 \times 6 \times 10^{-7} \times 180}{2 \times 0.1 \times 3 \times 10^{-4} \times 3.14} \Rightarrow (\mu - 1) = 0.573 \Rightarrow \mu = 1.573$

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THICKNESS OF THIN FILMS

When a glass plate of thickness t and refractive index μ is placed in front of the slit in YDSE then the central fringe shifts towards that side in which glass plate is placed because extra path difference is introduced by the glass plate.
In the path S_1P distance travelled by wave in air = $S_1P - t$



Distance travelled by wave in the sheet = t

Time taken by light to reach up to point P will be same from S_1 and S_2

$$\frac{S_2P}{c} = \frac{S_1P - t}{c} + \frac{t}{c/\mu} \Rightarrow \frac{S_2P}{c} = \frac{S_1P + (\mu - 1)t}{c} \Rightarrow S_2P = S_1P + (\mu - 1)t \Rightarrow S_2P - S_1P = (\mu - 1)t$$

Path difference = $(\mu - 1)t$ $\Rightarrow$ Phase difference $\phi = \frac{2\pi}{\lambda}(\mu - 1)t$

Distance of shifted fringe from central fringe $x = \frac{D(\mu - 1)t}{d}$ $\left[\because \frac{xd}{D} = (\mu - 1)t\right]$

$\therefore$ $x = \frac{\beta(\mu - 1)t}{\lambda}$ and $\beta = \frac{D\lambda}{d}$ Number of fringes displaced = $\frac{(\mu - 1)t}{\lambda}$

Ex. When a mica sheet of thickness 7 microns and μ = 1.6 is placed in the path of one of interfering beams in the biprism experiment then the central fringe gets at the position of seventh bright fringe. What is the wavelength of light used ?

Sol. $\lambda = \frac{(\mu - 1)t}{n} = \frac{(1.6 - 1)\,7 \times 10^{-6}}{7} = 6 \times 10^{-7}$ meter

(i) If a glass plate of refractive index μ_1 and μ_2 having same thickness t is placed in the path of ray coming from S_1 and S_2 then path difference $x = \frac{D}{d}(\mu_1 - \mu_2)t$

(ii) Distance of displaced fringe from central fringe $x = \frac{\beta(\mu_1 - \mu_2)t}{\lambda}$ $\because$ $\frac{\beta}{\lambda} = \frac{D}{d}$

Colours In Thin Films

When white light is made incident on a thin film (like oil film on the surface of water or a soap bubble) Then interference takes place between the waves reflected from its two surfaces and waves refracted through it. The intensity becomes maximum and minimum as a result of interference and colours are seen.

(i) The source of light must be an extended source

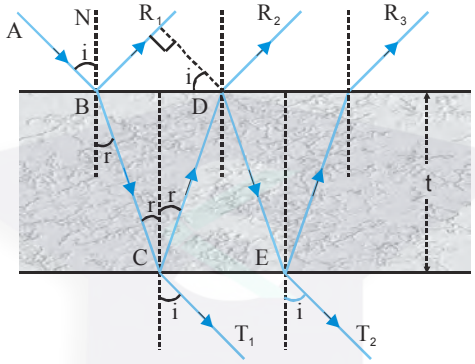
(ii) The colours obtained in reflected and transmitted light are mutually complementary.

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(iii) The colours obtains in thin films are due to interference whereas those obtained in prism are due to dispersion.

INTERFERENCE DUE TO THIN FILMS

Consider a thin transparent film of thickness t and refractive index μ . Let a ray of light AB incident on the film at B. At B, a part of light is reflected along BR_1, and a part of light refracted along BC. At C a part of light is reflected along CD and a part of light transmitted along CT_1. At D, a part of light is refracted along DR_2 and a part of light is reflected along DE. Thus interference in this film takes place due to reflected light in between BR_1 and DR_2 also in transmitted light in between CT_1 and ET_2.



(i) Reflected System

The path difference between BR_1 and DR_2 is $x = 2\mu t \cos r$ due to reflection from the surface of denser medium involves an additional phase difference of π or path difference λ/2. Therefore the exact path difference between BR_1 and DR_2 is. $\Rightarrow x' = 2\mu t \cos r - \lambda/2$ maximum or constructive Interference occurs when path difference between the light waves is $n\lambda .2\mu t \cos r - \lambda/2 = n\lambda \Rightarrow 2\mu t \cos r = n\lambda + \lambda/2$

So the film will appear bright if $2\mu t \cos r = (2n + 1)\lambda/2$ $(n = 0, 1, 2, 3 .....)$

(ii) For minima or destructive interference

When path difference is odd multiple of $\frac{\lambda}{2} \Rightarrow 2\mu t \cos r - \frac{\lambda}{2} = (2n - 1)\frac{\lambda}{2}$

So the film will appear dark if $2\mu t \cos r = n\lambda$

(iii) For transmitted system

Since No additional path difference between transmitted rays C T_1 and E T_2.

So the net path difference between them is $x = 2\mu t \cos r$

For maxima $2\mu t \cos r = n\lambda$, $n = 0, 1, 2.....$

Minima $2\mu t \cos r = (2n + 1)\frac{\lambda}{2}$, $n = 0, 1, 2.....s$

USES OF INTERFERENCE EFFECT

Thin layer of oil on water and soap bubbles show different colours due to interference of waves reflected from two surfaces of their films. Similarly when a lens of large radius of curvature is placed on a plane glass plate, an air film exist between the plate and the lens. If sodium light is put on this film, concentric bright and dark interference rings are formed. These rings are called as Newton's rings.

Uses

(i) Used to determine the wavelength of light precisely.

(ii) Used to determine refractive index or thickness of transparent sheet.

(iii) Used to test the flatness of plane surfaces. These surfaces are knows as optically plane surfaces.

(iv) Used to calibrate meters in terms of wavelength of light.

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(v) Used to design optical filter which allows a narrow band of wavelength to pass through it.

(vi) Used in holography to produce 3-D images.

Ex. Light of wavelength 6000Å is incident on a thin glass plate of refractive index 1.5 such that angle of refraction into the plate is 60°. Calculate the smallest thickness of plate which will make it appear dark by reflection.

Sol. $2\mu t \cos r = n\lambda \Rightarrow t = \frac{n\lambda}{2\mu \cos r} = \frac{1 \times 6 \times 10^{-7}}{2 \times 1.5 \times \cos 60} = \frac{6 \times 10^{-7}}{1.5} = 4 \times 10^{-7} m$

Ex. Light is incident on a glass plate ($\mu = 1.5$) such that angle of refraction is 60°. Dark band is observed corresponding to the wavelength of 6000Å . If the thickness of glass plate is 1.2×10^{-3} mm. calculate the order of the interference band.

Sol. $\mu = 1.5, r = 60°, \lambda = 6000Å = 6 \times 10^{-7} m \Rightarrow t = 1.2 \times 10^{-3} = 1.2 \times 10^{-6} m$

For dark band in the reflected light $2\mu t \cos r = n\lambda$

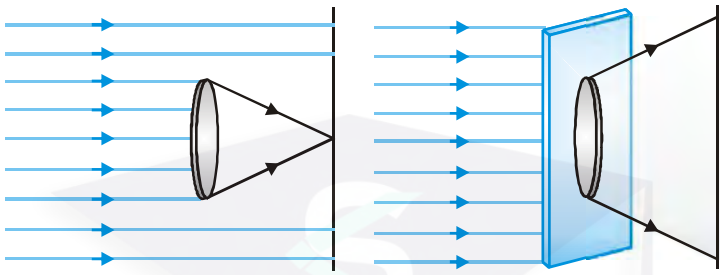
$$n = \frac{2\mu t \cos r}{\lambda} = \frac{2 \times 1.5 \times 1.2 \times 10^{-6} \times \cos 60^\circ}{6 \times 10^{-7}} = \frac{2 \times 1.5 \times 1.2 \times 10^{-6} \times \frac{1}{2}}{6 \times 10^{-7}} = 3$$

Thus third dark band is observed.

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DIFFERACTION OF LIGHT

Bending of light rays from sharp edges of an opaque obstacle or aperture and its spreading in the eometricle shaddow region is defined as diffraction of light or deviation of light from its rectilinear propogation tendency is defined as diffraction of light.



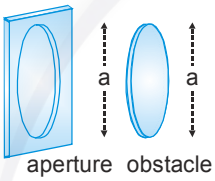
(i) Diffraction was discovered by Grimaldi

(ii) Theoritically explained by Fresnel

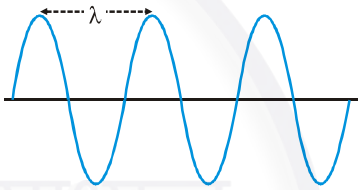
(iii) Diffraction is possible in all type of waves means in mechanical or electromagnetic waves shows diffraction.

Diffraction depends on two factors :

(a) Size of obstacles or aperture



(b) Wave length of the wave



Condition of diffraction Size of obstacle or aperture should be nearly equal to the wave length of light

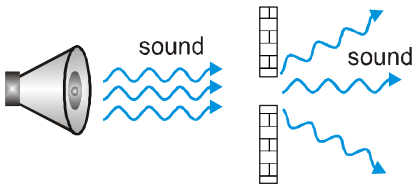
$\lambda \simeq a$ $\frac{a}{\lambda} \simeq 1$

If size of obstacle is much greater than wave length of light, then rectilinear motion of light is observed.

(iv) It is practically observed when size of aperture or obstacle is greater than 50 λ then obstacle or aperature does not shows diffraction.

(v) Wave length of light is in the order 10^{-7} m. In general obstacle of this wave length is not present so light rays does not show diffraction and it appears to travel in straight line Sound wave shows more diffraction as compare to light rays because wavelength of sound is high (16 mm to 16m). So it is generally diffracted by the objects in our daily life.

(vi) Diffraction of ultrasonic wave is also not observed as easily as sound wave because their wavelength is of the order of about 1 cm. Diffraction of radio waves is very conveniently observed because of its very large wavelength (2.5 m to 250 m). X-ray can be diffracted easily by crystel. It was discovered by Lave.



diffraction of sound from a window

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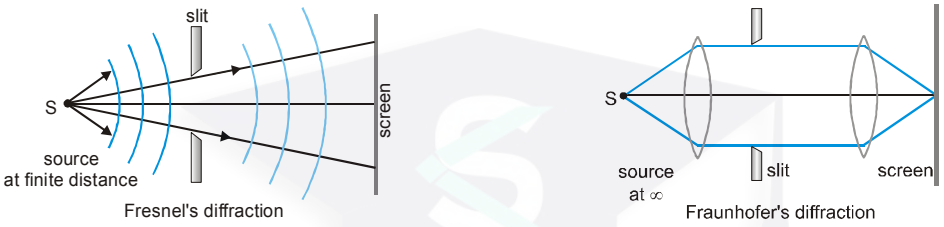
Types of Diffraction

There are two type of diffraction of light : **(a)** Fresnel's diffraction. **(b)** Fraunhofer's diffraction.

(a) Fresnel diffraction

If either source or screen or both are at finite distance from the diffracting device (obstacle or aperture), the diffraction is called Fresnel diffraction and the pattern is the shadow of the diffracting device modified by diffraction effect.

Ex. Diffraction at a straight edge, small opaque disc, narrow wire are examples of Fresnel diffraction.



(b) Fraunhofer diffraction

Fraunhofer diffraction is a particular limiting case of Fresnel diffraction. In this case, both source and screen are effectively at infinite distance from the diffracting device and pattern is the image of source modified by diffraction effects.

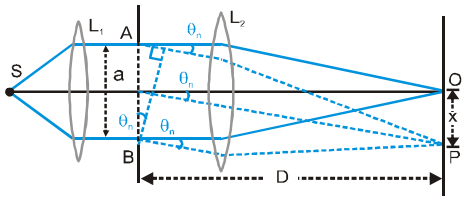
Ex. Diffraction at single slit, double slit and diffraction grating are the examples of fraunhofer diffraction.

Comparison between Fresnel and Fraunhofer diffraction

	Fresnel Diffraction	Fraunhofer Diffraction
(a)	Source and screen both are at finite distance from the diffractor.	Source and screen both are at infinite distance from the diffractor.
(b)	Incident and diffracted wave fronts are spherical or cylinderical.	Incident and diffracted wavefronts are plane due to infinite distance from source.
(c)	Mirror or lenses are not used for obtaining the diffraction pattern.	Lens are used in this diffraction pattern.
(d)	Centre of diffraction pattern is sometime bright and sometime dark depending on size of diffractor and distance of observation point.	Centre of diffraction is always bright.
(e)	Amplitude of wave coming from different half period zones are different due to difference of obliquity.	Amplitude of waves coming from different half period zones are same due to same obliquity.

Fraunhofer diffraction due to single slit

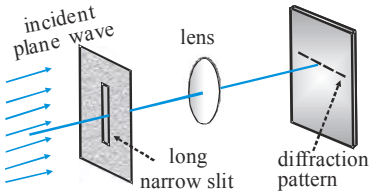
AB is single slit of width a, Plane wavefront is incident on a slit AB. Secondary wavelets coming from every part of AB reach the axial point P in same phase forming the central maxima. The intensity of central maxima is maximum in this diffraction. Where θ_n represents direction of n^{th} minima Path difference BB' = a sin θ_n



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for n^{th} minima $a \sin\theta_n = n\lambda$ $\quad\therefore\quad$ $\sin\theta_n \approx \theta_n = \frac{n\lambda}{a}$ (if θ_n is small)

(i) When path difference between the secondary wavelets coming from A and B is $n\lambda$ or $2n\left[\frac{\lambda}{2}\right]$ or even multiple of $\frac{\lambda}{2}$ then minima occurs



For minima $a \sin\theta_n = 2n\left[\frac{\lambda}{2}\right]$ where $n = 1, 2, 3 \ldots$

(ii) When path difference between the secondary wavelets coming from A and B is $(2n+1)\frac{\lambda}{2}$ or odd multiple of $\frac{\lambda}{2}$ then maxima occurs

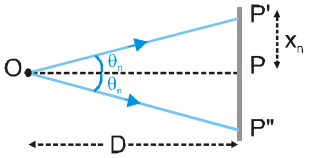
For maxima $a \sin\theta_n = (2n+1)\frac{\lambda}{2}$ where $n = 1, 2, 3 \ldots$

$n = 1 \rightarrow$ first maxima and $n = 2 \rightarrow$ second maxima

(iii) In alternate order minima and maxima occurs on both sides of central maxima.

For n^{th} minima

If distance of n^{th} minima from central maxima $= x_n$
distance of slit from screen $= D$, width of slit $= a$



Path difference $\delta = a \sin\theta_n = \frac{2n\lambda}{2} \Rightarrow \sin\theta_n = \frac{n\lambda}{a}$

In $\Delta POP'$ $\tan\theta_n = \frac{x_n}{D}$ If θ_n is small $\Rightarrow \sin\theta_n \approx \tan\theta_n \approx \theta_n$

$x_n = \frac{n\lambda D}{a} \Rightarrow \theta_n = \frac{x_n}{D} = \frac{n\lambda}{a}$ First minima occurs both sides on central maxima.

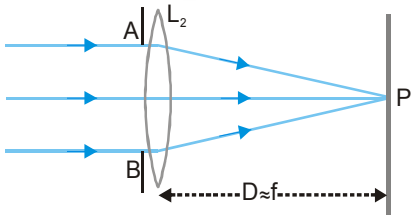
For first minima $x = \frac{D\lambda}{a}$ and $\theta = \frac{x}{D} = \frac{\lambda}{a}$

(iv) Linear width of central maxima $w_x = 2x \Rightarrow w_x = \frac{2D\lambda}{a}$

(v) Angular width of central maxima $w_\theta = 2\theta = \frac{2\lambda}{a}$

Special case

Lens L_2 is shifted very near to slit AB. In this case distance between slit and screen will be nearly equal to the focal length of lense L_2 (i.e. $D \approx f$) $\theta_n = \frac{x_n}{f} = \frac{n\lambda}{a} \Rightarrow x_n = \frac{n\lambda f}{a}$



$w_x = \frac{2\lambda f}{a}$ and angular width of central maxima $w_B = \frac{2x}{f} = \frac{2\lambda}{a}$

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Fringe width : Distance between two consecutive maxima (bright fringe) or minima (dark fringe) is known as fringe width. Fringe width of central maxima is doubled then the width of other maximas i.e.,

$$\beta = x_{n+1} - x_n = (n+1)\frac{\lambda D}{a} - \frac{n\lambda D}{a} = \frac{\lambda D}{a}$$

Intensity curve of Fraunhofer's Diffraction

Intensity of maxima in Fraunhofer's diffrection is determined by

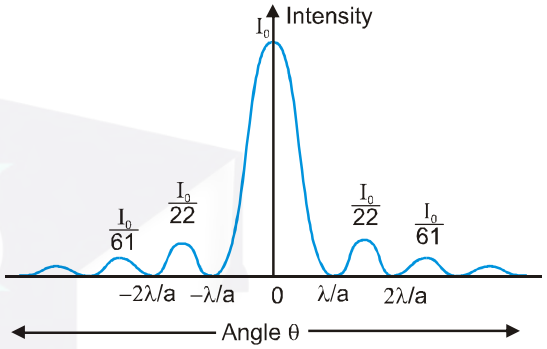
$$I = \left[\frac{2}{(2n+1)\pi}\right]^2 I_0$$

I_0 =intensity of central maxima

n = order of maxima

intensity of first maxima $I_1 = \frac{4}{9\pi^2} I_0 \approx \frac{I_0}{22}$

intensity of second maxima $I_2 = \frac{4}{25\pi^2} I_0 \approx \frac{I_0}{61}$



- Diffraction occurs in slit is always fraunhofer diffraction as diffraction pattern obtained from the cracks between the fingers, when viewed a distant tubelight and in YDSE experiment are fraunhofer diffraction.

(i) The width of central maxima $\propto \lambda$, that is, more for red colour and less for blue.

i.e., $w_x \propto \lambda$ as $\lambda_{blue} < \lambda_{red} \Rightarrow w_{blue} < w_{red}$

(ii) For obtaining the fraunhofer diffraction, focal length of second lens (L_2) is used.

$w_x \propto \lambda \propto f \propto 1/a$ width will be more for narrow slit

(iii) By decreasing linear width of slit, the width of central maxima increase.

Resolving Power (R.P.)

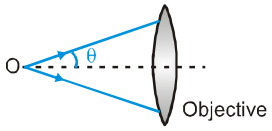
A large number of images are formed as a consequence of light diffraction from a source. If two sources are separated such that their central maxima do not overlap, their images can be distinguished and are said to be resolved R.P. of an optical instrument is its ability to distinguish two neighbouring points.

Linear R.P. = d/λDhere D = Observed distance

Angular R.P. = d/λ d = Distance between two points

(1) Microscope : In reference to a microscope, the minimum distance between two lines at which they are just distinct is called Resolving limit (RL) and it's reciprocal is called Resolving power (RP)

$$\text{R.L.} = \frac{\lambda}{2\mu\sin\theta} \text{ and } \text{R.P.} = \frac{2\mu\sin\theta}{\lambda} \Rightarrow \text{R.P.} \propto \frac{1}{\lambda}$$



λ = Wavelength of light used to illuminate the object

μ = Refractive index of the medium between object and objective,

θ = Half angle of the cone of light from the point object, μsinθ = Numerical aperture.

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(2) **Telescope :** Smallest angular separations (dθ) between two distant object, whose images are separated in the telescope is called resolving limit. So resolving limit $d\theta = \frac{1.22\lambda}{a}$ and resolving power

$(RP) = \frac{1}{d\theta} = \frac{a}{1.22\lambda} \Rightarrow R.P. \propto \frac{1}{\lambda}$ where a = aperture of objective.

Ex. Light of wavelength 6000Å is incident normally on a slit of width 24×10^{-5} cm. Find out the angular position of second minimum from central maximum ?

Sol. $a\sin\theta = 2\lambda$ given $\lambda = 6 \times 10^{-7}$ m, $a = 24 \times 10^{-5} \times 10^{-2}$ m

$\sin\theta = \frac{2\lambda}{a} = \frac{2\times6\times10^{-7}}{24\times10^{-7}} = \frac{1}{2}$ $\therefore \theta = 30°$

Ex. Light of wavelength 6328Å is incident normally on a slit of width 0.2 mm. Calculate the angular width of central maximum on a screen distance 9 m ?

Sol. given $\lambda = 6.328 \times 10^{-7}$ m, $a = 0.2 \times 10^{-3}$ m

$w_\theta = \frac{2\lambda}{a} = \frac{2\times6.328\times10^{-7}}{2\times10^{-4}}$ radian $= \frac{6.328\times10^{-3}\times180}{3.14} = 0.36°$

Ex. Light of wavelength 5000Å is incident on a slit of width 0.1 mm. Find out the width of the central bright line on a screen distance 2m from the slit ?

Sol. $w_x = \frac{2f\lambda}{a} = \frac{2\times2\times5\times10^{-7}}{10^{-4}} = 20$ mm

Ex. The fraunhofer diffraction pattern of a single slit is formed at the focal plane of a lens of focal length 1m. The width of the slit is 0.3 mm. If the third minimum is formed at a distance of 5 mm from the central maximum then calculate the wavelength of light.

Sol. $x_n = \frac{nf\lambda}{a} \Rightarrow \lambda = \frac{ax_n}{fn} = \frac{3\times10^{-4}\times5\times10^{-3}}{3\times1} = 5000Å$ • $\because$ n = 3]

Ex. Find the half angular width of the central bright maximum in the Fraunhofer diffraction pattern of a slit of width 12×10^{-5} cm when the slit is illuminated by monochromatic light of wavelength 6000 Å.

Sol. $\because$ $\sin\theta = \frac{\lambda}{a}$ θ = half angular width of the central maximum.

$a = 12 \times 10^{-5}$ cm, $\lambda = 6000$ Å $= 6 \times 10^{-5}$ cm $\therefore$ $\sin\theta = \frac{\lambda}{a} = \frac{6\times10^{-5}}{12\times10^{-5}} = 0.50$ $\Rightarrow \theta = 30°$

Ex. Light of wavelength 6000 Å is incident on a slit of width 0.30 mm. The screen is placed 2 m from the slit. Find **(a)** the position of the first dark fringe and **(b)** the width of the central bright fringe.

Sol. The first fringe is on either side of the central bright fringe.

here $n = \pm1, D = 2$ m, $\lambda = 6000$ Å $= 6 \times 10^{-7}$ m

$\therefore$ $\sin\theta = \frac{x}{D}$ $\Rightarrow a = 0.30$ mm $= 3 \times 10^{-4}$ m $\Rightarrow a\sin\theta = n\lambda \Rightarrow \frac{ax}{D} = n\lambda$

(a) $x = \frac{n\lambda D}{a} \Rightarrow x = \pm\left[\frac{1\times6\times10^{-7}\times2}{3\times10^{-4}}\right] = \pm4\times10^{-3}$ m

The positive and negative signs corresponds to the dark fringes on either side of the central bright fringe.

(b) The width of the central bright fringe $y = 2x = 2 \times 4 \times 10^{-3} = 8 \times 10^{-3}$ m = 8 mm

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Difference between interference and diffraction :

	Interference		Diffraction
1	It is the phenomenon of superposition of two waves coming from two different coherent sources.	1	It is the phenomenon of superposition of two waves coming from two different parts of the same wave front.
2	In interference pattern, all bright lines are equally bright and equally spaced.	2	All bright lines are not equally bright and equally wide. Brightness and width goes on decreasing with the angle of diffraction.
3	All dark lines are totally dark	3	Dark lines are not perfectly dark. Their on decreasing with angle of diffraction.
4	In interference bands are large in number	4	In diffraction bands are a few in number.

Ex. A Slit of width a is illuminated by monochromatic light of wavelength 650nm at normal incidence. Calculate the value of a when -

(a) The first minimum falls at an angle of diffraction of 30°

(b) The first maximum falls at an angle of diffraction of 30°.

Sol. **(a)** for first minimum $\sin\theta_1 = \frac{\lambda}{a}$ $\therefore$ $a = \frac{\lambda}{\sin\theta_1} = \frac{650\times10^{-9}}{\sin 30°} = \frac{650\times10^{-9}}{0.5} = 1.3 \times 10^{-6}$m

(b) For first maximum $\sin\theta_1 = \frac{3\lambda}{2a}$ $\therefore$ $a = \frac{3\lambda}{2\sin\theta} = \frac{3\times650\times10^{-9}}{2\times0.5} = 1.95 \times 10^{-6}$m

Ex. Red light of wavelength 6500Å from a distant source falls on a slit 0.50 mm wide. What is the distance between the first two dark bands on each side of the central bright of the diffraction pattern observed on a screen placed 1.8 m. from the slit.

Sol. Given $\lambda = 6500Å = 65 \times 10^{-8}$ m, $a = 0.5$ mm $= 0.5 \times 10^{-3}$ m., $D = 1.8$ m.

Required distance between first two dark bands will be equal to width of central maxima.

$$W_x = \frac{2\lambda D}{a} = \frac{2\times6500\times10^{-10}\times1.8}{0.5\times10^{-3}} = 468 \times 10^{-5} \text{ m} = 4.68 \text{ mm}$$

Ex. In a single slit diffraction experiment first minimum for $\lambda_1 = 660$ nm coincides with first maxima for wavelength λ_2. Calculate λ_2.

Sol. For minima in diffraction pattern $d\sin\theta = n\lambda$

For first minima $d\sin\theta_1 = (1)\lambda_1 \Rightarrow \sin\theta_1 = \frac{\lambda_1}{d}$

For first maxima $d\sin\theta_2 = \frac{3}{2}\lambda_2 \Rightarrow \sin\theta_2 = \frac{3\lambda_2}{2d}$

The two will coincide if, $\theta_1 = \theta_2$ or $\sin\theta_1 = \sin\theta_2$

$\therefore$ $\frac{\lambda_1}{d} = \frac{3\lambda_2}{2d} \Rightarrow \lambda_2 = \frac{2}{3}\lambda_1 = \frac{2}{3} \times 660 \text{ nm} = 440 \text{ nm}.$

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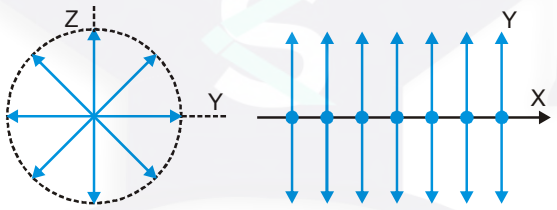
POLARISATION

Experiments on interference and diffraction have shown that light is a form of wave motion. These effects do not tell us about the type of wave motion i.e., whether the light waves are longitudinal or transverse.

The phenomenon of polarization has helped to establish beyond doubt that light waves are transverse waves.

Unpolarised light

An ordinary beam of light consists of a large number of waves emitted by the atoms of the light source. Each atom produces a wave with its own orientation of electric vector $\vec{E}$ so all direction of vibration of $\vec{E}$ are equally probable.



unpolarised light propagating along . X-axis

unpolarised light

The resultant electromagnetic wave is a super position of waves produced by the individual atomic sources and it is called unpolarised light. In ordinary or unpolarised light, the vibrations of the electric vector occur symmetrically in all possible directions in a plane perpendicular to the direction of propagation of light.

Polarisation

The phenomenon of restricting the vibration of light (electric vector) in a particular direction perpendicular to the direction of propagation of wave is called polarisation of light. In polarised light, the vibration of the electric vector occur in a plane perpendicular to the direction of propagation of light and are confined to a single direction in the plane (do not occur symmetrically in all possible directions). After polarisation the vibrations become asymmetrical about the direction of propagation of light.

Polariser

Tourmaline crystal : When light is passed through a tourmaline crystal cut parallel to its optic axis, the vibrations of the light carrying out of the tourmaline crystal are confined only to one direction in a plane perpendicular to the direction of propagation of light. The emergent light from the crystal is said to be plane polarised light.

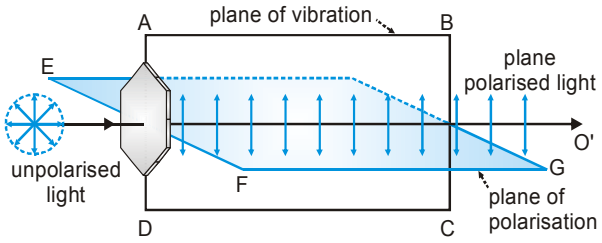
Nicol Prism : A nicol prism is an optical device which can be used for the production and detection of plane polarised light. It was invented by William Nicol in 1828.

Polaroid : A polaroid is a thin commercial sheet in the form of circular disc which makes use of the property of selective absorption to produce an intense beam of plane polarised light.

Plane of polarisation and Plane of vibration :

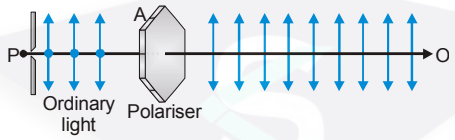
The plane in which vibrations of light vector and the direction of propogation lie is known as plane of vibration A plane normal to the plane of vibration and in which no vibration takes place is known as plane of polarisation

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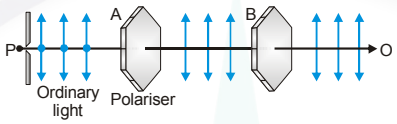
Experimental demonstration of polarisation of light

Take two tourmaline crystals cut parallel to their crystallographic axis (optic axis).

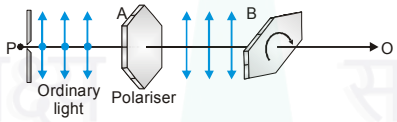


First hold the crystal A normally to the path of a beam of colour light. The emergent beam will be slightly coloured. Rotate the crystal A about PO. No change in the intensity or the colour of the emergent beam of light.

Take another crystal B and hold it in the path of the emergent beam of so that its axis is parallel to the axis of the crystal A. The beam of light passes through both the crystals and outcoming light appears coloured.



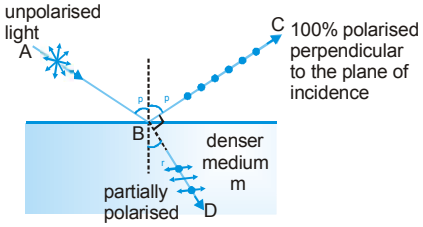
Now, rotate the crystal B about the axis PO. It will be seen that the intensity of the emergent beam decreases and when the axes of both the crystals are at right angles to each other no light comes out of the crystal B.



If the crystal B is further rotated light reappears and intensity becomes maximum again when their axes are parallel. This occurs after a further rotation of B through 90°. This experiment confirms that the light waves are transverse in nature. The vibrations in light waves are perpendicular to the direction of propagation of the wave. First crystal A polarises the light so it is called polariser. Second crystal B, analyses the light whether it is polarised or not, so it is called analyser.

Methods of obtaining plane polarised light

(i) **Polarisation by reflection :** The simplest method to produce plane polarised light is by reflection. This method was discovered by Malus in 1808. When a beam of ordinary light is reflected from a surface, the reflected light is partially polarised. The degree of polarisation of the polarised light in the reflected beam is greatest when it is incident at an angle called polarising angle or Brewster's angle.



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(ii) **Polarising Angle** : Polarising angle is that angle of incidence at which the reflected light is completely plane polarisation.

(iii) **Brewster's Law** : When unpolarised light strikes at polarising angle θ_p on an interface separating a rare medium from a denser medium of refractive index μ , such that $\mu = \tan\theta_p$ then the reflected light (light in rare medium) is completely polarised. Also reflected and refracted rays are normal to each other. This relation is known as Brewster's law. The law state that the tangent of the polarising angle of incidence of a transparent medium is equal to its refractive index $\mu = \tan\theta_p$

In case of polarisation by reflection :

(i) For $i = \theta_p$ refracted light is partially polarised.

(ii) For $i = \theta_p$ reflected and refracted rays are perpendicular to each other.

(iii) For $i < \theta_p$ or $i > \theta_p$ both reflected and refracted light become partially polarised.

According to snell's law $\mu = \dfrac{\sin\theta_p}{\sin\theta_r}$ .....**(i)**

But according to Brewster's law $\mu = \tan\theta_p = \dfrac{\sin\theta_p}{\cos\theta_p}$ .....**(ii)**

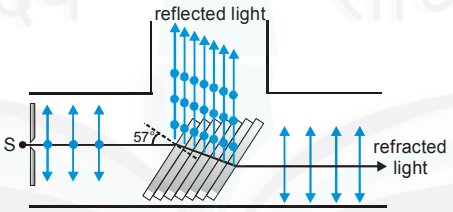
From equation **(i)** and **(ii)** $\dfrac{\sin\theta_p}{\sin\theta_r} = \dfrac{\sin\theta_p}{\cos\theta_p} \Rightarrow \sin\theta_r = \cos\theta_p$

$\therefore \sin\theta_r = \sin(90° - \theta_p) \Rightarrow \theta_r = 90° - \theta_p$ or $\theta_p + \theta_r = 90°$

Thus reflected and refracted rays are mutually perpendicular

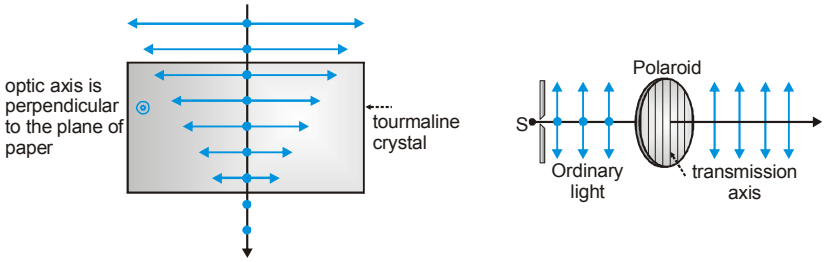
By Refraction

In this method, a pile of glass plates is formed by taking 20 to 30 microscope slides and light is made to be incident at polarising angle 57°. According Brewster law, the reflected light will be plane polarised with vibrations perpendicular to the plane of incidence and the transmitted light will be partially polarised. Since in one reflection about 15% of the light with vibration perpendicular to plane of paper is reflected therefore after passing through a number of plates emerging light will become plane polarised with vibrations in the plane of paper.



By Dichroism

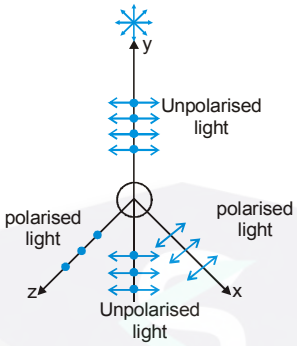
Some crystals such as tourmaline and sheets of iodosulphate of quinone have the property of strongly absorbing the light with vibrations perpendicular of a specific direction (called transmission axis) and transmitting the light with vibration parallel to it. This selective absorption of light is called dichroism. So if unpolarised light passes through proper thickness of these, the transmitted light will plane polarised with vibrations parallel to transmission axis. Polaroids work on this principle.



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By scattering

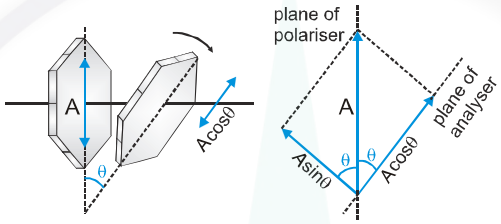
When light is incident on small particles of dust, air molecule etc. (having smaller size as compared to the wavelength of light), it is absorbed by the electrons and is re-radiated in all directions. The phenomenon is called as scattering. Light scattered in a direction at right angles to the incident light is always plane-polarised.



Law of Malus

When a completely plane polarised light beam light beam is incident analyser, then intensity intensity of emergent light varies as the square of cosine of the angle between the planes of transmission of the analyser and the polarizer.

$I \propto \cos^2\theta \Rightarrow I = I_0 \cos^2\theta$



(i) If $\theta = 0°$ then $I = I_0$ maximum value (Parallel arrangement)

(ii) If $\theta = 90°$ then $I = 0$ minimum value (Crossed arrangement)

If plane polarised light of intensity $I_0 (= KA^2)$ is incident on a polaroid and its vibrations of amplitude A make angle θ with transmission axis, then the component of vibrations parallel to transmission axis will be $A\cos\theta$ while perpendicular to it will be $A\sin\theta$.

Polaroid will pass only those vibrations which are parallel to transmission axis i.e. $A\cos\theta$, $\because I_0 \propto A^2$

So the intensity of emergent light $I = K(A\cos\theta)^2 = KA^2\cos^2\theta$

If an unpolarised light is converted into plane polarised light its intensity becomes half.

If light of intensity I_1, emerging from one polaroid called polariser is incident on a second polaroid (called analyser) the intensity of light emerging from the second polaroid is $I_2 = I_1 \cos^2\theta$ θ = angle between the transmission axis of the two polaroids.

Optical Activity

When plane polarised light passes through certain substances, the plane of polarisation of the emergent light is rotated about the direction of propagation of light through a certain angle. This phenomenon is optical rotation.

The substance which rotate the plane of polarision rotates the plane of polarisation is known as optical active substance. Ex. Sugar solution, sugar crystal, sodium chlorate etc.

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Optical activity of a substance is measured with the help of polarimeter in terms of specific rotation which is defined as the rotation produced by a solution of length 10 cm (1dm) and of unit concentration (1g/cc) for a given wave length of light at a given temp.

specific rotation $[\alpha]^{\lambda}_{t^\circ C} = \frac{\theta}{L \times C}$ θ = rotation in length L at concentration

Types of optically active substances

(a) Dextro rotatory substances

Those substances which rotate the plane of polarisation in clockwise direction are called dextro rotatory of right handed substances.

(b) Laveo rotatory substances

These substances which rotate the plane of polarisation in the anticlockwise direction are called laveo rotatory or left handed substances.

The amount of optical rotation depends upon the thickness and density of the crystal or concentration in case of solutions, the temperature and the wavelength of light used.

Rotation varies inversely as the square of the wavelength of light.

Applications and uses of polarisation

(i) By determining the polarising angle and using Brewster's Law $\mu = \tan\theta_p$ refractive index of dark transparent substance can be determined.

(ii) In calculators and watches, numbers and letters are formed by liquid crystals through polarisation of light called liquid crystal display (L.C.D.)

(iii) In CD player polarised laser beam acts as needle for producing sound from compact disc.

(iv) It has also been used in recording and reproducing three dimensional pictures.

(v) Polarised light is used in optical stress analysis known as photoelasticity.

(vi) Polarisation is also used to study asymmetries in molecules and crystals through the phenomenon of optical activity.

Ex. Two polaroids are crossed to each other. When one of them is rotated through 60°, then what percentage of the incident unpolarised light will be transmitted by the polaroids ?

Sol. Initially the polaroids are crossed to each other, that is the angle between their polarising directions is 90°. When one is rotated through 60°, then the angle between their polarising directions will become 30°.

Let the intensity of the incident unpolarised light = I_0

Then the intensity of light emerging from the first polaroid is $I_1 = \frac{1}{2} I_0$

This light is plane polarised and passes through the second polaroid.

The intensity of light emerging from the second polaroid is $I_2 = I_1 \cos^2\theta$

θ = the angle between the polarising directions of the two polaroids.

$I_1 = \frac{1}{2} I_0$ and $\theta = 30°$ So $I_2 = I_1 \cos^2 30° = \frac{1}{2} I_0 \cos^2 30° \Rightarrow \frac{I_2}{I_0} = \frac{3}{8}$

$\therefore$ transmission percentage $= \frac{I_2}{I_0} \times 100 = \frac{3}{8} \times 100 = 37.5\%$

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Ex. At what angle of incidence will the light reflected from water ($\mu = 1.3$) be completely polarised ?

Sol. $\mu = 1.3$,

From Brewster's law $\tan\theta_p = \mu = 1.3 \quad \Rightarrow \quad \theta = \tan^{-1} 1.3 = 53°$

Ex. If light beam is incident at polarising angle (56.3°) on air-glass interface, then what is the angle of refraction in glass?

Sol. $\because i_p + r_p = 90° \quad \therefore r_p = 90° - i_p = 90° - 56.3° = 33.7°$

Ex. A polariser and an analyser are oriented so that maximum light is transmitted, what will be the intensity of outcoming light when analyser is rotated through 60°.

Sol. According to Malus Law $I = I_0 \cos^2\theta = I_0 \cos^2 60° = I_0\left[\frac{1}{2}\right]^2 = \frac{I_0}{4}$

Ex. A 300 mm long tube containing 60 cm^3 of sugar solution produces an optical rotations of 10° when placed in a saccharimeter. If specific rotation of sugar is 60°, calculate the quantity of sugar contained in the tube solution.

Sol. $\ell = 300$ mm $= 30$ cm $= 3$ decimetre, $\theta = 10°$, $[\alpha]_\lambda^T = 60°$, volume of solution $= 60\ cm^3$

$$\theta = [\alpha]_\lambda^T \ell C \Rightarrow C = \frac{\theta}{[\alpha]_\lambda^T \ell} = \frac{10°}{60° \times 3} = \frac{1}{18}\ g\ cm^{-3}$$

$$\text{Quantity of sugar contained} = \frac{1}{18} \times 60 = 3.33\ g$$

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TIPS & FORMULAS

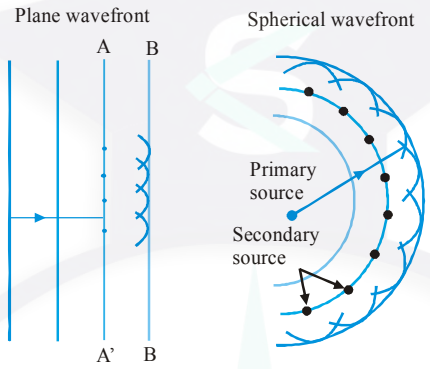
Huygen`s in 1678 assumed that a body emits light in the form of waves.

(a) Each point source of light is a centre of disturbance from which waves spread in all directions. The locus of all the particles of the medium vibrating in the same phase at a given instant is called a wavefront.

(b) Each point on a wave front is a source of new disturbance, called secondary wavelets. These wavelets are spherical and travel with speed of light in that medium.

(c) The forward envelope of the secondary wavelets at any instant gives the new wavefront.

(d) In homogeneous medium, the wavefront is always perpendicular to the direction of wave propagation.



2. Coherent Sources :

Two sources will be coherent if and only if they produce waves of same frequency (and hence wavelength) and have a constant initial phase difference.

3. Incoherent Sources :

The sources are said to be incoherent if they have different frequency and initial phase difference is not constant w.r.t. time.

4. Interference : YDSE

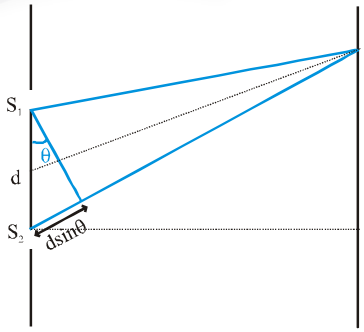
5. Resultant intensity for coherent sources $I = I_1 + I_2 + \sqrt{I_1 I_2}\cos\phi_0$

6. Resultant intensity for incoherent sources $I = I_1 + I_2$

7. Intensity $\propto$ width of slit $\propto$ amplitude

$$\Rightarrow \frac{I_1}{I_2} = \frac{W_1}{W_2} = \frac{a_1^2}{a_2^2} \Rightarrow \frac{I_{max}}{I_{min}} = \frac{\left(\sqrt{I_1}+\sqrt{I_2}\right)^2}{\left(\sqrt{I_1}-\sqrt{I_2}\right)^2} = \left(\frac{a_1+a_2}{a_1-a_2}\right)^2$$

8. Distance of n^{th} bright fringe $X_n = \frac{n\lambda D}{d}$



Path difference $= n\lambda$

where $n = 0, 1, 2, 3, ...$

Distance of m^{th} dark fringe

$$X_m = \frac{(2m+1)\lambda D}{2d}$$

Path difference $= (2m+1)\frac{\lambda}{2}$ where $m = 0, 1, 2, 3, ...$

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10. Fringe width $\beta = \frac{\lambda D}{d}$

11. Angular fringe width $= \frac{\beta}{D} = \frac{\lambda}{d}$

12. Fringe visibility $= \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \times 100\%$

13. If a transparent sheets of refractive index μ and thickness t is introduced in one of the paths of interfering waves, optical path will becomes 'μt' instead of 't'. Entire fringe pattern is displaced by $\frac{D[(\mu-1)t]}{d} = \frac{\beta}{\lambda}(\mu-1)t$ towards the side in which the thin sheet is introduced without any change in fringe width.

14. The law of conservation of energy holds good in the phenomenon of interference.

15. Fringes are neither image now shadow of slit but locus of a point which moves such a way that its path difference from the two sources remains constant.

16. The interference fringes for two coherent point sources are hyperboloids with axis S_1S_2.

17. If the interference experiment is repeated with bichromatic light, the fringes of two wavelengths will be coincident for the first time when

$$n(\beta)_{longer} = (n+1)(\beta)_{shorter}$$

18. No interference pattern is detected when two coherent sources are infinitely close to each other, because $\beta \propto \frac{1}{d}$

19. If maximum number of maximas/minimas are asked in the question, use the fact that value of sinθ/cosθ can`t be greater than 1.

DIFFRACTION

20. **In Fraunhofer diffraction**

(a) For minima $a\sin\theta_n = n\lambda$

(b) For maxima $a\sin\theta_n = (2n+1)\frac{\lambda}{2}$

(c) Linear width of central maxima $W_x = \frac{2\lambda D}{a}$

(d) Angular width of central maxima $W_\theta = \frac{2\lambda}{a}$

(e) Intensity of maxima

where I_0 = Intensity of central maxima

$$I = I_0\left[\frac{\sin\left(\beta/2\right)}{\beta/2}\right]^2 \text{ and } \beta = \frac{2\pi}{\lambda}\, a\sin\theta$$

21. **Polarization :**

(a) Brewsters' law :

$\mu = \tan\theta_p \rightarrow$

$\theta \rightarrow$ polarization of Brewster's angle

(b) Here reflecting and refracting rays are perpendicular to each other.

(c) Malus law :

$I = I_0 \cos^2\theta$

$I_0 \rightarrow$ Maximum intensity of polarized light.

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SOLVED EXAMPLE

Ex.1 Young's double slit experiment is carried out using microwaves of wavelength $\lambda = 3$ cm. Distance in between plane of slits and the screen is D = 100 cm. and distance in between the slits is 5 cm. Find

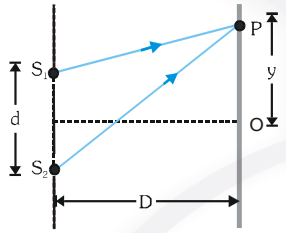
(A) the number of maximas and

(B) their positions on the screen

Sol. **(A)** The maximum path difference that can be produced = distance between the sources or 5 cm. Thus, in this case we can have only three maximas, one central maxima and two on its either side for a path difference of λ or 3 cm.

(B) For maximum intensity at P, $S_2P - S_1P = \lambda$

$$\Rightarrow \sqrt{(y + d/2)^2 + D^2} - \sqrt{(y - d/2)^2 + D^2} = \lambda$$



substiuting d = 5 cm, D = 100 cm and λ = 3cm we get y = ± 75 cm

Thus, the three maximas will be at y = 0 and y = ± 75 cm

Ex.2 State two conditions to obtain sustained interference of light. In Young's double slit experiment, using light of wavelength 400 nm, interference fringes of width 'X' are obtained. The wavelength of light is increased to 600 nm and the separation between the slits is halved. If one wants the observed fringe width on the screen to be the same in the two cases, find the ratio of the distance between the screen and the plane of the slits in the two arrangements.

Sol. Conditions for sustained interference of light

(i) Sources should be coherent.

(ii) There should be point sources

$\because$ fringe width $\beta = \frac{\lambda D}{d}$ Here, $\beta_1 = \frac{\lambda_1 D_1}{d_1}$ and

$\beta_2 = \frac{\lambda_2 D_2}{d_2}$

As $\beta_1 = \beta_2 \Rightarrow \frac{\lambda_1 D_1}{d_1} = \frac{\lambda_2 D_2}{d_2}$

$$\Rightarrow \frac{D_1}{D_2} = \frac{\lambda_2 d_1}{\lambda_1 d_2} = \frac{600}{400} \times \frac{1}{1/2} = \frac{6}{2} = \frac{3}{1}$$

Ex.3 A beam of light consisting of two wavelengths 6500 Å and 5200 Å is used to obtain interference fringes in a young's double slit experiment. The distance between the slits is 2 mm and the distance between the plane of the slits and screen is 120 cm.

(A) Find the distance of the third bright fringe on the screen from the central maxima for the wavelength 6500 Å.

(B) What is the least distance from the central maxima where the bright fringes due to both the wave-lengths coincide?

Sol. **(A)** Distance of third bright fringe from centre of screen

$$x_3 = \frac{nD\lambda}{d} = \frac{3 \times 120 \times 10^{-2} \times 6500 \times 10^{-10}}{2 \times 10^{-3}}$$

$= 1.17 \times 10^{-3}\,m = 1.17\,mm$

(B) When bright fringes coincide to each other then

$$n_1\lambda_1 = n_2\lambda_2 \Rightarrow \frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1} = \frac{5200E}{6500E} = \frac{4}{5}$$

for minimum value of n_1 & n_2 $n_1 = 4$, $n_2 = 5$

$$\text{So } x = \frac{n_1\lambda_1 D}{d} = \frac{4 \times 6500 \times 10^{-10} \times 120 \times 10^{-2}}{2 \times 10^{-3}}$$

$= 0.156 \times 10^{-2}\,m = 0.156\,cm$

Ex.4 Two slits separated by a distance of 1 mm are illuminated with red light of wavelength 6.5×10^{-7} m. The interference fringes are observed on a screen placed 1m from the slits. The distance between the third dark fringe and the fifth bright fringe is equal to

(A) 0.65 mm **(B)** 1.625 mm

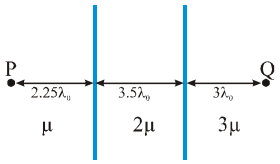
(C) 3.25 mm **(D)** 0.975 mm

Sol. Distance between third dark fringe and the fifth bright fringe

$$= 2.5\beta = 2.5\frac{\lambda D}{d} = 2.5\frac{6.5 \times 10^{-7} \times 1}{10^{-3}} = 1.625 \text{ mm}$$

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Ex.5 An electromagnetic wave of wavelength λ_0 (in vacuum) passes from P towards



Q crossing three different media of refractive index μ, 2μ and 3μ respectively as shown in figure. ϕ_P and ϕ_Q be the phase of the wave at points P and Q. Find the phase difference $\phi_Q - \phi_P$. [Take : μ=1]

(A) 0 **(B)** $\frac{\pi}{4}$

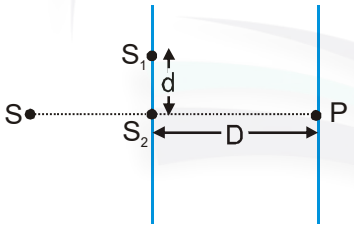
(C) $\frac{\pi}{2}$ **(D)** π

Sol. Optical path difference between (OPD) P & Q

$(O.P.D.) = 2.25\lambda_0 \times 1 + (3.5\lambda_0) \times 2 + 3\lambda_0 \times 3 = 18.25\lambda_0$

and phase difference $\Delta\phi = \frac{2\pi}{\lambda_0} \times \Delta x = \frac{\pi}{2}$

Ex.6 In a YDSE experiment two slits S_1 and S_2 have separation of d = 2 mm. The distance of the screen is D = $\frac{8}{5}$ m. Source S starts moving from a very large distance towards S_2 perpendicular to S_1S_2 as shown in figure. The wavelength of monochromatic light is 500 nm. The number of maximas observed on the screen at point P as the source moves towards S_2 is



(A) 4001 **(B)** 3999

(C) 3998 **(D)** 4000

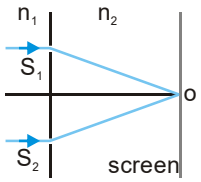
Sol. $S_1P - S_2P = \frac{d^2}{2D} = \frac{2\times10^{-3}\times2\times0^{-3}}{2\times\frac{8}{5}} = \frac{5}{2}\lambda$

$(\lambda = 500nm)$

So when S is at ∞ there is I[st] minima and when S is at S_2 there is last minima because d/λ=4000

So the number of minima's will be 4001 and number of maxima's will be 4000.

Ex.7 In a Young's double slit experiment the slits S_1 & S_2 are illuminated by a parallel beam of light of wavelength 4000 Å, from the medium of refractive index n_1 = 1.2. A thin film of thickness 1.2μm and refractive index n = 1.5 is placed infront of S_1 perpendicular to path of light. The refractive index of medium between plane of slits & screen is n_2 = 1.4. If the light coming from the film and S_1 & S_2 have equal intensities I then intensity at geometrical centre of the screen O is



(A) 0

(B) 2I

(C) 4I

(D) None of these

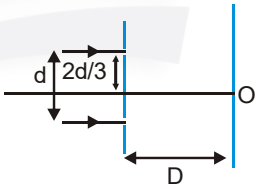
Sol. Path difference at O : $(\mu_{rel} - 1)\,t = \left(\frac{n}{n_2} - 1\right)t$

∴ Phase difference at O: $t\left(\frac{n}{n_2} - 1\right)\frac{2\pi}{\lambda_2}$ where

$n_1\lambda_1 = n_2\lambda_2$

⇒ Phase difference= $\frac{\pi}{2}$ ⇒ Resultant intensity = 2I

Ex.8 In the figure shown if a parallel beam of white light is incident on the plane of the slits then the distance of the only white spot on the screen from O is :[assume d << D , λ << d]



(A) 0 **(B)** d/2

(C) d/3 **(D)** d/6

Sol. White spot will be at the symmetrical point w.r.t. slits . Its distance from O will be ,(2d/3) – (d/2) = d/6 .

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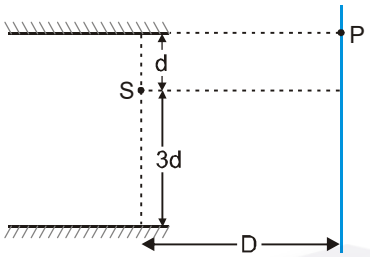
Ex.9 Consider the optical system shown in figure. The point source of light S is having wavelength equals to λ. The light is reaching screen only after reflection. For point P to be 2nd maxima, the value of λ would be (D>>d and d>>λ)

(A) $\frac{12d^2}{D}$

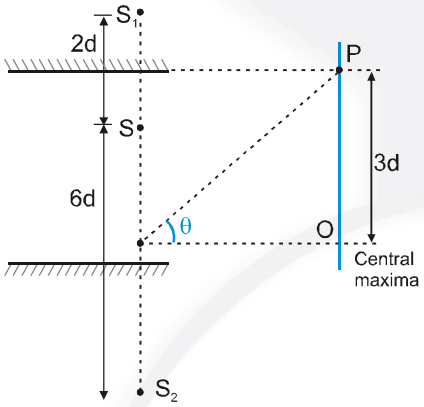
(B) $\frac{6d^2}{D}$

(C) $\frac{3d^2}{D}$

(D) $\frac{24d^2}{D}$



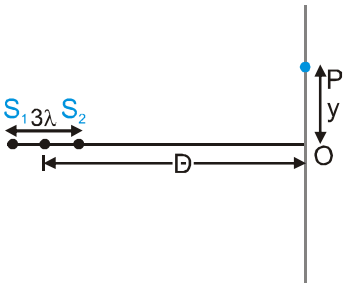
Sol.



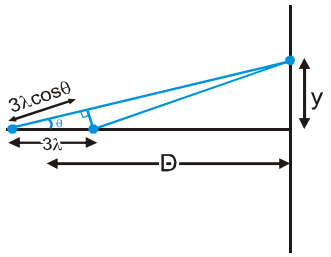
At P, $\Delta x = \frac{(8d)\times 3d}{D}$; For 2nd maxima, $\Delta x = 2\lambda$

$\Rightarrow \frac{24d^2}{D} = 2\lambda \Rightarrow \lambda = \frac{12d^2}{D}$

Ex.10 Figure shows two coherent microwave source S_1 and S_2 emitting waves of wavelength λ and separated by a distance 3λ. For λ <<D and y≠ 0, the minimum value of y for point P to be an intensity maximum is $\frac{\sqrt{m}\,D}{n}$. Determine the value of m + n, if m and n are coprime numbers.



Sol. Path difference = $3\lambda\cos\theta = 2\lambda \Rightarrow \cos\theta = \frac{2}{3}$



$y = D\tan\theta = \frac{D\sqrt{5}}{2} \Rightarrow m + n = 5 + 2 = 7$

Ex.11 **Statement–1:** In Young's double slit experiment the two slits are at distance d apart. Interference pattern is observed on a screen at distance D from the slits. At a point on the screen when it is directly opposite to one of the slits, a dark fringe is observed. Then, the wavelength of wave is proportional to square of distance of two slits.

Statement–2 : In Young's double slit experiment, for identical slits, the intensity of a dark fringe is zero.

(A) Statement–1 is True, Statement–2 is True ; Statement–2 is a correct explanation for Statement–1

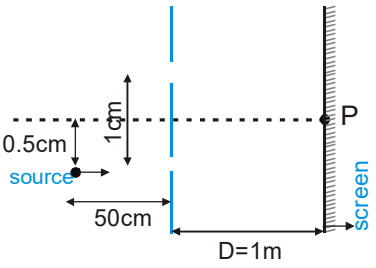
(B) Statement–1 is True, Statement–2 is True ; Statement–2 is not a correct explanation for Statement–1

(C) Statement–1 is True, Statement–2 is False.

(D) Statement–1 is False, Statement–2 is True.

Sol. **(B)**

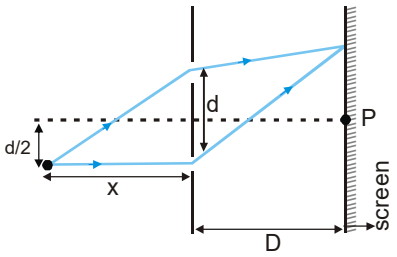
Ex.12 In a typical Young's double slit experiment a point source of monochromatic light is kept as shown in the figure. If the source is given an instantaneous velocity v=1 mm per second towards the screen, then the instantaneous velocity of central maxima is given as $\alpha \times 10^{-\beta}$ cm/s upward in scientific notation. Find the value of α+β.



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Sol. The central maxima

$$\frac{dy}{D} = \sqrt{d^2 + x^2} - x = x\left[1 + \frac{d^2}{2x^2}\right] - x = \frac{d^2}{2x}$$



$$y = \frac{Dd}{2x} \Rightarrow$$

$$\Rightarrow \frac{dy}{dt} = -\frac{Dd}{2x^2}\left(\frac{dx}{dt}\right) = \left(\frac{1\times 0.01}{2\times 0.5\times 0.5}\right)\times(0.001)$$

$= 0.02$ m m/s

$\Rightarrow y = 2 \times 10^{-3}$ cm/s $\Rightarrow \alpha + \beta = 5$

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Exercise # 1 SINGLE OBJECTIVE NEET LEVEL

1. By corpuscular theory of light, the phenomenon which can be explained is
(A) Refraction (B) Interference
(C) Diffraction (D) Polarisation

2. According to corpuscular theory of light, the different colours of light are due to
(A) Different electromagnetic waves
(B) Different force of attraction among the corpuscles
(C) Different size of the corpuscles
(D) None of the above

3. Huygen's conception of secondary waves
(A) Allow us to find the focal length of a thick lens
(B) Is a geometrical method to find a wavefront
(C) Is used to determine the velocity of light
(D) Is used to explain polarisation

4. The idea of the quantum nature of light has emerged in an attempt to explain
(A) Interference
(B) Diffraction
(C) Radiation spectrum of a black body
(D) Polarisation

5. Two coherent sources of light can be obtained by
(A) Two different lamps
(B) Two different lamps but of the same power
(C) Two different lamps of same power and having the same colour
(D) None of the above

6. By Huygen's wave theory of light, we cannot explain the phenomenon of
(A) Interference (B) Diffraction
(C) Photoelectric effect (D) Polarisation

7. The phenomenon of interference is shown by
(A) Longitudinal mechanical waves only
(B) Transverse mechanical waves only
(C) Electromagnetic waves only
(D) All the above types of waves

8. Two coherent monochromatic light beams of intensities I and $4I$ are superposed. The maximum and minimum possible intensities in the resulting beam are
(A) $5I$ and I (B) $5I$ and $3I$
(C) $9I$ and I (D) $9I$ and $3I$

9. Light appears to travel in straight lines since
(A) It is not absorbed by the atmosphere
(B) It is reflected by the atmosphere
(C) Its wavelength is very small
(D) Its velocity is very large

10. The idea of secondary wavelets for the propagation of a wave was first given by
(A) Newton (B) Huygen
(C) Maxwell (D) Fresnel

11. Young's experiment establishes that
(A) Light consists of waves
(B) Light consists of particles
(C) Light consists of neither particles nor waves
(D) Light consists of both particles and waves

12. In the interference pattern, energy is
(A) Created at the position of maxima
(B) Destroyed at the position of minima
(C) Conserved but is redistributed
(D) None of the above

13. Monochromatic green light of wavelength $5 \times 10^{-7}\ m$ illuminates a pair of slits 1 mm apart. The separation of bright lines on the interference pattern formed on a screen 2 m away is
(A) 0.25 mm (B) 0.1 mm
(C) 1.0 mm (D) 0.01 mm

14. In Young's double slit experiment, if the slit widths are in the ratio 1 : 9, then the ratio of the intensity at minima to that at maxima will be
(A) 1 (B) 1/9
(C) 1/4 (D) 1/3

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15. In Young's double slit interference experiment, the slit separation is made 3 fold. The fringe width becomes

(A) 1/3 *times* **(B)** 1/9 *times*

(C) 3 *times* **(D)** 9 *times*

16. In a certain double slit experimental arrangement interference fringes of width 1.0 *mm* each are observed when light of wavelength 5000 Å is used. Keeping the set up unaltered, if the source is replaced by another source of wavelength 6000 Å, the fringe width will be

(A) 0.5 *mm* **(B)** 1.0 *mm*

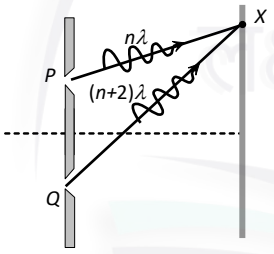
(C) 1.2 *mm* **(D)** 1.5 *mm*

17. Two coherent light sources S_1 and S_2 (λ= 6000 Å) are 1*mm* apart from each other. The screen is placed at a distance of 25 *cm* from the sources. The width of the fringes on the screen should be

(A) 0.015 *cm* **(B)** 0.025 *cm*

(C) 0.010 *cm* **(D)** 0.030 *cm*

18. The figure shows a double slit experiment P and Q are the slits. The path lengths PX and QX are $n\lambda$ and $(n+2)\lambda$ respectively, where n is a whole number and λ is the wavelength. Taking the central fringe as zero, what is formed at X



(A) First bright **(B)** First dark

(C) Second bright **(D)** Second dark

19. In Young's double slit experiment, if one of the slit is closed fully, then in the interference pattern

(A) A bright slit will be observed, no interference pattern will exist

(B) The bright fringes will become more bright

(C) The bright fringes will become fainter

(D) None of the above

20. In Young's double slit experiment, a glass plate is placed before a slit which absorbs half the intensity of light. Under this case

(A) The brightness of fringes decreases

(B) The fringe width decreases

(C) No fringes will be observed

(D) The bright fringes become fainter and the dark fringes have finite light intensity

21. The observed wavelength of light coming from a distant galaxy is found to be increased by 0.5% as compared with that coming from a terrestrial source. The galaxy is

(A) Stationary with respect to the earth

(B) Approaching the earth with velocity of light

(C) Receding from the earth with the velocity of light

(D) Receding from the earth with a velocity equal to $1.5 \times 10^6\ m/s$

22. A star producing light of wavelength 6000 Å moves away from the earth with a speed of 5 *km/sec*. Due to Doppler effect the shift in wavelength will be ($c = 3 \times 10^8\ m/\text{sec}$)

(A) 0.1 Å **(B)** 0.05 Å

(C) 0.2 Å **(D)** 1 Å

23. If the shift of wavelength of light emitted by a star is towards violet, then this shows that star is

(A) Stationary

(B) Moving towards earth

(C) Moving away from earth

(D) Information is incomplete

24. Assuming that universe is expanding, if the spectrum of light coming from a star which is going away from earth is tested, then in the wavelength of light

(A) There will be no change

(B) The spectrum will move to infrared region

(C) The spectrum will seems to shift to ultraviolet side

(D) None of the above

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25. Doppler's effect in sound in addition to relative velocity between source and observer, also depends while source and observer or both are moving. Doppler effect in light depend only on the relative velocity of source and observer. The reason of this is

(A) Einstein mass - energy relation

(B) Einstein theory of relativity

(C) Photoelectric effect

(D) None of these

26. A rocket is moving away from the earth at a speed of $6 \times 10^7 \, m/s$. The rocket has blue light in it. What will be the wavelength of light recorded by an observer on the earth (wavelength of blue light = 4600 Å)

(A) 4600 Å **(B)** 5520 Å

(C) 3680 Å **(D)** 3920 Å

27. A spectral line $\lambda = 5000$ Å in the light coming from a distant star is observed as a 5200 Å. What will be recession velocity of the star

(A) $1.15 \times 10^7 \, cm/\text{sec}$ **(B)** $1.15 \times 10^7 \, m/\text{sec}$

(C) $1.15 \times 10^7 \, km/\text{sec}$ **(D)** 1.15 *km/sec*

28. The apparent wavelength of the light from a star moving away from the earth is 0.01% more than its real wavelength. Then the velocity of star is

(A) 60 *km/sec* **(B)** 15 *km/sec*

(C) 150 *km/sec* **(D)** 30 *km/sec*

29. A star emits light of 5500 Å wavelength. Its appears blue to an observer on the earth, it means

(A) Star is going away from the earth

(B) Star is stationary

(C) Star is coming towards earth

(D) None of the above

30. The velocity of light emitted by a source *S* observed by an observer *O*, who is at rest with respect to *S* is *c*. If the observer moves towards *S* with velocity *v*, the velocity of light as observed will be

(A) c + v **(B)** c – v

(C) c **(D)** $\sqrt{1 - \frac{v^2}{c^2}}$

31. A slit of width *a* is illuminated by white light. For red light ($\lambda = 6500$ Å), the first minima is obtained at $\theta = 30^o$. Then the value of *a* will be

(A) 3250 Å **(B)** $6.5 \times 10^{-4} \, mm$

(C) 1.24 *microns* **(D)** $2.6 \times 10^{-4} \, cm$

32. The light of wavelength 6328 Å is incident on a slit of width 0.2 *mm* perpendicularly, the angular width of central maxima will be

(A) 0.36° **(B)** 0.18°

(C) 0.72° **(D)** 0.09°

33. The bending of beam of light around corners of obstacles is called

(A) Reflection **(B)** Diffraction

(C) Refraction **(D)** Interference

34. The penetration of light into the region of geometrical shadow is called

(A) Polarisation **(B)** Interference

(C) Diffraction **(D)** Refraction

35. A slit of size 0.15 *cm* is placed at 2.1 *m* from a screen. On illuminated it by a light of wavelength 5×10^{-5} *cm*. The width of central maxima will be

(A) 70 *mm* **(B)** 0.14 *mm*

(C) 1.4 *mm* **(D)** 0.14 *cm*

36. A diffraction is obtained by using a beam of red light. What will happen if the red light is replaced by the blue light

(A) Bands will narrower and crowd full together

(B) Bands become broader and further apart

(C) No change will take place

(D) Bands disappear

37. What will be the angle of diffracting for the first minimum due to Fraunhoffer diffraction with sources of light of wave length 550 *nm* and slit of width 0.55 *mm*

(A) 0.001 *rad* **(B)** 0.01 *rad*

(C) 1 *rad* **(D)** 0.1 *rad*

38. Angular width **(B)** of central maximum of a diffraction pattern on a single slit does not depend upon

(A) Distance between slit and source

(B) Wavelength of light used

(C) Width of the slit

(D) Frequency of light used

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39. A single slit of width 0.20 *mm* is illuminated with light of wavelength 500 *nm*. The observing screen is placed 80 *cm* from the slit. The width of the central bright fringe will be

(A) 1 *mm* **(B)** 2 *mm*

(C) 4 *mm* **(D)** 5 *mm*

40. Yellow light is used in single slit diffraction experiment with slit width 0.6 *mm*. If yellow light is replaced by *X*-rays then the pattern will reveal

(A) That the central maxima is narrower

(B) No diffraction pattern

(C) More number of fringes

(D) Less number of fringes

41. A polariser is used to

(A) Reduce intensity of light

(B) Produce polarised light

(C) Increase intensity of light

(D) Produce unpolarised light

42. Light waves can be polarised as they are

(A) Transverse **(B)** Of high frequency

(C) Longitudinal **(D)** Reflected

43. Through which character we can distinguish the light waves from sound waves

(A) Interference **(B)** Refraction

(C) Polarisation **(D)** Reflection

44. The angle of polarisation for any medium is 60°, what will be critical angle for this

(A) $\sin^{-1}\sqrt{3}$ **(B)** $\tan^{-1}\sqrt{3}$

(C) $\cos^{-1}\sqrt{3}$ **(D)** $\sin^{-1}\frac{1}{\sqrt{3}}$

45. The angle of incidence at which reflected light is totally polarized for reflection from air to glass (refraction index n) is

(A) $\sin^{-1}(n)$ **(B)** $\sin^{-1}\left(\frac{1}{n}\right)$

(C) $\tan^{-1}\left(\frac{1}{n}\right)$ **(D)** $\tan^{-1}(n)$

46. Which of following can not be polarised

(A) Radio waves **(B)** Ultraviolet rays

(C) Infrared rays **(D)** Ultrasonic waves

47. A polaroid is placed at 45° to an incoming light of intensity I_0. Now the intensity of light passing through polaroid after polarisation would be

(A) I_0 **(B)** $I_0/2$

(C) $I_0/4$ **(D)** Zero

48. Plane polarised light is passed through a polaroid. On viewing through the polaroid we find that when the polariod is given one complete rotation about the direction of the light, one of the following is observed

(A) The intensity of light gradually decreases to zero and remains at zero

(B) The intensity of light gradually increases to a maximum and remains at maximum

(C) There is no change in intensity

(D) The intensity of light is twice maximum and twice zero

49. Out of the following statements which is not correct

(A) When unpolarised light passes through a Nicol's prism, the emergent light is elliptically polarised

(B) Nicol's prism works on the principle of double refraction and total internal reflection

(C) Nicol's prism can be used to produce and analyse polarised light

(D) Calcite and Quartz are both doubly refracting crystals

50. A ray of light is incident on the surface of a glass plate at an angle of incidence equal to Brewster's angle ϕ. If μ represents the refractive index of glass with respect to air, then the angle between reflected and refracted rays is

(A) $90+\phi$

(B) $\sin^{-1}(\mu\cos\phi)$

(C) 90°

(D) $90^\circ - \sin^{-1}(\sin\phi/\mu)$

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51. Which of the following statement is wrong

(A) Infrared photon has more energy than the photon of visible light

(B) Photographic plates are sensitive to ultraviolet rays

(C) Photographic plates can be made sensitive to infrared rays

(D) Infrared rays are invisible but can cast shadows like visible light rays

52. Pick out the longest wavelength from the following types of radiations

(A) Blue light **(B)** γ-rays

(C) X-rays **(D)** Red light

53. Wave which cannot travel in vacuum is

(A) X-rays **(B)** Infrasonic

(C) Ultraviolet **(D)** Radiowaves

54. Light is an electromagnetic wave. Its speed in vacuum is given by the expression

(A) $\sqrt{\mu_o \varepsilon_o}$ **(B)** $\sqrt{\frac{\mu_o}{\varepsilon_o}}$

(C) $\sqrt{\frac{\varepsilon_o}{\mu_o}}$ **(D)** $\frac{1}{\sqrt{\mu_o \varepsilon_o}}$

55. The range of wavelength of the visible light is

(A) 10 Å to 100 Å **(B)** 4,000 Å to 8,000 Å

(C) 8,000 Å to 10,000 Å **(D)** 10,000 Å to 15,000 Å

56. Which radiation in sunlight, causes heating effect

(A) Ultraviolet **(B)** Infrared

(C) Visible light **(D)** All of these

57. Which of the following represents an infrared wavelength

(A) 10^{-4} cm **(B)** 10^{-5} cm

(C) 10^{-6} cm **(D)** 10^{-7} cm

58. The wavelength of light visible to eye is of the order of

(A) $10^{-2}\ m$ **(B)** $10^{-10}\ m$

(C) $1\ m$ **(D)** $6 \times 10^{-7}\ m$

59. The speed of electromagnetic wave in vacuum depends upon the source of radiation

(A) Increases as we move from γ-rays to radio waves

(B) Decreases as we move from γ-rays to radio waves

(C) Is same for all of them

(D) None of these

60. Which of the following radiations has the least wavelength

(A) γ-rays **(B)** β-rays

(C) α-rays **(D)** X-rays

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Exercise # 2 SINGLE OBJECTIVE AIIMS LEVEL

1. Huygen's principle is applicable to
(A) Only light waves
(B) Only sound waves
(C) Only mechanical waves
(D) For all the above waves

2. Which of the following phenomenon can not be explained by the Huygen's theory-
(A) Refraction (B) Reflection
(C) Diffraction
(D) Formation of spectrum

3. According to huygen's theory of secondary waves, following can be explained-
(A) Propagation of light in medium
(B) Reflection of light
(C) Refraction of light
(D) All of the above

4. The main drawback of huygen's theory was-
(A) Failure in explanation of rectilinear propagation of lignt
(B) Failure of explain the spectrum of white light
(C) Failure to explain the formation of newton's rings
(D) A failure of experimental verification of ether medium

5. Huygen's theory of secondary waves can be used to find-
(A) Velocity of light
(B) The wavelength of light
(C) Wave front geometrically
(D) Magnifying power of microscope

6. Two coherent sources of intensities I_1 and I_2 produce an interference pattern. The maximum intensity in the interference pattern will be :–
(A) $I_1 + I_2$ (B) $I_1^2 + I_2^2$
(C) $(I_1 + I_2)^2$ (D) $(\sqrt{I_1} + \sqrt{I_2})^2$

7. The colour are characterized by which of following character of light–
(A) Frequency (B) Amplitude
(C) Wavelength (D) Velocity

8. Light has a wave nature, because-
(A) the light travel in a straight line
(B) Light exhibts phenomenon of reflection and re fraction
(C) Light exhibits phenomenon interference
(D) Light exhibits phenomenon of photo electric ef fect

9. Two wave are represented by the equations $y_1 = a \sin \omega t$ and $y_2 = a \cos \omega t$. The first wave :–
(A) leads the second by π
(B) lags the seconds by π
(C) leads the second by $\frac{\pi}{2}$
(D) lags the seconds by $\frac{\pi}{2}$

10. The phase difference corresponding to path difference of x is :–
(A) $\frac{2\pi x}{\lambda}$ (B) $\frac{2\pi\lambda}{x}$
(C) $\frac{\pi x}{\lambda}$ (D) $\frac{\pi\lambda}{x}$

11. The resultant amplitude of a vibrating particle by the superposition of the two waves
$y_1 = a\sin\left[\omega t + \frac{\pi}{3}\right]$ and $y_2 = a \sin \omega t$ is :–
(A) a (B) $\sqrt{2}$ a
(C) 2a (D) $\sqrt{3}$ a

12. The energy in the phenomenon of interference :–
(A) is conserved, gets redistributed
(B) is equal at every point
(C) is destroyed in regions of dark fringes
(D) is created at the place of bright fringes

13. Phenomenon of interference is observed :–
(A) only for light waves
(B) only for sound waves
(C) for both sound and light waves
(D) none of above

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14. The resultant amplitude in interference with two coherent sources depends upon :–

(A) only amplitude

(B) only phase difference

(C) on both the previous option

(D) none of the above

15. For the sustained interference of light, the necessary condition is that the two sources should :–

(A) have constant phase difference

(B) be narrow

(C) be close to each other

(D) of same amplitude

16. Two coherent sources must have the same :–

(A) amplitude **(B)** phase difference

(C) frequency **(D)** both (B) and (C)

17. If the ratio of the intensity of two coherent sources is 4 then the visibility $[(I_{max} - I_{min})/(I_{max} + I_{min})]$ of the fringes is

(A) 4 **(B)** 4/5

(C) 3/5 **(D)** 9

18. If the distance between the first maxima and fifth minima of a double slit pattern is 7 mm and the slits are separated by 0.15 mm with the screen 50 cm from the slits, then wavelength of the light used is

(A) 600 nm **(B)** 525 nm

(C) 467 nm **(D)** 420 nm

19. Two monochromatic and coherent point sources of light are placed at a certain distance from each other in the horizontal plane. The locus of all those points in the horizontal plane which have constructive interference will be–

(A) A hyperbola

(B) Family of hyperbolas

(C) Family of straight lines

(D) Family of parabolas

20. In Young's double slit experiment using sodium light (λ = 5898Å), 92 fringes are seen. If given colour (λ = 5461Å) is used, how many fringes will be seen

(A) 62 **(B)** 67

(C) 85 **(D)** 99

21. In Young's double slit experiment, the separation between the slits is halved and the distance between the slits and the screen is doubled. The fringe width is :–

(A) unchanged **(B)** halved

(C) doubled **(D)** quadrupled

22. In Young's double slit experiment, a mica sheet of thickness t and refractive index μ is introduced in the path of ray from the first source S_1. By how much distance the fringe pattern will be displaced

(A) $\frac{d}{D}(\mu - 1)t$ **(B)** $\frac{D}{d}(\mu - 1)t$

(C) $\frac{d}{(\mu - 1)D}$ **(D)** $\frac{D}{d}(\mu - 1)$

23. In Young's experiment, one slit is covered with a blue filter and the other (slit) with a yellow filter. Then the interference pattern :–

(A) will be blue **(B)** will be yellow

(C) will be green **(D)** will not be formed

24. In the young's double slit experiment the central maxima is observed to be I_0. If one of the slits is covered, then intensity at the central maxima will become :–

(A) $\frac{I_0}{2}$ **(B)** $\frac{I_0}{\sqrt{2}}$

(C) $\frac{I_0}{4}$ **(D)** I_0

25. In Young's double slit experiment, if monochromatic light is replaced by white light :–

(A) all bright fringes become white

(B) all bright fringes have coloures between violet and red

(C) only the central fringe is white, all other fringes are coloured

(D) no fringes are observed

26. In Young's double slit experiment, one of the slits is so painted that intensity of light emitted from it is half of that of the light emitted from other slit. Then

(A) fringe system will disappear

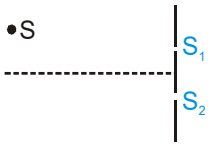
(B) bright fringes will become brighter and dark fringes will be darker

(C) both bright and dark fringes will become darker

(D) dark fringes will become less dark and bright fringes will become less bright.

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27. In YDSE, the source placed symmetrically with respect to the slit is now moved parallel to the plane of the slits it is closer to the upper slit, as shown. Then ,



(A) the fringe width will increase and fringe pattern will shift down.

(B) the fringe width will remain same but fringe pattern will shift up.

(C) the fringe width will decrease and fringe pattern will shift down.

(D) the fringe width will remain same but fringe pattern will shift down.

28. In YDSE how many maxima can be obtained on the screen if wavelength of light used is 200 nm and d = 700 nm :

(A) 12 **(B)** 7

(C) 18 **(D)** None of these

29. In a double slit experiment, instead of taking slits of equal widths, one slit is made twice as wide as the other. Then in the interference pattern.

(A) the intensifies of both the maxima and minima increase.

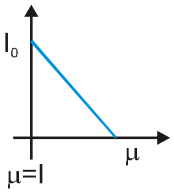
(B) the intensity of the maxima increases and the minima has zero intensity.

(C) the intensity of the maxima decreases and that of minima increases

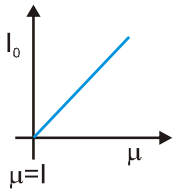
(D) the intensity of the maxima decreases and the minima has zero intensity.

30. In a YDSE experiment if a slab whose refractive index can be varied is placed in front of one of the slits then the variation of resultant intensity at mid–point of screen with 'μ' will be best represented by (μ ≥ 1). [Assume slits of equal width and there is no absorption by slab]

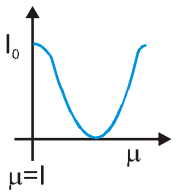
(A)



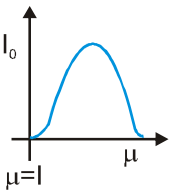
(B)



(C)



(D)



31. When light is refracted into a denser medium-

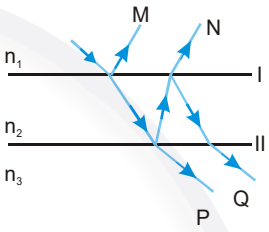
(A) Its wavelength and frequency both increase.

(B) Its wavelength increases but frequency remains unchanged.

(C) Its wavelength decreases but frequency remains unchanged.

(D) its wavelength and frequency both decrease.

32. A ray of light is incident on a thin film. As shown in figure M, N are two reflected rays and P, Q are two transmitted rays, Rays N and Q undergo a phase change of π. Correct ordering of the refracting indices is :



(A) $n_2 > n_3 > n_1$

(B) $n_3 > n_2 > n_1$

(C) $n_3 > n_1 > n_2$

(D) none of these, the specified changes can not occur

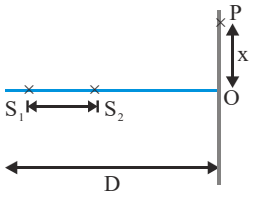
33. Let S_1 and S_2 be the two slits in Young's double slit experiment. If central maxima is observed at P and angle $\angle S_1PS_2 = \theta$, then the fringe width for the light of wavelength λ will be. (Assume θ to be a small angle)

(A) λ/θ **(B)** λθ

(C) 2λ/θ **(D)** λ/2θ

34. Two coherent narrow slits emitting light of wavelength λ in the same phase are placed parallel to each other at a small separation of 3λ. The light is collected on a screen S which is placed at a distance D (>>λ) from the slits. The smallest distance x such that the P is a maxima.

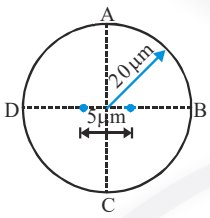
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(A) $\sqrt{3D}$ (B) $\sqrt{8}D$

(C) $\sqrt{5}D$ (D) $\sqrt{5}\frac{D}{2}$

35. Two point source separated by d = 5 μm emit light of wavelength λ=2 μm in phase. A circular wire of radius 20 μm is placed around the source as shown in figure.



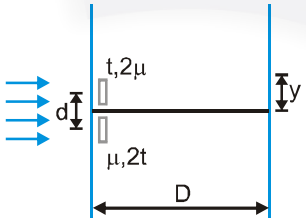
(A) Points A and B are dark and points C and D are bright.

(B) Points A and B are bright and point C and D are dark.

(C) Points A and C are dark and points B and D are bright.

(D) Points A and C are bright and points B and D are dark.

36. In the YDSE shown the two slits are covered with thin sheets having thickness t & 2t and refractive index 2μ and μ. Find the position (y) of central maxima



(A) zero (B) $\frac{tD}{d}$

(C) $-\frac{tD}{d}$ (D) None of these

37. Minimum thickness of a mica sheet having $\mu = \frac{3}{2}$ which should be placed in front of one of the slits in YDSE is required to reduce the intensity at the centre of screen to half of maximum intensity is-

(A) λ/4 (B) λ/8

(C) λ/2 (D) λ/3

38. Diffraction and interference of light refers to :–

(A) quantum nature of light

(B) wave nature of light

(C) transverse nature of light

(D) electromagnetic nature of light

39. In a YDSE with two identical slits, when the upper slit is covered with a thin, perfectly transparent sheet of mica, the intensity at the centre of screen reduces to 75% of the initial value. Second minima is observed to be above this point and third maxima below it. Which of the following can not be a possible value of phase difference caused by the mica sheet

(A) $\frac{\pi}{3}$ (B) $\frac{13\pi}{3}$

(C) $\frac{17\pi}{3}$ (D) $\frac{11\pi}{3}$

40. Sound waves shows more diffraction as compare to light rays :–

(A) wavelength of sound waves is more as compare to light rays

(B) wavelength of light rays is more as compare to sound waves

(C) wavelength of sound waves and light ray is same

(D) none of these

41. The phenomenon of diffraction of light was discovered by :–

(A) Huygens (B) Newton

(C) Fresnel (D) Grimaldi

42. Diffraction initiated from obstacle, depends upon the

(A) size of obstacle

(B) wave length, size of obstacle

(C) wave length and distance of obstacle from screen

(D) size of obstacle and its distance from screen

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43. The conversation going on, in some room, can be heared by the person outside the room. The reason for it is :–
(A) interference of sound (B) reflection of sound
(C) diffraction of sound (D) refraction of sound

44. Diffraction of light is observed only, when the obstacle size is :–
(A) very large
(B) very small
(C) of the same order that of wavelength of light
(D) any size

45. Phenomenon of diffraction occurs :–
(A) only in case of light and sound waves
(B) for all kinds of waves
(C) for electro-magnetic waves and not for matter waves
(D) for light waves only

46. All fringes of diffraction are of :–
(A) the same intensity (B) unequal width
(C) the same width (D) full darkness

47. Which of the following ray gives more distinct diffraction :–
(A) X-ray (B) light ray
(C) γ –ray (D) Radio wave

48. Direction of the second maximum in the Fraunhofer diffraction pattern at a single slit is given by (a is the width of the slit) :–
(A) $a\sin\theta = \frac{\lambda}{2}$ (B) $a\cos\theta = \frac{3\lambda}{2}$
(C) $a\sin\theta = \lambda$ (D) $a\sin\theta = \frac{3\lambda}{2}$

49. A single slit of width d is placed in the path of beam of wavelength λ. The angular width of the principal maximum obtained is :–
(A) $\frac{d}{\lambda}$ (B) $\frac{\lambda}{d}$
(C) $\frac{2\lambda}{d}$ (D) $\frac{2d}{\lambda}$

50. Red light is generally used to observe diffraction pattern from single slit. If green light is used instead of red light, then diffraction pattern :–
(A) will be more clear (B) will be contract
(C) will be expanded (D) will not visualize

51. Angular width (θ) of central maximum of a diffraction pattern of a single slit does not depend upon :–
(A) distance between slit and source
(B) wavelength of light used
(C) width of the slit
(D) frequency of light used

52. In single slit Fraunhoffer diffraction which type of wavefront is required :–
(A) cylindrical (B) spherical
(C) elliptical (D) plane

54. Central fringe obtained in diffraction pattern due to a single slit :–
(A) is of minimum intensity
(B) is of maximum intensity
(C) intensity does not depend upon slit width
(D) none of the above

53. Calculate angular width of central maxima if $\lambda = 6000$ Å, $a = 18 \times 10^{-5}$ cm :–
(A) 20° (B) 40°
(C) 30° (D) 260°

55. In the diffraction pattern of a single slit aperture, the width of the central fringe compared to widths of the other fringes, is :–
(A) equal (B) less
(C) little more (D) double

56. In the laboratory, diffraction of light by a single slit is being observed. If slit is made slightly narrow, then diffraction pattern will :–
(A) be more spreaded than before
(B) be less spreaded than before
(C) be spreaded as before
(D) be disappeared

57. In a single slit diffraction pattern, if the light source is used of less wave length then previous one. Then width of the central fringe will be :–
(A) less (B) increase
(C) unchanged (D) none of the above

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58. In a Fraunhofer's diffraction by a slit, if slit width is a, wave length λ, focal length of lens is f, linear width of central maxima is :–

(A) $\frac{f\lambda}{a}$ **(B)** $\frac{fa}{\lambda}$

(C) $\frac{2f\lambda}{a}$ **(D)** $\frac{f\lambda}{2a}$

59. Find the half angular width of the central bright maximum in the Fraunhofer diffraction pattern of a slit of width 12×10^{-5} cm when the slit is illuminated by monochromatic light of wavelength 6000 Å.

(A) 40° **(B)** 45°

(C) 30° **(D)** 60°

60. In a Fraunhofer's diffraction obtained by a single slit aperture, the value of path difference for n^{th} order of minima is:–

(A) nλ **(B)** 2nλ

(C) $\frac{(2n-1)\lambda}{2}$ **(D)** (2n–1)λ

61. Light waves can be polarised as they are :

(A) Transverse **(B)** Of high frequency

(C) Longitudinal **(D)** Reflected

62. A polariser is used to :

(A) Reduce intensity of light

(B) Produce polarised light

(C) Increase intensity of light

(D) Produce unpolarised light

63. The angle of polarisation for any medium is 60°, what will be critical angle for this :

(A) $\sin^{-1}\sqrt{3}$ **(B)** $\tan^{-1}\sqrt{3}$

(C) $\cos^{-1}\sqrt{3}$ **(D)** $\sin^{-1}\frac{1}{\sqrt{3}}$

64. Through which character we can distinguish the light waves from sound waves :

(A) Interference **(B)** Refraction

(C) Polarisation **(D)** Reflection

65. A polaroid is placed at 45° to an incoming light of intensity I_0. Now the intensity of light passing through polaroid after polarisation would be :

(A) I_0 **(B)** $I_0/2$

(C) $I_0/4$ **(D)** Zero

66. The angle of incidence at which reflected light is totally polarized for reflection from air to glass (refractive index n)

(A) $\sin^{-1}(n)$ **(B)** $\sin^{-1}\left(\frac{1}{n}\right)$

(C) $\tan^{-1}\left(\frac{1}{n}\right)$ **(D)** $\tan^{-1}(n)$

67. A ray of light is incident on the surface of a glass plate at an angle of incidence equal to Brewster's angle ϕ. If μ represents the refractive index of glass with respect to air, then the angle between reflected and refracted rays is :

(A) 90 + ϕ **(B)** $\sin^{-1}(\mu\cos\phi)$

(C) 90° **(D)** $90° - \sin^{-1}(\sin\phi/\mu)$

68. Plane polarised light is passed through a polaroid. On viewing through the polariod we find that when the polariod is given one complete rotation about the direction of the light, one of the following is observed.

(A) The intensity of light gradually decreases to zero and remains at zero

(B) The intensity of light gradually increases to a maximum and remains at maximum

(C) There is no change in intensity

(D) The intensity of light is twice maximum and twice zero

69. Polarised glass is used in sun glasses because :

(A) It reduces the light intensity to half an account of polarisation

(B) It is fashionable

(C) It has good colour

(D) It is cheaper

70. A beam of light strikes a glass plate at an angle of incident 60° and reflected light is completely polarised than the refractive index of the plate is:-

(A) 1.5 **(B)** $\sqrt{3}$

(C) $\sqrt{2}$ **(D)** $\frac{3}{2}$

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71. When the angle of incidence on a material is 60°, the reflected light is completely polarized. The velocity of the refracted ray inside the material is (in ms^{-1}) :

(A) 3×10^8 **(B)** $\left(\frac{3}{\sqrt{2}}\right) \times 10^8$

(C) $\sqrt{3} \times 10^8$ **(D)** 0.5×10^8

72. When unpolarized light beam is incident from air onto glass (n=1.5) at the polarizing angle :

(A) Reflected beam is polarized 100 percent

(B) Reflected and refracted beams are partially polarized

(C) The reason for (A) is that almost all the light is reflected

(D) All of the above

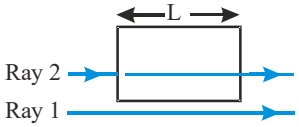
73. The path difference between two interfering waves at a point on the screen is $\lambda/6$. The ratio of intensity at this point and that at the central bright fringe will be : (Assume that intensity due to each slit is same)

(A) 0.853 **(B)** 8.53

(C) 0.75 **(D)** 7.5

74. As shown in arrangement waves with identical wavelengths and amplitudes and that are initially in phase travel through different media, Ray 1 travels through air and Ray 2 through a transparent medium for equal length L, in four different situations. In each situation the two rays reach a common point on the screen. The number of wavelengths in length L is N_2 for Ray 2 and N_1 for Ray 1. In the following table, values of N_1 and N_2 are given for all four situations, The order of the situations according to the intensity of the light at the common point in descending order is

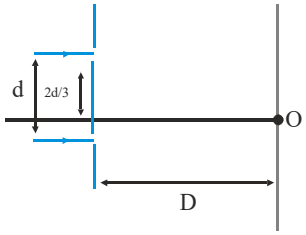
Situations	1	2	3	4
N_1	2.25	1.80	3.00	3.25
N_2	2.75	2.80	3.25	4.00



(A) $I_3 = I_4 > I_2 > I_1$ **(B)** $I_1 > I_3 = I_4 > I_2$

(C) $I_1 > I_2 > I_3 > I_4$ **(D)** $I_2 > I_3 = I_4 > I_1$

75. In the figure shown if a parallel beam of white light is incident on the plane of the slits then the distance of the nearest white spot on the screen from O is : [assume d << D, λ << d]



(A) 0 **(B)** d/2

(C) d/3 **(D)** d/6

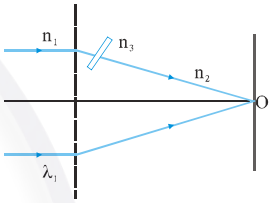
76. In the figure shown in a YDSE, a parallel beam of light is incident on the slits from a medium of refractive index n_1. The wavelength of light in this medium is λ_1. A transparent slab of thickness 't' and refractive index n_3 is put in front of one slit. The medium between the screen and the plane of the slits is n_2. The phase difference between the light waves reaching point O (Symmetrical , relative to the slits) is :

(A) $\frac{2\pi}{n_1\lambda_1}(n_3 - n_2)\, t$

(B) $\frac{2\pi}{\lambda_1}(n_3 - n_2)\, t$

(C) $\frac{2\pi n_1}{n_2\lambda_1}\left(\frac{n_3}{n_2} - 1\right)t$

(D) $\frac{2\pi n_1}{\lambda_1}(n_3 - n_2)\, t$



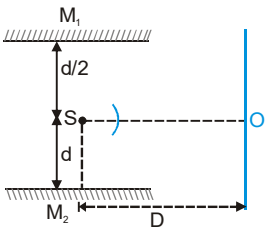
77. M_1 and M_2 are plane mirrors and kept parallel to each other. At point O there will be a maxima for wavelength λ. Light from monochromatic source S of wavelength λ is not reaching directly on the screen. Then λ is : [D >> d >> λ]

(A) $\frac{3d^2}{D}$

(B) $\frac{3d^2}{2D}$

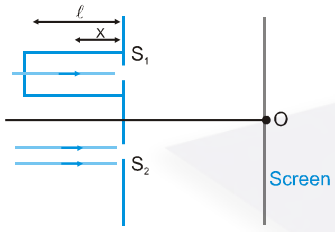
(C) $\frac{d^2}{D}$

(D) $\frac{2d^2}{D}$



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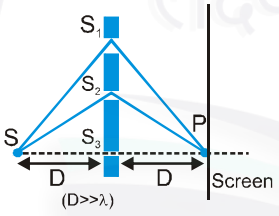
78. In the figure shown, a parallel beam of light is incident on the plane of the slits of Young's double slit experiment. Light incident on the slit, S_1 passes through a medium of variable refractive index $\mu = 1 + ax$ (where 'X' is the distance from the plane of slits as shown), upto a distance 'ℓ' before falling on S_1 . Rest of the space is filled with air. If at 'O' a minima is formed, then the minimum value of the positive constant a (in terms of ℓ and wavelength 'λ' in air) is:



(A) $\frac{\lambda}{\ell}$ **(B)** $\frac{\lambda}{\ell^2}$

(C) $\frac{\ell^2}{\lambda}$ **(D)** none of these

79. A monochromatic light source of wavelength λ is placed at S. Three slits S_1,S_2 and S_3 are equidistant from the source S and the point P on the screen. $S_1P - S_2P = \lambda/6$ and $S_1P - S_3P = 2\lambda/3$. If I be the intensity at P when only one slit is open, the intensity at P when all the three slits are open is–



(A) 3 I **(B)** 5 I

(C) 8 I **(D)** zero

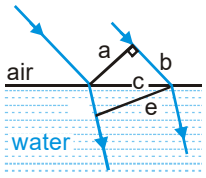
80. Figure shows plane waves refracted from air to water using Huygen's principle a,b,c,d,e are lengths on the diagram. The refractive index of water w.r.t air is the ratio.

(A) a/e

(B) b/e

(C) b/d

(D) d/b

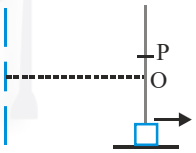


81. Two monochromatic (wavelength = a/5) and coherent sources of electromagnetic waves are placed on the x-axis at the points (2a,0) and (–a,0). A detector moves in a circle of radius R(>>2a) whose centre is at the origin. The number of maximas detected during one circular revolution by the detector are-

(A) 60 **(B)** 15

(C) 64 **(D)** None

82. In a Young's Double slit experiment, first maxima is observed at a fixed point P on the screen. Now the screen is continuously moved away from the plane of slits. The ratio of intensity at point P to the intensity at point O (centre of the screen)-



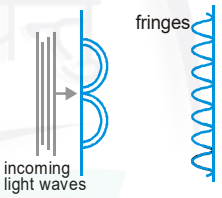
(A) Remains constant

(B) Keeps on decreasing

(C) First decreases and then increases

(D) First decreases and then becomes constant

83. In a Young's double slit experiment, green light is incident on the two slits. The interference pattern is observed on a screen. Which of the following changes would cause the observed fringes to be more closely spaced ?



(A) Reducing the separation between the slits

(B) Using blue light instead of green light

(C) Used red light instead of green light

(D) Moving the light source further away from the slits.

84. A thin slice is cut out of a glass cylinder along a plane parallel to its axis. The slice is placed on a flat glass plate with the curved surface downwards. Monochromatic light is incident normally from the top. The observed interference fringes from the combination do not follow on of the following statements.

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(A) The fringes are straight and parallel to the length of the piece.

(B) The line of contact of the cylindrical glass piece and the glass plate appears dark.

(C) The fringe spacing increases as we go outwards.

(D) The fringes are formed due to the interference of light rays reflected from the curved surface of the cylindrical piece and the top surface of the glass plate.

85. A circular planar wire loop is dipped in a soap solution and after taking it out, held with its plane vertical in air. Assuming thickness of film at the very small, as sunlight falls on the soap film, & observer receive reflected light.

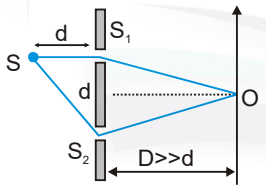
(A) The top portion appears dark while the first colour to be observed as one moves down is red.

(B) The top portion appears violet while the first colour to be observed as one moves down in indigo.

(C) The top potion appears dark while the first colour to be observed as one move down in violet.

(D) The top portion appears dark while the first colour to be observed as one move down depends on the refractive index of the soap solution.

86. To make the central fringe at the centre O, a mica sheet of refractive index 1.5 is introduced. Choose the correct statements (s)-



(A) The thickness of sheet is $2(\sqrt{2}-1)$ d infront of S_1.

(B) The thickness of sheet is $(\sqrt{2}-1)$ d infront of S_2.

(C) The thickness of sheet is $2\sqrt{2}$d infront of S_1.

(D) The thickness of sheet is $(2\sqrt{2}-1)$ d infront of S_1.

87. A parallel coherent beam of light falls on fresnel biprism of refractive index μ and angle α. The fringe width on a screen at a distance D from biprism will be (wavelength = λ)

(A) $\frac{\lambda}{2(\mu-1)\alpha}$ **(B)** $\frac{\lambda D}{2(\mu-1)\alpha}$

(C) $\frac{D}{2(\mu-1)\alpha}$ **(D)** None of these

88. Ratio of intensities of two light waves is given by 4 : 1. The ratio of the amplitudes of the waves is :

(A) 2 : 1 **(B)** 1 : 2

(C) 4 : 1 **(D)** 1 : 4

89. Soap bubble appears coloured due to the phenomenon of :–

(A) interference **(B)** diffraction

(C) dispersion **(D)** reflection

90. The contrast in the fringes in any interference pattern depends on :

(A) Fringe width

(B) Wavelength

(C) Intensity ratio of the sources

(D) Distance between the sources

91. Two coherent monochromatic light beams of intensities I and 4I are superposed; the maximum and minimum possible intensities in the resulting beam are :

(A) 5I and I **(B)** 5I and 3I

(C) 9I and I **(D)** 9I and 3I

92. In a YDSE: D = 1 m, d = 1 mm and λ = 500 n m. The distance of 1000^{th} maxima from the central maxima is:

(A) 0.5 m **(B)** 0.577 m

(C) 0.495 m **(D)** does not exist

93. In a Young's double slit experiment, d = 1 mm, λ = 6000 Å & D = 1 m. The slits produce same intensity on the screen. The minimum distance between two points on the screen having 75 % intensity of the maximum intensity is:

(A) 0.45 mm **(B)** 0.40 mm

(C) 0.30 mm **(D)** 0.20mm

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94. Yellow light emitted by sodium lamp in Young's double slit experiment is replaced by monochromatic blue light of the same intensity :

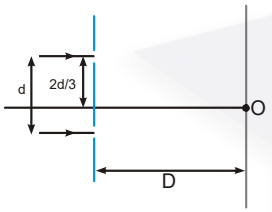
(A) fringe width will decrease.

(B) fringe width will increase.

(C) fringe width will remain unchanged.

(D) fringes will become less intense.

95. In the figure shown if a parallel beam of white light is incident on the plane of the slits then the distance of the nearest white spot on the screen from O is: [assume d << D, λ << d]



(A) 0 **(B)** d/2

(C) d/3 **(D)** d/6

96. The Young's double slit experiment is performed with blue and with green light of wavelengths 4360 Å and 5460 Å respectively. If X is the distance of 4th maximum from the central one, then :

(A) X(blue) = X(green)

(B) X(blue) > X(green)

(C) X(blue) < X(green)

(D) $\frac{X(blue)}{X(green)} = \frac{5460}{4360}$

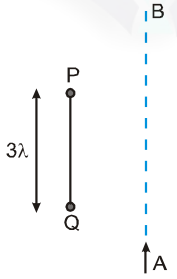
97. Two coherent light sources each of wavelength λ are separated by a distance 3λ. The total number of minima formed on line AB which runs from $-\infty$ to $+\infty$ is:

(A) 2

(B) 4

(C) 6

(D) 8



98. A two slit Young's interference experiment is done with monochromatic light of wavelength 6000 Å. The slits are 2 mm apart. The fringes are observed on a screen placed 10 cm away from the slits. Now a transparent plate of thickness 0.5 mm is placed in front of one of the slits and it is found that the interference pattern shifts by 5 mm. The refractive index of the transparent plate is :

(A) 1.2 **(B)** 0.6

(C) 2.4 **(D)** 1.5

99. In a YDSE both slits produce equal intensities on the screen. A 100 % transparent thin film is placed in front of one of the slits. Now the intensity of the geometrical centre of system on the screen becomes 75 % of the previous intensity. The wavelength of the light is 6000Å and $\mu_{glass} = 1.5$. The thickness of the film cannot be:

(A) 0.2 μm **(B)** 1.0 μm

(C) 1.4 μm **(D)** 1.6 μm

100. A slit of size 0.15 cm is placed at 2.1 m from a screen. On illuminated it by a light of wavelength 5×10^{-5} cm. The width of diffraction pattern will be:-

(A) 70 mm **(B)** 0.14 mm

(C) 1.4 cm **(D)** 0.14 cm

101. White light is incident normally on a glass plate (in air) of thickness 500 nm and refractive index of 1.5. The wavelength (in nm) in the visible region (400 nm - 700nm) that is strongly reflected by the plate is:

(A) 450 **(B)** 600

(C) 400 **(D)** 500

102. If the ratio of the intensity of two coherent sources is 4 then the visibility $[(I_{max} - I_{min})/(I_{max} + I_{min})]$ of the fringes is

(A) 4 **(B)** 4/5

(C) 3/5 **(D)** 9

103. In a Young's double slit experiment the slit is illuminated by a source having two wavelengths of 400 nm and 600 nm. If distance between slits, d = 1mm, and distance between the plane of the slit and screen, D = 10 m then the smallest distance from the central maximum where there is complete darkness is :

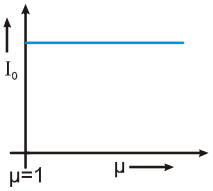
(A) 2mm **(B)** 3mm

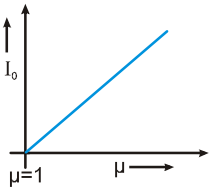
(C) 12 mm

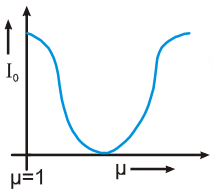
(D) there is no such point

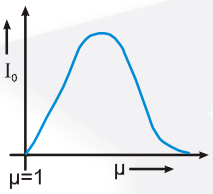
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104. In a YDSE experiment if a slab whose refractive index can be varied is placed in front of one of the slits then the variation of resultant intensity at mid-point of screen with 'μ' will be best represented by ($\mu \geq 1$).[Assume slits of equal width and there is no absorption by slab]

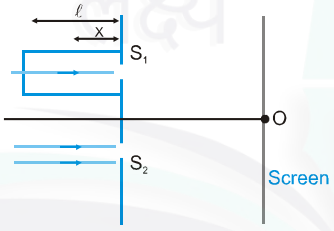
(A) 

(B) 

(C) 

(D) 

105. In the figure shown, a parallel beam of light is incident on the plane of the slits of a Young's double slit experiment. Light incident on the slit, S_1 passes through a medium of variable refractive index $\mu = 1 + ax$(where 'x' is the distance from the plane of slits as shown), upto a distance 'ℓ' before falling on S_1. Rest of the space is filled with air. If at 'O' a minima is formed, then the minimum value of the positive constant a (in terms of ℓ and wavelength 'λ' in air) is



(A) $\frac{\lambda}{\ell}$

(B) $\frac{\lambda}{\ell^2}$

(C) $\frac{\ell^2}{\lambda}$

(D) None of these

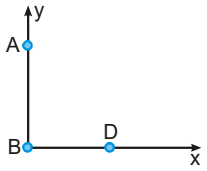
106. An interference is observed due to two coherent sources 'A' & 'B' having phase constant zero separated by a distance 4 λ along the $y-$axis where λ is the wavelength of the source. A detector D is moved on the positive $x-$axis. The number of points on the $x-$axis excluding the points $x = 0$ & $x = \infty$ at which maximum will be observed is

(A) three

(B) four

(C) two

(D) infinite



107. If the first minima in a Young's slit experiment occurs directly infront of one of the slits. (distance between slit & screen D = 12 cm and distance between slits d = 5 cm) then the wavelength of the radiation used is :

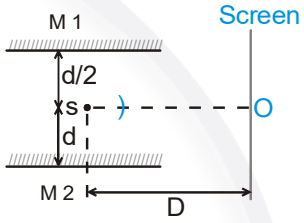
(A) 2 cm only

(B) 4 cm only

(C) 2m, $\frac{2}{3}$ cm, $\frac{2}{5}$ cm

(D) 4cm, $\frac{4}{3}$ cm, $\frac{4}{5}$ cm

108. M1 and M2 are two plane mirrors which are kept parallel to each other as shown. There is a point 'O' on perpendicular screen just infront of 'S'. What should be the wavelength of light coming from monchromatic source 'S'. So that a maxima is formed at 'O' due to interference of reflected light from both the mirrors. [Consider only 1st reflection]. [$D >> d, d >> \lambda$]



(A) $\frac{3d^2}{D}$

(B) $\frac{3d^2}{2D}$

(C) $\frac{d^2}{D}$

(D) $\frac{2d^2}{D}$

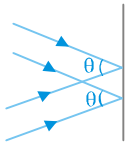
109. Two parallel beams of light of wavelength λ inclined to each other at angle θ (<<1) are incident on a plane at near normal incidence. The fringe width will be :

(A) $\frac{\lambda}{2\theta}$

(B) $\frac{2\lambda}{\theta}$

(C) $\frac{\lambda}{\theta}$

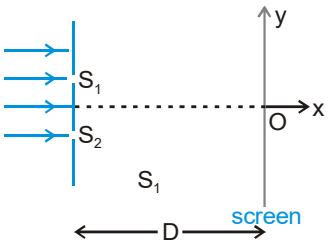
(D) $2\lambda \sin\theta$



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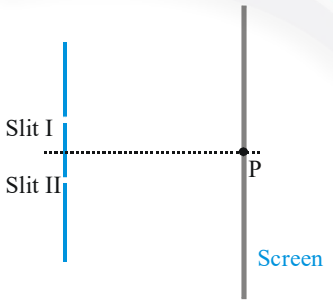
Exercise # 3 PART - 1 MATRIX MATCH COLUMN

1. A monochromatic parallel beam of light of wavelength λ is incident normally on the plane containing slits S_1 and S_2. The slits are of unequal width such that intensity only due to one slit on screen is four times that only due to the other slit. The screen is placed perpendicular to x-axis as shown. The distance between slits is d and that between screen and slit is D. Match the statements in column-I with results in column-II. ($S_1S_2 << D$ and $\lambda << S_1S_2$)



Column-I		Column-II	
(A)	The distance between two points on screen having equal intensities, such that intensity at those points is $\frac{1}{9}$ th of maximum intensity.	(P)	$\frac{D\lambda}{3d}$
(B)	The distance between two points on screen having equal intensities, such that intensity at those points is $\frac{3}{9}$ th of maximum intensity.	(Q)	$\frac{D\lambda}{d}$
(C)	The distance between two points on screen having equal intensities, such that intensity at those points is $\frac{5}{9}$ th of maximum intensity.	(R)	$\frac{2D\lambda}{d}$
(D)	The distance between two points on screen having equal intensities, such that intensity at those points is $\frac{7}{9}$ th of maximum intensity.	(S)	$\frac{3D\lambda}{d}$

2. A double slit interference pattern is produced on a screen, as shown in the figure, using monochromatic light of wavelength 500nm. Point P is the location of the central bright fringe, that is produced when light waves arrive in phase without any path difference. A choice of three strips A, B and C of transparent materials with different thicknesses and refractive indices is available, as shown in the table. These are placed over one or both of the slits, singularly or in conjunction, causing the interference pattern to be shifted across the screen from the original pattern. In the column–I, how the strips have been placed, is mentioned whereas in the column–II, order of the fringe at point P on the screen that will be produced due to the placement of the strips(s), is shown. Correctly match both the column.

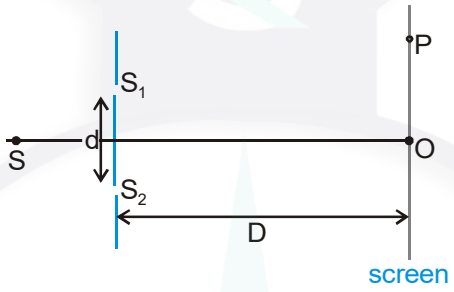


Film	A	B	C
Thickness (in μm)	5	1.5	0.25
Refractive index	1.5	2.5	2

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	Column I		Column II
(A)	Only strip B is placed over slit–I	(P)	First Bright
(B)	Strip A is placed over slit–I and strip C is placed over slit–II	(Q)	Fourth Dark
(C)	Strip A is placed over the slit–I and strip B and strip C are placed over the slit–II in conjunction	(R)	Fifth Dark
(D)	Strip A and strip C are placed over slit–I (in conjuction) and strip B is placed over Slit–II	(S)	Central Bright
		(T)	Fifth bright

3. In a typical Young's double slit experiment, S_1 and S_2 are identical slits and equidistant from a point monochromatic source S of light having wavelength λ. The distance between slits is represented by d and that between slits and screen is represented by D. P is a fixed point on the screen at a distance $y = \frac{\lambda D_o}{2d_o}$ from central order bright on the screen: where D_o, d_o are initial values of D and d respectively. In each statement of column-I some changes are made to above mentioned situation. The distance between the slits and the source is very large. The effect of corresponding changes is given in column-II. Match the statements in column-I with resulting changes in column-II.



	Column-I		Column-II
(A)	The distance d between the slits is doubled keeping distance between slits and screen fixed	(P)	fringe width increases .
(B)	The distance D between slit and screen is doubled by shifting screen to right	(Q)	Magnitude of optical path difference between interfering waves at P will decrease.
(C)	The width of slit S_1 is decreased (such that intensity of light due to slit S_1 on screen decreases) and the distance D between slit and screen is doubled by shifting screen to right	(R)	Magnitude of optical path difference between interfering waves at P will increase.
(D)	The whole setup is submerged in water of refractive index $\frac{4}{3}$. (neglecting absorption in medium)	(S)	The intensity at P will increase

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Exercise # 3 PART - 2 ASSERTION & REASONING

These questions contains, Statement I (assertion) and Statement II (reason).

(A) If both assertion and reason are true and the reason is the correct explanation of the assertion.

(B) If both assertion and reason are true but reason is not the correct explanation of the assertion.

(C) If assertion is true but reason is false.

(D) If assertion is false but reason is true.

(E) If the assertion and reason both are false.

1. **Assertion :** In YDSE, if a thin film is introduced in front of the upper slit, then the fringe pattern shifts in the downward direction.

Reason : In YDSE if the slit widths are unequal, the minima will be completely dark

2. **Assertion :** If white light is used in YDSE, then the central bright fringe will be white

Reason : In case of white light used in YDSE, all the wavelengths produce their zero order maxima at the same position

3. **Assertion :** In YDSE, interference pattern disappears when one of the slits is closed.

Reason : In YDSE, interference occurs due to super–imposition of light wave from two coherent sources.

4. **Assertion :** The phase difference between any two points on a wave front is zero.

Reason : Light from the source reaches every point of the wave front at the same time.

5. **Assertion :** In YDSE central maxima means the maxima formed with zero optical path difference. It may be formed anywhere on the screen.

Reason : In an interference pattern, whatever energy disappears at the minimum, appears at the maximum.

6. **Assertion :** Two coherent point sources of light having nonzero phase difference are seperated by small distance. Then on the perpendicular bisector of line segment joining both the point sources, constructive interference cannot be obtained.

Reason : For two waves from coherent point sources to interfere constructively at a point, the magnitude of their phase difference at that point must be $2m\pi$ (where m is a nonnegative integer) .

7. **Assertion :** No interference pattern is detected when two coherent sources are infinitely close to each other.

Reason : The fringe width is inversely proportional to the distance between the two slits.

8. **Assertion :** As light travels from one medium to another, the frequency of light doesn't change.

Reason : Frequency is the characteristic of source.

9. **Assertion :** When a light wave travels from a rarer to a denser medium, it loses speed. The reduction in speed imply a reduction in energy carried by the light wave.

Reason : The energy of a wave is proportional to velocity of wave.

10. **Assertion :** A narrow pulse of light is sent through a medium. The pulse will retain its shape as it travels through the medium.

Reason : A narrow pulse is made of harmonic waves with a large range of wavelengths.

11. **Assertion :** No interference pattern is detected when two coherent sources are infinitely close to each other.

Reason : The fringe width is inversely proportional to the distance between the two slits.

12. **Assertion :** Newton's rings are formed in the reflected system. When the space between the lens and the glass plate is filled with a liquid of refractive index greater than that of glass, the central spot of the pattern is dark.

Reason : The reflection is Newton's ring cases will be from a denser to a rarer medium and the two interfering rays are reflected under similar conditions.

13. **Assertion :** The film which appears bright in reflected system will appear dark in the transmitted light and vice-versa.

Reason : The conditions for film to appear bright or dark in reflected light are just reverse to those in the transmitted light.

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14. **Assertion :** For best contrast between maxima and minima in the interference pattern of Young's double slit experiment, the intensity of light emerging out of the two slits should be equal.

Reason : The intensity of interference pattern is proportional to square of amplitude.

15. **Assertion :** In Young's double slit experiment, the fringes become indistinct if one of the slits is covered with cellophane paper.

Reason : The cellophane paper decrease the wavelength of light.

16. **Assertion :** The unpolarised light and polarised light can be distinguished from each other by using polaroid.

Reason : A polaroid is capable of producing plane polarised beams of light.

17. **Assertion :** Nicol prism is used to produce and analyse plane polarised light.

Reason : Nicol prism reduces the intensity of light to zero.

18. **Assertion :** In everyday life the Doppler's effect is observed readily for sound waves than light waves.

Reason : Velocity of light is greater than that of sound.

19. **Assertion :** In Young's experiment, the fringe width for dark fringes is different from that for white fringes.

Reason : In Young's double slit experiment the fringes are performed with a source of white light, then only black and bright fringes are observed.

20. **Assertion :** Coloured spectrum is seen when we look through a muslin cloth.

Reason : It is due to the diffraction of white light on passing through fine slits.

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Exercise # 4 PART - 1 PREVIOUS YEAR (NEET/AIPMT)

1. Which of the following phenomena exhibits particle nature of light?

(A) Interference **(B)** Diffraction
(C) Polarisation **(D)** Photoelectric effect

2. Transmission of light in optical fibre is

(A) scattering
(B) diffraction
(C) polarisation
(D) multiple total internal reflections

3. A beam of light composed of red and green rays in incident obliquely at a point on the face of a rectangular glass slab. when coming out on the opposite parallel face, the red and green rays emerge from

(A) two points propagating in two different non-parallel directions
(B) two points propagating in two different parallel directions
(C) one point propagating in two different directions
(D) one point propagating in the same direction

4. A telescope has an objective lens of 10 cm diameter and is situated at a distance of one kilometre from two objects. The minimum distance between these two objects, which can be resolved by the telescope, when the mean wavelength of light is 5000 Å, is of the order of

(A) 0.5 m **(B)** 5 m
(C) 5 mm **(D)** 5 cm

5. The angular resolution of a 10 cm diameter telescope at a wavelength of 5000 Å is of the order of

(A) 10^{6} rad **(B)** 10^{-2} rad
(C) 10^{-4} rad **(D)** 10^{-6} rad

6. Which of the following is not due to total internal reflection?

(A) Difference between apparent and real depth of a pond
(B) Mirage on hot summer days
(C) Brilliance of dimond
(D) Working of optical fibre

7. In Young's double slit experiment, the slits are 2 mm apart and are illuminated by photons of two wavelengths $\lambda_1 = 12000$ Å and $\lambda_2 = 10000$ Å. At what minimum distance from the common central bright fringe on the screen 2 m from the slit will a bright fringe from one interference pattern coincide with a bright fringe from the other?

(A) 8 mm **(B)** 6 mm
(C) 4 mm **(D)** 3 mm

8. If the focal length of objective lens is increased, then magnifying power of

(A) microscope will increase but that of telescope decrease
(B) microscope and telescope both will increase
(C) microscope and telescope both will decrease
(D) microscope will decrease but that of telescope will increase

9. In the Young's double-slit experiment, the intensity of light at a point on the screen (where the path difference is λ) is K, (λ being the wavelength of light used). The intensity at a point where the path difference is λ/4, will be

(A) K **(B)** K/4
(C) K/2 **(D)** zero

10. A beam of light of λ = 600 nm from a distant source falls ona single slit 1 nm wide and the resulting diffraction pattern is observed on a screen 2 m away. The distance between first dark fringes on either side of the central bright fringe is

(A) 1.2 cm **(B)** 1.2 mm
(C) 2.4 cm **(D)** 2.4 mm

11. The Young's modulus of steel is twice that of brass. Two wires of same length and of same area of cross-section, one of steel and another of brass are suspended from the same roof. It we want the lower ends of the wires to be at the same level, then the weight added to the steel and brass wires must be in the ratio of

(A) 1 : 2 **(B)** 2 : 1
(C) 4 : 1 **(D)** 1 : 1

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12. At the firt minimum adjacent to the central maximum of a single slit diffraction pattern, wavelet from the edge of the slit and the wavelet from the midpoint of the slit is

(A) $\frac{\pi}{4}$ radian (B) $\frac{\pi}{2}$ radian

(C) π radian (D) $\frac{\pi}{8}$ radian

13. Two slits in Youngs experiment have widths in the ratio 1 : 25. The ratio of intensity at the maxima and minima in the interference pattern $\frac{I_{max}}{I_{min}}$ is

(A) $\frac{9}{4}$ (B) $\frac{121}{49}$

(C) $\frac{49}{121}$ (D) $\frac{4}{9}$

14. In an astronomical telescope in normal adjustment a straight black line of length L is drawn on inside part of objective lens. The eye-piece forms a real image of this line. the length

(A) $\frac{L}{I}+1$ (B) $\frac{L}{I}-1$

(C) $\frac{L+1}{L-1}$ (D) $\frac{L}{I}$

15. The refracting angle of a prism is A, and refractive index of the matrial of the prism is cot (A/2). The angle of minimum deviation is

(A) $180°-3A$ (B) $180°-2A$

(C) $90°-C$ (D) $180°+2A$

16. In a double slit experiment, the two slits are 1 mm apart and the screen is placed 1 m away. A monochromatic light of wavelength 500 nm is used. What will be the width of each slit for obtaining ten maxima of double slit within the central maxima of single slit pattern?

(A) 0.2 mm (B) 0.1 mm

(C) 0.5 mm (D) 0.02 mm

17. For a parallel beam of monochromatic light of wavelength 'λ' diffraction is produced by a single slit whose width 'a' is of the order of the wavelength of the light. If 'D' is the distance of the screen from the slit, the width of the central maxima will be

(A) $\frac{2D\lambda}{a}$ (B) $\frac{D\lambda}{a}$

(C) $\frac{Da}{\lambda}$ (D) $\frac{2Da}{\lambda}$

18. A linear aperture whose width is 0.02 cm is placed immediately in front of a lens of focal length 60 cm. The aperture is illuminated normally by a parallel beam of wavelength 5×10^{-5} cm. The distance of the first dark band of the diffraction pattern from the centre of the screen is

(A) 0.10 cm (B) 0.25 cm

(C) 0.20 cm (D) 0.15 cm

19. The interference pattern is obtained with two coherent light sources of intensity ratio n. In the interference pattern, the ratio $\frac{I_{max}-I_{min}}{I_{min}+I_{min}}$ will be

(A) $\frac{\sqrt{n}}{n+1}$ (B) $\frac{2\sqrt{n}}{n+1}$

(C) $\frac{\sqrt{n}}{(n+1)^2}$ (D) $\frac{2\sqrt{n}}{(n+1)^2}$

20. A astronomical telescope has objective and eyepiece of focal lengths 40 cm 4 cm respectively. To view an object 200 cm away from the objective, the lenses must be separated by a distance

(A) 46.0 cm (B) 50.0 cm

(C) 54.0 cm (D) 37.3 cm

21. In a diffraction pattern due to a single slit of width a, the first minimum is observed at an angle 30° when light of wavelength 5000Å is incident on the slit. The first secondary maximum is observed at an angle of

(A) $\sin^{-1}\left(\frac{2}{3}\right)$ (B) $\sin^{-1}\left(\frac{1}{2}\right)$

(C) $\sin^{-1}\left(\frac{3}{4}\right)$ (D) $\sin^{-1}\left(\frac{1}{4}\right)$

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22. The intensity at the maximum in a Young's double slit experiment is I_0. Distance between two slits is d = 5λ, where λ is the wavelength of light used in the experiment. What will be the intensity infront of one of the slits on the screen placed at a distance D = 10 d?

(A) $\frac{I_0}{4}$ (B) $\frac{3}{4}I_0$

(C) $\frac{I_0}{2}$ (D) I_0

23. Two polaroids P_1 and P_2 are placed with their axis perpendicular to each other. Unpolarised light I_0 is incident on P_1. A third polaroid P3 is kept in between P_1 and P_2 such that its axis makes an angle 45° with that of P_1. The intensity of transmitted light through P_2 is

(A) $\frac{I_0}{2}$ (B) $\frac{I_0}{4}$

(C) $\frac{I_0}{8}$ (D) $\frac{I_0}{16}$

24. Young's double slit experiment is first performed in air and then in a medium other than air. It is found that 8th bright fringe in the medium lies where 5th dark frigne lies in air. The refractive index of the medium is nearly

(A) 1.25 (B) 1.59

(C) 1.69 (D) 1.78

25. A beam of light from a source L is incident normally on a plane mirror fixed at a certain distance x from the source. The beam is reflected back as a spot on a scale placed just above the source L. When the mirror rotated through a small angle θ, the spot of the ligth is found to move through a distance y on the scale. The angle θ is given by

(A) $\frac{y}{2x}$ (B) $\frac{y}{x}$

(C) $\frac{x}{2y}$ (D) $\frac{x}{y}$

26. The ratio of resolving powers of an optical microscope for two wavelengths $\lambda_1 = 4000$ Å and $\lambda_2 = 6000$ Å is [N

(A) 8 : 27 (B) 9 : 4

(C) 3 : 2 (D) 16 : 81

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Exercise # 4 PART - 2 PREVIOUS YEAR (AIIMS)

1. Two coherent monochromatic light beams of amplitude 3 and 5 units are superposed. The maximum and minimum possible intensities in the resulting beams are in the ratio
(A) 4 : 2 (B) 16 : 1
(C) 8 : 2 (D) 4 : 2

2. If red light is replaced by white light then width of diffraction pattern will
(A) increases
(B) decreases
(C) a central white band is obtained
(D) no effect

3. Golden view of sea shell is due to
(A) diffraction (B) polarisation
(C) dispersion (D) reflection.

4. What is the path difference for destructive interference ?
(A) $n\lambda$ (B) $\frac{(n+1)\lambda}{2}s$
(C) $n(\lambda+1)$ (D) $\frac{(2n+1)\lambda}{2}$

5. A double slit experiment is performed with light of wavelength 500 nm. A thin film of thickness 2 μm and refractive index 1.5 is introduced in the path of the upper beam. The location of the central maximum will
(A) remain unshifted
(B) shift downward by nearly two fringes
(C) shift upward by nearly two fringes
(D) shift downward by 10 fringes.

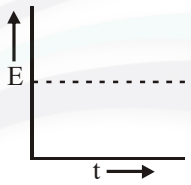
6. A monochromatic beam of light is used for the formation of fringes on the screen by illuminating the two slits in the Young's double slit interference experiment. When a thin film of mica is interposed in the path of one of the interfering beams then
(A) the fringe width increases
(B) the fringe width decreases
(C) the fringe width remains the same but the pattern shifts
(D) the fringe pattern disappears.

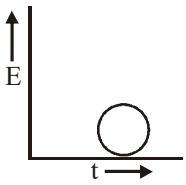
7. When a compact disc is illuminated by a source of white light, coloured lines are observed. This is due to
(A) dispersion (B) diffraction
(C) interference (D) refraction.

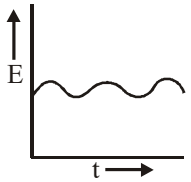
8. When exposed to sunlight, thin films of oil on water often exhibit brilliant colours due to the phenomenon of
(A) interference
(B) diffraction
(C) dispersion
(D) polarisation

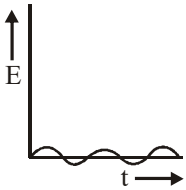
9. In case of linearly polarised light, the magnitude of the electric field vector
(A) does not change with time
(B) varies periodically with time
(C) increases and decreases linearly with time
(D) is parallel to the direction of propagation.

10. According to Hubble's law, the redshift (Z) of a receding galaxy and its distance r from earth are related as
(A) $Z \propto r$ (B) $Z \propto 1/r$
(C) $Z \propto 1/r^2$ (D) $Z \propto r^{3/2}$

11. Which of the following diagrams represents the variation of electric field vector with time for a circularly polarized light ?
(A) 

(B) 

(C) 

(D) 

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12. In Young's double slit experiment, the distance between two slits is made three times then the fringe width will become

(A) 9 times (B) 1/9 times
(C) 3 times (D) 1/3 times

13. Light is incident normally on a diffraction grating through which the first diffraction is seen at 32°. In this case the second order diffraction will be

(A) 80°
(B) at 64°
(C) at 48°
(D) there is no second order diffraction

14. Which out of following, cannot produce two coherent sources ?

(A) Lloyd's mirror (B) Fresnel biprism
(C) Young's double slit (D) Prism

15. In Young's double slit experiment, the two slits act as coherent sources of equal amplitude a and of wavelength λ. In another experiment with the same set up, the two slits are sources of equal amplitude a and wavelength λ, but are incoherent. The ratio of intensities of light at the mid point of the screen in the first case to that in the second case is

(A) 2 : 1 (B) 1 : 2
(C) 3 : 4 (C) 4 : 3

16. In an interference, the intensity of two interfering waves are I and 4I respectively. They produce intensity at two points A and B with phase angles of $\pi/2$ and π respectively. Then difference in between them is

(A) I (B) 2I
(C) 4I (D) 5I

17. In a single slit diffraction with $\lambda = 500$ nm and a lens of diameter 0.1 mm then width of central maxima, obtain on screen at a distance of 1 m will be

(A) 5 mm (B) 1 mm
(C) 10 mm (D) 2.5 mm

18. In Young's double slit experiment, fringe order is represented by m, then fringe width is

(A) Independent of m.
(B) Directly proportional to m.
(C) Directly proportional to (2m + 1).
(D) Inversely proportional to (2m + 1).

19. A light ray is incident on a glass slab, it is partially reflected and partially transmitted. Then the reflected ray is

(A) completely polarised and highly intense.
(B) partially polarised and poorly intense.
(C) partially polarised and highly intense.
(D) completely polarised and poorly intense.

20. Polaroid glass is used in sun glasses because

(A) it reduces the light intensity to half on account of polarisation
(B) it is fashionable
(C) it has good colour
(D) it is cheaper

21. In a Young's double slit experiment the spacing between the slits is 0.3 mm and the screen is kept at a distance of 1.5 m. The second bright fringe is found 6 mm from the central fringe. The wavelength of the light used in the experiment is

(A) 625 nm (B) 600 nm
(C) 550 nm (D) 500 nm

22. In a Young's double slit experiment the intensity of light when slit is a distance λ from central is I. What will be the intensity at the distance of slit is $\frac{\lambda}{6}$?

(A) $\frac{I}{6}$ (B) $\frac{I}{12}$
(C) $\frac{3}{4}I$ (D) $\frac{I}{8}$

23. Resolving power of reflecting microscope increases with

(A) decrease in wavelength of incident light
(B) increase in wavelength of incident light
(C) increase in diameter of objective lens
(D) none of these

24. In a certain double slit experimental arrangement, interference fringes of width 1 mm each are observed when light of wavelength 5000 Å is used. Keeping the setup unaltered, if the source is replaced by another of wavelength 6000 Å, the fringe width will be

(A) 1.2 mm (B) 0.5 mm
(C) 1 mm (D) 1.5 mm

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25. In a Fraunhofer diffraction at single slit of width d with incident light of wavelength 5500 Å, the first minimum is observed at angle 30°. The first secondary maximum is observed at an angle θ =

(A) $\sin^{-1}\frac{1}{\sqrt{2}}$ (B) $\sin^{-1}\frac{1}{4}$

(C) $\sin^{-1}\frac{3}{4}$ (D) $\sin^{-1}\frac{\sqrt{3}}{2}$

26. The intensity ratio of the maxima and minima in an interference pattern produced by two coherent sources of light is 9 : 1. The intensities of the used light sources are in ratio

(A) 3 : 1 (B) 4 : 1

(C) 9 : 1 (D) 10 : 1

27. The two coherent sources with intensity ratio β produce interference. The fringe visibility will be

(A) $\frac{2\sqrt{\beta}}{1+\beta}$ (B) 2β

(C) $\frac{2}{(1+\beta)}$ (D) $\frac{\sqrt{\beta}}{1+\beta}$

ASSERTION AND REASON

28. **Assertion :** Skiers uses glasses.

Reason : Light reflected by snow is partially polarised.

29. **Assertion :** When tiny circular obstacle is placed in the path of light from some distance, a bright spot is seen at the centre of the shadow of the obstacle.

Reason : Destructive interference occurs at the centre of the shadow.

30. **Assertion :** Coloured spectrum is seen when we look through a muslin cloth.

Reason : It is due to the diffraction of white light on passing through fine slits.

31. **Assertion :** thin films such a soap bubble or a thin layer of oil on water show beautiful colours when illuminated by white light.

Reason : Light reflected from the upper surface of the thin film due to the interference.

32. **Assertion :** At the first glance, the top surface of the Morpho butterfly's wing appears a beautiful blue-green. If the wing moves the colour changes.

Reason : Different pigments in the wing reflect light at different angles.

33. **Assertion :** The clouds in sky generally appear to be whitish.

Reason : diffraction due to clouds is efficient in equal measure at all wavelengths.

34. **Assertion :** The resolving power of a telescope is more if the diameter of the objective lens is more.

Reason : Objective lens of large diameter collects more light.

35. **Assertion :** Standard optical diffraction gratings can not be used for discriminating between different X-ray wavelengths.

Reason : The grating spacing is not of the order of X-ray wavelengths.

36. **Assertion :** When light ray is incident at polarising angle on glass, refracted light is partially polarised.

Reason : The intensity of light decreases in polarisation.

37. **Assertion :** Resolving power of a telescope depends only on wavelength.

Reason : This is proportional to square of wavelength.

38. **Assertion :** The resolving power of a telescope is more if the diameter of the objective lens is more.

Reason : Objective lens of large diameter collects more light.

39. **Assertion :** The frequencies of incident, reflected and refracted beam of monochromatic light passing from one medium to another are the same.

Reason : The incident, the reflected and refracted rays are coplanar.

40. **Assertion :** In YDSE bright and dark fringe are equally spaced.

Reason : It only depends upon phase difference.

41. **Assertion :** Electron microscope has more resolving power than optical microscope.

Reason : We can control the energy of electron.

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MOCK TEST

STRAIGHT OBJECTIVE TYPE

1. Two light waves are given by, $E_1 = 2\sin(100\pi t - kx + 30^\circ)$ and $E_2 = 3\cos(200\pi t - k'x + 60^\circ)$
The ratio of intensity of first wave to that of second wave is :

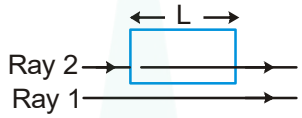
(A) $\frac{2}{3}$ **(B)** $\frac{4}{9}$ **(C)** $\frac{1}{9}$ **(D)** $\frac{1}{3}$

2. The wavefront of a light beam is given by the equation $x + 2y + 3z = c$, (where c is arbitrary constant) then the angle made by the direction of light with the y-axis is :

(A) $\cos^{-1}\frac{1}{\sqrt{14}}$ **(B)** $\cos^{-1}\frac{2}{\sqrt{14}}$ **(C)** $\sin^{-1}\frac{1}{\sqrt{14}}$ **(D)** $\sin^{-1}\frac{2}{\sqrt{14}}$

3. If the ratio of the intensity of two coherent sources is 4 then the visibility $[(I_{max} - I_{min})/(I_{max} + I_{min})]$ of the fringes is
(A) 4 **(B)** 4/5 **(C)** 3/5 **(D)** 9

4. As shown in arrangement waves with identical wavelengths and amplitudes and that are initially in phase travel through different media, Ray 1 travels through air and Ray 2 through a transparent medium for equal length L, in four different situations. In each situation the two rays reach a common point on the screen. The number of wavelengths in length L is N_2 for Ray 2 and N_1 for Ray 1. In the following table, values of N_1 and N_2 are given for all four situations, The order of the situations according to the intensity of the light at the common point in descending order is :



(A) $I_3 = I_4 > I_2 > I_1$ **(B)** $I_1 > I_3 = I_4 > I_2$ **(C)** $I_1 > I_2 > I_3 > I_4$ **(D)** $I_2 > I_3 = I_4 > I_1$

5. If the distance between the first maxima and fifth minima of a double slit pattern is 7mm and the slits are separated by 0.15 mm with the screen 50 cm from the slits, then wavelength of the light used is :
(A) 600 nm **(B)** 525 nm **(C)** 467 nm **(D)** 420 nm

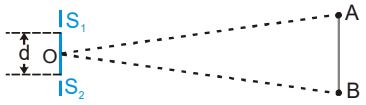
6. In a YDSE: D = 1 m, d = 1 mm and λ = 5000 nm. The distance of 100th maxima from the central maxima is:

(A) $\frac{1}{2}$ m **(B)** $\frac{\sqrt{3}}{2}$ m **(C)** $\frac{1}{\sqrt{3}}$ m **(D)** does not exist

7. Let S_1 and S_2 be the two slits in Young's double slit experiment. If central maxima is observed at P and angle $\angle S_1PS_2 = \theta$, then the fringe width for the light of wavelength λ will be. (Assume θ to be a small angle)
(A) λ/θ **(B)** $\lambda\theta$ **(C)** $2\lambda/\theta$ **(D)** $\lambda/2\theta$

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8. Figure shows two coherent sources S_1, S_2 vibrating in same phase. AB is an irregular wire lying at a far distance from the sources S_1 and S_2. Let $\frac{\lambda}{d} = 10^{-3}$. $\angle BOA = 0.12°$. How many bright spots will be seen on the wire, including points A and B.

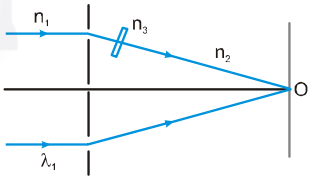


(A) 2 **(B)** 3 **(C)** 4 **(D)** more than 4

9. The path difference between two interfering waves at a point on the screen is $\lambda/6$. The ratio of intensity at this point and that at the central bright fringe will be : (Assume that intensity due to each slit in same)

(A) 0.853 **(B)** 8.53 **(C)** 0.75 **(D)** 7.5

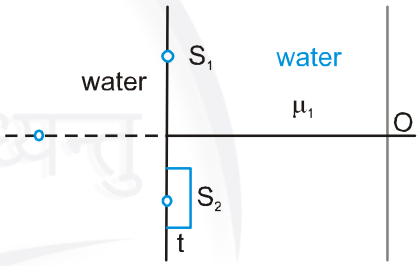
10. In the figure shown in a YDSE, a parallel beam of light is incident on the slits from a medium of refractive index n_1. The wavelength of light in this medium is λ_1. A transparent slab of thickness 't' and refractive index n_3 is put infront of one slit. The medium between the screen and the plane of the slits is n_2. Find the phase difference between the light waves reaching point 'O' (symmetrical, relative to the slits)



(A) $\frac{2\pi}{n_1 \lambda_1}(n_3 - n_2)t$ **(B)** $\frac{2\pi}{\lambda_1}(n_3 - n_2)t$

(C) $\frac{2\pi n_1}{n_2 \lambda_1}\left(\frac{n_3}{n_2} - 1\right)t$ **(D)** $\frac{2\pi n_1}{\lambda_1}(n_3 - n_2)t$

11. A Young's double slit experiment is conducted in water (μ_1) as shown in the figure, and a glass plate of thickness t and refractive index μ_2 is placed in the path of S_2. The magnitude of the phase difference at O is : (Assume that 'λ' is the wavelength of light in air)



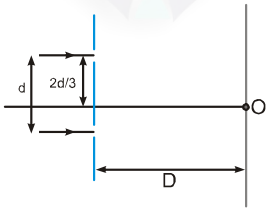
(A) $\left|\left(\frac{\mu_2}{\mu_1} - 1\right)t\right|\frac{2\pi}{\lambda}$

(B) $\left|\left(\frac{\mu_1}{\mu_2} - 1\right)t\right|\frac{2\pi}{\lambda}$

(C) $|(\mu_2 - \mu_1)t|\frac{2\pi}{\lambda}$

(D) $|(\mu_2 - 1)t|\frac{2\pi}{\lambda}$

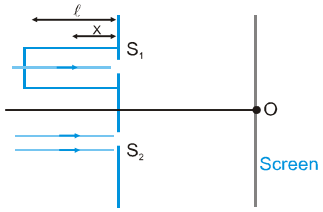
12. In the figure shown if a parallel beam of white light is incident on the plane of the slits then the distance of the nearest white spot on the screen from O is: [assume d << D, λ << d]



(A) 0 **(B)** d/2 **(C)** d/3 **(D)** d/6

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13. In the figure shown, a parallel beam of light is incident on the plane of the slits of a Young's double slit experiment. Light incident on the slit, S_1 passes through a medium of variable refractive index $\mu = 1 + ax$(where 'x' is the distance from the plane of slits as shown), upto a distance 'ℓ' before falling on S_1. Rest of the space is filled with air. If at 'O' a minima is formed, then the minimum value of the positive constant a (in terms of ℓ and wavelength 'λ' in air) is :

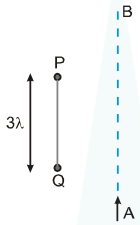


(A) $\frac{\lambda}{\ell}$ **(B)** $\frac{\lambda}{\ell^2}$ **(C)** $\frac{\ell^2}{\lambda}$ **(D)** None of these

14. Interference fringes were produced using white light in a double slit arrangement. When a mica sheet of uniform thickness of refractive index 1.6 (relative to air) is placed in the path of light from one of the slits, the central fringe moves through some a distance. This distance is equal to the width of 30 interference bands if light of wavelength 4800 Å is used. The thickness (in 1 μm) of mica is:

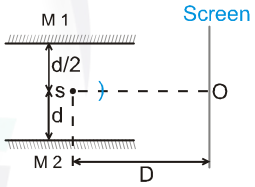
(A) 90 **(B)** 12 **(C)** 14 **(D)** 24

15. Two coherent light sources each of wavelength λ are separated by a distance 3λ. The total number of minima formed on line AB which runs from $-\infty$ to $+\infty$ is:



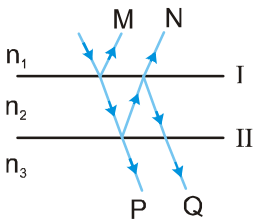
(A) 2 **(B)** 4 **(C)** 6 **(D)** 8

16. M1 and M2 are two plane mirrors which are kept parallel to each other as shown. There is a point 'O' on perpendicular screen just infront of 'S'. What should be the wavelength of light coming from monchromatic source 'S'. So that a maxima is formed at 'O' due to interference of reflected light from both the mirrors. [Consider only 1st reflection].



(A) $\frac{3d^2}{D}$ **(B)** $\frac{3d^2}{2D}$ **(C)** $\frac{d^2}{D}$ **(D)** $\frac{2d^2}{D}$

17. A ray of light is incident on a thin film. As shown in figure M,N are two reflected rays and P,Q are two transmitted rays. Rays N and Q undergo a phase change of π . Correct order of the refracting indices is:



(A) $n_2 > n_3 > n_1$

(B) $n_3 > n_2 > n_1$

(C) $n_3 > n_1 > n_2$

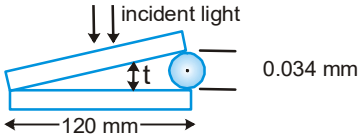
(D) None of these, the specified changes can not occur

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18. From a medium of index of refraction n_1, monochromatic light of wavelength λ is incident normally on a thin film of uniform thickness L (where $L > 0.1\ \lambda$) and index of refraction n_2. The light transmitted by the film travels into a medium with refractive index n_3. The value of minimum film thickness when maximum light is transmitted if $(n_1 < n_2 < n_3)$ is :

(A) $\frac{n_1\lambda}{2n_2}$ **(B)** $\frac{n_1\lambda}{4n_2}$ **(C)** $\frac{\lambda}{4n_2}$ **(D)** $\frac{\lambda}{2n_2}$

19. A broad source of light (l = 680 nm) illuminates normally two glass plates 120 mm long that touch at one end and are separated by a wire 0.034 mm in diameter at the other end. The total number of bright fringes that appear over the 120 mm distance is :



(A) 50 **(B)** 100 **(C)** 200 **(D)** 400

20. If the first minima in a Young's slit experiment occurs directly in front of one of the slits, (distance between slit & screen D = 12 cm and distance between slits d = 5 cm) then the wavelength of the radiation used can be :

(A) 2 cm **(B)** 4 cm **(C)** $\frac{2}{3}$ cm **(D)** $\frac{4}{3}$ cm

21. If one of the slits of a standard Young's double slit experiment is covered by a thin parallel sided glass slab so that it transmits only one half the light intensity of the other, then:

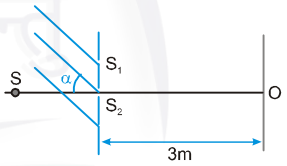
(A) The fringe pattern will get shifted towards the covered slit

(B) The fringe pattern will get shifted away from the covered slit

(C) The bright fringes will become less bright and the dark ones will become more bright

(D) The fringe width will remain unchanged

22. A parallel beam of light (λ =5000 Å) is incident at an angle $\alpha = 30°$ with the normal to the slit plane in a young's double slit experiment. Assume that the intensity due to each slit at any point on the screen is I_0. Point O is equidistant from S_1 & S_2.The distance between slits is 1mm.



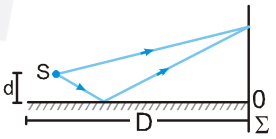
(A) the intensity at O is $4I_0$

(B) the intensity at O is zero

(C) the intensity at a point on the screen 4m from O is $4I_0$

(D) the intensity at a point on the screen 4m from O is zero

23. A long narrow horizontal slit lies 1 mm above a plane mirror. The interference pattern produced by the slit and its image is viewed on a screen Σ distant 1m from the slit. The wavelength of light is 600 nm. Then the distance of the first maxima above the mirror is equal to (d << D):



(A) 0.30 mm **(B)** 0.15 mm **(C)** 60 mm **(D)** 7.5 mm

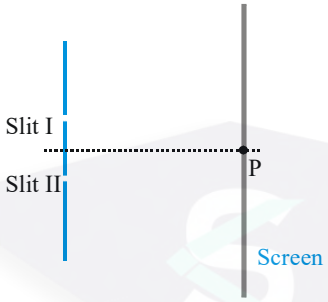
24. A parallel monochromatic beam of light is incident normally on a narrow slit. A diffraction pattern is formed on a screen placed perpendicular to the direction of the incident beam. At the first minimum of the diffraction pattern, the phase difference between the rays coming from the two edges of the slit is:

(A) 0 **(B)** $\pi/2$ **(C)** π **(D)** 2π

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MATRIX - MATCH TYPE

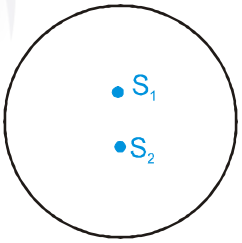
25. A double slit interference pattern is produced on a screen, as shown in the figure, using monochromatic light of wavelength 500 nm. Point P is the location of the central bright fringe, that is produced when light waves arrive in phase without any path difference. A choice of three strips A, B and C of transparent materials with different thicknesses and refractive indices is available, as shown in the table. These are placed over one or both of the slits, singularly or in conjunction, causing the interference pattern to be shifted across the screen from the original pattern. In the column-I, how the strips have been placed, is mentioned whereas in the column-II, order of the fringe at point P on the screen that will be produced due to the placement of the strip(s), is shown. Correctly match both the column.



Film	A	B	C
Thickness (in μm)	5	1.5	0.25
Refractive index	1.5	2.5	2

Column - I	Column - II
(A) Only strip B is placed over slit-I	**(P)** First Bright
(B) Strip A is placed over slit-I and strip C is placed over slit-II	**(Q)** Fourth Dark
(C) Strip A is placed over the slit-I and strip B and strip C are placed over the slit-II in conjunction.	**(R)** Fifth Dark
(D) Strip A and strip C are placed over slit-I (inconjuction) and strip B is placed over slit-II.	**(S)** Central Bright

26. Two coherent point sources of light having wavelength λ are seperated by a distance d. A circle is drawn in space surrounding both the point sources as shown. The plane of circle contains both the point sources. The distance d between both the sources is given in column-I and the total number of corresponding points of maximum intensity and minimum intensity on the periphery of the shown circle are given in column-II. Match each situation of column-I with the results in column-II.



Column-I	Column-II
(A) $d = 99.4\ \lambda$	**(P)** 398 points of maximum intensity
(B) $d = 99.6\ \lambda$	**(Q)** 400 points of maximum intensity
(C) $d = 100\ \lambda$	**(R)** 396 points of minimum intensity
(D) $d = 100.4\ \lambda$	**(S)** 400 points of minimum intensity
	(T) 402 points of maximum intensity

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ASSERTION AND REASON TYPE

These questions contains, Statement 1 (assertion) and Statement II (reason).

(A) Statement-1 is True, Statement-2 is True; Statement-2 **is** a correct explanation for Statement-1

(B) Statement-1 is True, Statement-2 is True; Statement-2 **is NOT** a correct explanation for Statement-1

(C) Statement-1 is True, Statement-2 is False

(D) Statement-1 is False, Statement-2 is True.

27. **Assertion :** Two point coherent sources of light S_1 and S_2 are placed on a line as shown. P and Q are two points on that line. If at point P maximum intensity is observed then maximum intensity should also be observed at Q.

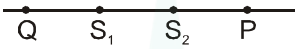


Reason : In the figure of statment 1, the distance $|S_1P - S_2P|$ is equal to distance $|S_2Q - S_1Q|$.

28. **Assertion :** Two coherent point sources of light having nonzero phase difference are seperated by small distance. Then on the perpendicular bisector of line segment joining both the point sources, constructive interference cannot be obtained.

Reason : For two waves from coherent point sources to interfere constructively at a point, the magnitude of their phase difference at that point must be $2m\pi$ (where m is a nonnegative integer) .

29. **Assertion :** Two point coherent sources of light S_1 and S_2 are placed on a line as shown. P and Q are two points on that line. If at point P maximum intensity is observed then maximum intensity should also be observed at Q.



Reason : In the figure of statment 1, the distance $|S_1P - S_2P|$ is equal to distance $|S_2Q - S_1Q|$.

30. **Assertion :** Thin films such as soap bubble or a thin layer of oil on water show beautiful colours when illuminated by white light.

Reason : It happens due to the interference of light reflected from the upper surface of the thin film.

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ANSWER KEY

EXERCISE - 1

1. A **2.** C **3.** B **4.** C **5.** D **6.** C **7.** D **8.** C **9.** C **10.** B **11.** A **12.** C **13.** C
14. C **15.** A **16.** C **17.** A **18.** C **19.** A **20.** D **21.** D **22.** A **23.** B **24.** B **25.** B **26.** B
27. B **28.** D **29.** C **30.** C **31.** C **32.** A **33.** B **34.** C **35.** C **36.** A **37.** A **38.** A **39.** C
40. B **41.** B **42.** A **43.** C **44.** D **45.** D **46.** D **47.** B **48.** D **49.** A **50.** C **51.** A **52.** D
53. B **54.** D **55.** B **56.** B **57.** A **58.** D **59.** C **60.** A

EXERCISE - 2

1. D **2.** D **3.** D **4.** D **5.** C **6.** D **7.** A **8.** C **9.** D **10.** A **11.** D **12.** A **13.** C
14. C **15.** A **16.** D **17.** B **18.** A **19.** B **20.** D **21.** D **22.** B **23.** D **24.** C **25.** C **26.** D
27. D **28.** B **29.** A **30.** C **31.** C **32.** B **33.** A **34.** B **35.** D **36.** B **37.** C **38.** B **39.** A
40. A **41.** D **42.** B **43.** C **44.** C **45.** B **46.** B **47.** D **48.** D **49.** C **50.** B **51.** A **52.** D
53. B **54.** B **55.** D **56.** A **57.** A **58.** C **59.** C **60.** A **61.** A **62.** B **63.** D **64.** C **65.** B
66. D **67.** C **68.** D **69.** A **70.** B **71.** C **72.** A **73.** C **74.** D **75.** D **76.** A **77.** B **78.** B
79. A **80.** C **81.** A **82.** C **83.** B **84.** C **85.** C **86.** A **87.** A **88.** A **89.** A **90.** C **91.** C
92. B **93.** D **94.** A **95.** D **96.** C **97.** C **98.** A **99.** D **100.** D **101.** B **102.** B **103.** D **104.** C
105. B **106.** A **107.** A **108.** B **109.** C

EXERCISE - 3 : PART # 1

1. A → Q,R,S ; B → P,Q,R,S; C → Q,R,S; D → P,Q,R,S **2.** A → T ; B → R ; C ; S → D → P
3. A → R,S ; B → P,Q,S ; C → P,Q,S ; D → R,S

PART # 2

1. E **2.** A **3.** B **4.** A **5.** B **6.** D **7.** A **8.** A **9.** D **10.** E **11.** B **12.** A **13.** A
14. B **15.** C **16.** A **17.** C **18.** B **19.** D **20.** A

EXERCISE - 4 : PART # 1

1. D **2.** D **3.** B **4.** C **5.** D **6.** A **7.** B **8.** D **9.** C **10.** D **11.** B **12.** C **13.** A
14. D **15.** B **16.** A **17.** A **18.** D **19.** B **20.** C **21.** C **22.** C **23.** C **24.** D **25.** A **26.** C

PART # 2

1. B **2.** C **3.** B **4.** D **5.** C **6.** C **7.** B **8.** A **9.** B **10.** A **11.** B **12.** D **13.** D
14. D **15.** A **16.** C **17.** C **18.** A **19.** B **20.** A **21.** B **22.** C **23.** A **24.** A **25.** C **26.** B
27. A **28.** B **29.** C **30.** A **31.** C **32.** C **33.** C **34.** A **35.** A **36.** D **37.** D **38.** A **39.** B
40. C **41.** B

MOCK TEST

1. B **2.** B **3.** B **4.** D **5.** A **6.** B **7.** A **9.** C **10.** A **11.** C **12.** D **13.** B **14.** D
15. C **16.** B **17.** B **18.** B **19.** B **20.** A,C **21.** A,C,.D **22.** A,C **23.** B **24.** D
25. A → R, B → R, C → S, D → P
26. A → P,R ; B → P,S ; C → Q,S ; D → S,T
27. D **28.** D **29.** D **30.** C

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HINTS & SOLUTIONS

EXERCISE - 1

NEET LEVEL

1. **(A)** Corpuscular theory explains refraction of light.

2. **(C)** According to Corpuscular theory different colour of light are due to different size of Corpuscules.

3. **(B)**

4. **(C)** According to Plank's hypothesis, black bodies emits radiations in the form of photons.

5. **(D)** The coherent source cannot be obtained from two different light sources.

6. **(C)** Huygen's wave theory fails to explain the particle nature of light (*i.e.* photoelectric effect)

7. **(D)** Interference is shown by transverse as well as mechanical waves.

8. **(C)** $I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2 = (\sqrt{I} + \sqrt{4I})^2 = 9I$

$I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2 = (\sqrt{I} - \sqrt{4I})^2 = I$

9. **(C)**

10. **(B)** The idea of secondary wavelets is given by Huygen.

11. **(A)**

12. **(C)** In interference of light the energy is transferred from the region of destructive interference to the region of constructive interference. The average energy being always equal to the sum of the energies of the interfering waves. Thus the phenomenon of interference is in complete agreement with the law of conservation of energy.

13. **(C)** $\beta = \frac{\lambda D}{d} = \frac{5\times10^{-7}\times2}{10^{-3}} m = 10^{-3} m = 1.0\ mm$.

14. **(C)** Slit width ratio = 1 : 9

Since slit width ratio is the ratio of intensity and intensity $\propto$ (amplitude)^2

$\therefore I_1 : I_2 = 1 : 9$

$\Rightarrow a_1^2 : a_2^2 = 1 : 9 \Rightarrow a_1 : a_2 = 1 : 3$

$I_{max} = (a_1 + a_2)^2,\ I_{min} = (a_1 - a_2)^2 \Rightarrow \frac{I_{min}}{I_{max}} = \frac{1}{4}$

15. **(A)** $\beta \propto \frac{1}{d} \Rightarrow$ If d becomes thrice, then β become becomes $\frac{1}{3}$ times.

16. **(C)** $\frac{\beta_1}{\beta_2} = \frac{\lambda_1}{\lambda_2}$ or $\frac{1.0}{\beta_2} = \frac{5000}{6000}$ or $\beta_2 = \frac{6000}{5000} = 1.2\ mm$.

17. **(A)** $\beta = \frac{6000\times10^{-10}\times25\times10^{-2}}{10^{-3}}$

$= 150000\times10^{-9} = 0.15\times10^{-3} m = 0.015\ cm$.

18. **(C)** For brightness, path difference $= n\lambda = 2\lambda$

So second is bright.

19. **(A)** If one of slit is closed then interference fringes are not formed on the screen but a fringe pattern is observed due to diffraction from slit.

20. **(D)**

21. **(D)** $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$, Now $\Delta\lambda = \frac{0.5}{100}\lambda \Rightarrow \frac{\Delta\lambda}{\lambda} = \frac{0.5}{100}$

$\therefore v = \frac{0.5}{100}\times c = \frac{0.5}{100}\times3\times10^8 = 1.5\times10^6 m/s$

Increase in λ indicates that the star is receding.

22. **(A)** Doppler's shift is given by

$\Delta\lambda = \frac{v\lambda}{c} = \frac{5000\times6000}{3\times10^8} = 0.1\text{Å}$

23. **(B)** Shifting towards ultraviolet region shows that Apparent wavelength decreased. Therefore the source is moving towards the earth.

24. **(B)** Due to expansion of universe, the star will go away from the earth thereby increasing the observed wavelength. Therefore the spectrum will shift to the infrared region.

25. **(B)** With reference to this theory the velocity of the observer is neglected *w.r.t.* the light velocity.

26. **(B)** $\frac{\Delta\lambda}{\lambda} = \frac{v}{c} = \frac{6\times10^7}{3\times10^8} = 0.2$

$\Delta\lambda = \lambda' - \lambda = 0.2\lambda \Rightarrow \lambda' = 1.2\lambda = 1.2\times4600 = 5520\text{Å}$

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27. **(B)** $\Delta\lambda = 5200 - 5000 = 200\text{Å}$

Now $\frac{\Delta\lambda}{\lambda'} = \frac{v}{c} \Rightarrow v = \frac{c\Delta\lambda}{\lambda'} = \frac{3\times10^8\times200}{5000}$

$= 1.2\times10^7 m/\sec \approx 1.15\times10^7 m/\sec$

28. **(D)** $\frac{\Delta\lambda}{\lambda} = \frac{v}{c} \Rightarrow v = \frac{c}{\lambda}\Delta\lambda = \frac{c}{\lambda}(\lambda'-\lambda) = c\times\frac{0.01}{100}$

$= 3\times10^4 m/s = 30\ km/\sec$

29. **(C)** Blue radiations have the wavelength around 4600Å. It shows that apparent wavelength is smaller than the real wavelength. It means that the star is proceeding towards earth.

30. **(C)**

31. **(C)** For first minima $\theta = \frac{\lambda}{a}$ or $a = \frac{\lambda}{\theta}$

$\therefore a = \frac{6500\times10^{-8}\times6}{\pi}$ (As $30^o = \frac{\pi}{6}$ radian)

$= 1.24\times10^{-4} cm = 1.24$ microns

32. **(A)** The angular half width of the central maxima is given by $\sin\theta = \frac{\lambda}{a} \Rightarrow \theta = \frac{6328\times10^{-10}}{0.2\times10^{-3}}\ rad$

$= \frac{6328\times10^{-10}\times80}{0.2\times10^{-3}\times\pi} degree = 0.18^o$

Total width of central maxima $= 2\theta = 0.36^o$

33. **(B)**

34. **(C)** It is caused due to turning of light around corners.

35. **(C)** Width of central maxima $= \frac{2\lambda D}{d}$

$= \frac{2\times2.1\times5\times10^{-7}}{0.15\times10^{-2}} = 1.4\times10^{-3} m = 1.4\ mm$

36. **(A)** Band width $\propto \lambda$,

$\because \lambda_{blue} < \lambda_{red}$, hence for blue light the diffraction bands becomes narrower and crowded together.

37. **(A)** Using $d\sin\theta = n\lambda$, for $n = 1$

$\sin\theta = \frac{\lambda}{d} = \frac{550\times10^{-9}}{0.55\times10^{-3}} = 10^{-3} = 0.001\ rad$

38. **(A)** For single slit diffraction pattern $d\sin\theta = \lambda$ (d = slit width)

Angular width = $2\theta = 2\sin^{-1}\left(\frac{\lambda}{d}\right)$

It is independent of D *i.e.* distance between screen and slit

39. **(C)** Width of central bright fringe.

$= \frac{2\lambda D}{d} = \frac{2\times500\times10^{-9}\times80\times10^{-2}}{0.20\times10^{-3}} = 4\times10^{-3} m = 4mm.$

40. **(B)** Diffraction is obtained when the slit width is of the order of wavelength of EM waves (or light). Here wavelength of X-rays (1-100 Å) is very-very lesser than slit width (0.6 *mm*). Therefore no diffraction pattern will be observed.

41. **(B)** Polariser produced prolarised light.

42. **(A)** Only transverse waves can be polarised.

43. **(C)** Polarisation is not shown by sound waves.

44. **(D)** By using $\mu = \tan\theta_p \Rightarrow \mu = \tan 60 = \sqrt{3}$,

also $C = \sin^{-1}\left(\frac{1}{\mu}\right) \Rightarrow C = \sin^{-1}\left(\frac{1}{\sqrt{3}}\right)$

45. **(D)** $\mu = \tan\theta_p \Rightarrow \theta_p = \tan^{-1} n$

46. **(D)** Ultrasonic waves are longitudinal waves.

47. **(B)** $I = I_0\cos^2\theta = I_0\cos^2 45 = \frac{I_0}{2}$

48. **(D)**

49. **(A)** It magnitude of light vector varies periodically during it's rotation, the tip of vector traces an ellipse and light is said to be elliptically polarised. This is not in nicol prism.

50. **(C)** At polarizing angle, the reflected and refracted rays are mutually perpendicular to each other.

51. **(A)**

52. **(D)** $\lambda_{Red} > \lambda_{Blue} > \lambda_{X-ray} > \lambda_{\gamma}$

53. **(B)** Infrasonic waves are mechanical waves.

54. **(D)** $\mu_0 = 4\pi\times10^{-7}, \varepsilon_0 = 8.85\times10^{-12}\ \frac{N\text{-}m^2}{C^2}$

so $c = \frac{1}{\sqrt{\mu_0\varepsilon_0}} = 3\times10^8\ \frac{meter}{sec}$.

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55. (B) Wavelength of visible spectrum is 3900 Å – 7800 Å.

56. (B) Infrared causes heating effect.

57. (A) **58. (D)**

59. (C) Speed of EM waves in vacuum = $\frac{1}{\sqrt{\mu_0 \in_0}}$ =constant

60. (A) $\lambda_{\gamma-rays} < \lambda_{x-rays} < \lambda_{\alpha-rays} < \lambda_{\beta-rays}$.

EXERCISE - 2
AIIMS LEVEL

1. (D) **2. (D)** **3. (D)** **4. (D)** **5. (C)**

6. (D) $I_1 \propto a_1^2, I_2 \propto a_2^2$

$I_{resultant} = I_1 + I_2 + 2\sqrt{I_1}\sqrt{I_2}\cos\phi$

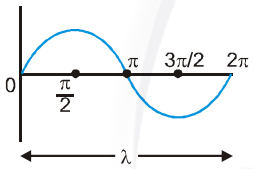
$I_{max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$, When $\cos\phi = 1, \phi = 0, 2\pi, ...$

7. (A) **8. (C)**

9. (D) $y_1 = a\sin\omega t = a\cos(\omega t - \pi/2)$,

$y_2 = a\cos\omega t$

10. (A)



When path difference is λ then phase difference is 2π

When path difference is 1 then phase difference is $\frac{2\pi}{\lambda}$

When path difference is x then phase difference is $\frac{2\pi}{\lambda}x$

11. (D) $y_1 = a\sin\left(\omega t + \frac{\pi}{3}\right)$ and $y_2 = a\sin\omega t$

$A = \sqrt{a_1^2 + a_2^2 + 2a_1a_2\cos\phi}$ where $\phi = \frac{\pi}{3}$

$= \sqrt{a^2 + a^2 + 2aa\cos\frac{\pi}{3}} = \sqrt{3}a$

12. (A) In interference pattern we can see that resultant amplitude of super imposed wave depends on the phase difference of waves so it varies from maximum to minimum amplitude by redistributing of energy but total energy remains conserved.

13. (C)

14. (C) Resultant amplitude $A = \sqrt{a_1^2 + a_2^2 + 2a_1a_2\cos\phi}$

ϕ – Angle between two waves or phase difference. So A depends on both amplitude & phase difference.

15. (A) Sustained interference means a interference pattern (arrangement of fringes) can not be change with time. It is only possible when the phase difference between waves at a point does not change with time.

16. (D) From the definition of coherent source.

17. (B) Given $\frac{I_1}{I_2} = 4$ $\therefore I_1 = 4I$ (let the $I_2 = I$)

$I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2 = (2\sqrt{I} + \sqrt{I})^2 = 9I$

$I_{min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2 = \left(2\sqrt{I} - \sqrt{I}\right)^2 = I$

$\therefore \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{9I - I}{9I + I} = \frac{8I}{101} = \frac{4}{5}$

18. (A) For minima $y_n = (2n-1)\frac{\lambda D}{2d}$ where n is the no. of minimum. For maxima $y_n = \frac{n\lambda D}{d}$

$y_{5^{th}\,dark} = \frac{9\lambda D}{2d}$; $y_{1^{st}\,maxima} = \frac{\lambda D}{d}$

By Equation $y_{5^{th}\,min} - y_{1^{st}\,max} = 7 \times 10^{-3}$

$\frac{9\lambda D}{2d} - \frac{\lambda D}{d} = 7 \times 10^{-3}$

$\Rightarrow \lambda = \frac{7 \times 10^{-3} \times 15 \times 10^{-5} \times 2}{7 \times 50 \times 10^{-2}}$ $\therefore$ $\lambda = 600$ nm

19. (B)

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20. (D) On a given screen width nβ = car tan, Here n is number of fringes and $\beta=\frac{\lambda d}{D}$ is the fringe width

$n_1\beta_1 = n_2\beta_2 \Rightarrow n_2\lambda_1=n_2\lambda_2$

$\Rightarrow n_2 = \frac{n_1\lambda_1}{\lambda_2} = \frac{92\times 5898}{5461} \cong 99.360$

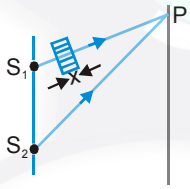
Number of fringes are integers so $n_2 = 99$

21. (D) Fringe width $\beta = \frac{\lambda D}{d}$;

$\beta' = \frac{\lambda' D'}{d'} = \frac{\lambda \times 2D}{d/2}$, $\beta' = 4\frac{\lambda D}{d} = 4\beta$

22. (B) Mica sheet of thickness 't'

Refractive index 'μ'



$\Delta X_P = S_2P - [(S_1P - t)_{air} + t_{sheet}]$

$= (S_2P - S_1P) - (\mu t - t)$

$= d\sin\theta - (\mu - 1)t$

Additional path difference

Position of n^{th} maxima

$n\lambda = \frac{dy_n}{D} - (\mu-1)t \Rightarrow y_n = \frac{nD\lambda}{d} + \frac{D}{d}(\mu-1)t$

Shift of interference pattern $= \frac{D}{d}(\mu-1)t$

23. (D)

24. (C) Central maxima i.e.

$I_0 = (\sqrt{I_1} + \sqrt{I_2})^2 \Rightarrow I_0 = (2\sqrt{I})^2 = 4I$

$\therefore I = \frac{I_0}{4}$

[Intensity due to single slit]

25. (C) Central fringe is that fringe where the path difference $\Delta x = 0$, for all wavelengths. So the central fringe is white followed by the some coloured fringes and after that there is very much overlapping in fringes so equal illumination exists.

26. (D) For maxima, $I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$

When $I_1 = I_2$ then $I_{max} = 4I$

For minima $I_{min} = \left(\sqrt{I_1} \sim \sqrt{I_2}\right)^2$ $I_{min} = 0$

$I_2 = \frac{I_1}{2}$, then $I'_{max} = \left(\sqrt{\frac{I_1}{2}} + \sqrt{I_1}\right)^2 < 4I_1$

$I'_{min} = \left(\sqrt{\frac{I_1}{2}} \sim I_1\right)^2 > I_{min}$

27. (D) Fringe width remains unchanged $\beta = \frac{\lambda d}{D}$

But central bright fringe (zero path difference)

Shift downwards therefore whole fringe pattern shifts downwards.

28. (B) $\lambda = 200nm$, $d = 700$ nm

No. of maxima $= \frac{2d}{\lambda} = \frac{2\times 700nm}{200nm} = 7$

29. (A)

30. (C) When μ=1 i.e. no change in path difference due to optical path difference so the mid point of the screen is again the central bright fringe.

But when μ > 1 the central bright fringe will shift according to $\frac{D}{d}(\mu-1)t$

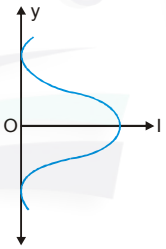
As μ increases, CBF will shift upwards from midpoint i.e. at mid point. Less bright fringe appears and when the shift is equal to value of fringe width, the dark fringe (zero intensity) will appear.

OR

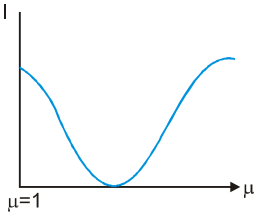
❖ Intensity variation

O ≡ central bright fringe

y ≡ distance from 'O' screen



❖ When μ increases, the fringe patterns shift towards the slit when sheet introduced shift $\frac{D(\mu-1)}{t}$ from the above two fact variation in I with μ is

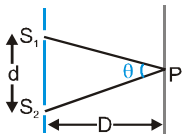


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31. (C)

32. (B) There is a phase change of π when the ray enters from rarer medium into denser medium, the boundary is called rigid boundary and also no change in phase when it enters into rarer medium.

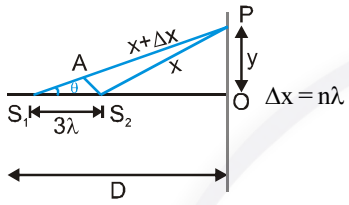
33. (A) As distance between S_1 & S_2 is very much less and equal to 'd' so the angle made at 'P' is very much small



$\therefore$ Angle $= \frac{\text{Arc}}{D} \Rightarrow \theta = \frac{d}{D}$

$\therefore$ Fringe width $= \frac{\lambda D}{d} = \frac{\lambda}{\theta}$ $\left(\because \frac{d}{D} = \theta\right)$

34. (B)



$\Delta x = n\lambda$

in this case path difference is d cos θ.

So $n\lambda = \lambda = 3\lambda \cos\theta \Rightarrow \cos\theta = \frac{1}{3}$

$\Rightarrow \frac{D}{\sqrt{D^2 + y^2}} = \frac{1}{3} \Rightarrow 3D = \sqrt{D^2 + y^2}$

$\Rightarrow y = \sqrt{8}D = 2\sqrt{2}D$

35. (D) Path difference for points A & C is O so constructive interference take place.

Path difference for B & D = 5μm $= \frac{5\lambda}{2}$

So distructive interference take place.

36. (B) At the central Maxima Δx=0

But upward shift $= \frac{(2\mu - 1)tD}{d}$ and

Downward shift $= \frac{(\mu - 1)2tD}{d}$

So net shift $y = \frac{tD}{d}[2\mu - 1 - 2\mu + 2] \Rightarrow y = \frac{tD}{d}$

37. (C) Let t be the thickness so corresponding

$\Delta x = \mu t = \frac{3}{2}t$. Also $I_{max} = 4I$ So $I' = 2I$

We know $I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

$\Rightarrow 2I = I + I + 2\sqrt{I^2}\cos\left(\frac{3\pi t}{\lambda}\right) \Rightarrow \cos\left(\frac{3\pi t}{\lambda}\right) = 0$

$\Rightarrow \cos\left(\frac{3\pi t}{\lambda}\right) = \cos\frac{\pi}{2}$ or $\cos\frac{3\pi}{2}$ or $\frac{5\pi}{2}$

$\Rightarrow \frac{3\pi t}{\lambda} = \frac{\pi}{2} \Rightarrow t = \frac{\lambda}{6}$; $\frac{3\pi t}{\lambda} = \frac{3\pi}{2} \Rightarrow t = \frac{\lambda}{2}$

and $\frac{3\pi t}{\lambda} = \frac{5\pi}{2} \Rightarrow t = \frac{5\lambda}{6}$

38. (B)

39. (A) $I' = \frac{3}{4}(4I) = 3I$.

So $4I = I + I + 2I\cos\phi \Rightarrow \cos\phi = \frac{1}{2} \Rightarrow \phi = \frac{\pi}{3}$

But value should lie between 3π & 6π.

So it cannot be $\frac{\pi}{3}$

For second minima $\phi = 3\pi$

For third maxima $\phi = 6\pi$

40. (A) 41. (D) 43. (C) 44. (C) 45. (B) 46. (B)
47. (D) 48. (D) 49. (C) 50. (B) 51. (A) 52. (D)
53. (B) 54. (B) 55. (D) 56. (A) 57. (A) 58. (C)
59. (C) 60. (A) 61. (A) 62. (B) 63. (D) 64. (C)
65. (B) 66. (D) 67. (C) 68. (D) 69. (A) 70. (B)
71. (C) 72. (A) 73. (A) 74. (D) 75. (D) 76. (A)
77. (B) 78. (B) 79. (A) 80. (C) 81. (A) 82. (C)
83. (B) 84. (C) 85. (C) 86. (A) 87. (A)

88. (A) We know $I \alpha A^2$.

$\Rightarrow \frac{I_1}{I_2} = \frac{A_1^2}{A_2^2} \Rightarrow \sqrt{\frac{4}{1}} = \frac{A_1}{A_2} \Rightarrow A_1 : A_2 = 2 : 1$

89. (A)

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90. (C) Contrast indicates the ratio of maximum possible intensity on screen to the minimum possible intensity.

$$\text{As } \frac{I_{max}}{I_{min}} = \frac{\left(\sqrt{I_1}+\sqrt{I_2}\right)^2}{\left(\sqrt{I_1}-\sqrt{I_2}\right)^2}$$

so it only depends on the source intensity.

91. (C)

92. (B) As $\lambda << d$; we can we $\beta = \frac{\lambda D}{d}$

$$\text{we get } \beta = \frac{500\times10^{-9}\times1}{10^{-3}} = 0.5 \text{ mm.}$$

As β is not very small; hence it might so happen that till 1000th maxima, we no longer can apply

$y' = 1000 \times \beta$.

Lets see if we can apply:

At 1000th maxima. Path difference is $1000\,\lambda$.

$$\Rightarrow \quad 1000\,\lambda = d\sin\theta = \frac{d\times y}{\sqrt{D^2+y^2}}$$

$$\Rightarrow \quad (5\times10^{-4})^2 = \frac{(10^{-3}\text{ m})^2\times y^2}{D^2+y^2}$$

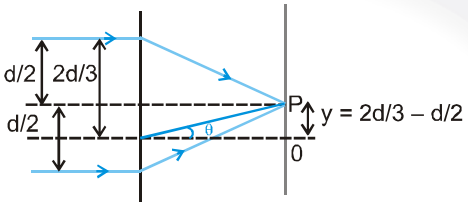
$$\Rightarrow \quad 0.25\,D^2 = y^2(1-0.25) \Rightarrow y = \left(\frac{0.25}{0.75}\right)^{\frac{1}{2}}\times D$$

$$y = \frac{D}{\sqrt{3}} = 0.577 \text{ m.}$$

As 0.577 m. and 0.5 m. are quite distant, so we could not use $y' = 1000\,\beta$ for such a high maxima.

93. (D) **94. (A)**

95. (D)

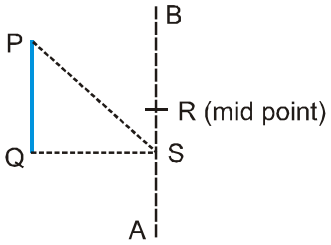


we know that P will be the central maxima (at which path difference is zero)

Now $OP = \frac{d}{2} - \frac{d}{3} = \frac{d}{6}$

96. (C)

97. (C) Lets take any general point S on the line AB.



Clearly: for any position of S on line AB; we have for Δ PQS:

PQ + QS > PS {in any triangle sum of 2 sides is more then the third side}

$\Rightarrow$ PS – QS < 3λ.

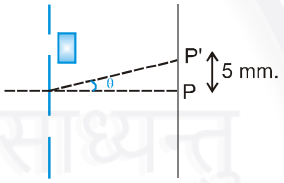
As PS – QS represents the path difference at any point on AB $\Rightarrow$ it can never be more than 3λ. Now minimas occur at.

$\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}$ only.

so 3 minimas below R (mid point of AB)

and 3 also above R.

98. (A)



Clearly the central maxima at P(initially) shifts to P' where PP' = 5 mm.

So now, path difference at P' must be zero.

$\Rightarrow$ $d\sin\theta = (\mu-1)t \Rightarrow d\tan\theta = (\mu-1)t$

$$\mu = 1 + \frac{d.(PP')}{Dt}\text{; get } \mu = 1.2$$

99. (D) **100. (D)**

101. (B) For strong reflection.

$$2\mu t = \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2} \ldots\ldots \Rightarrow \lambda = 4\mu t, \frac{4\mu t}{3}, \frac{4\mu t}{5}, \frac{4\mu t}{7} \ldots\ldots$$

$\Rightarrow$ 3000 nm. 1000 nm, 600 nm, 430 nm, 333 nm.

$\Rightarrow$ only option is 600 nm.

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102. (B) $\dfrac{I_{max}-I_{min}}{I_{max}+I_{min}}=\dfrac{\left(\sqrt{I_1}+\sqrt{I_2}\right)^2-\left(\sqrt{I_1}-\sqrt{I_2}\right)^2}{\left(\sqrt{I_1}+\sqrt{I_2}\right)^2+\left(\sqrt{I_2}-\sqrt{I_2}\right)^2}$

$$=\frac{I_1}{I_1}\times\frac{\left(1+\sqrt{\frac{I_2}{I_1}}\right)^2-\left(1-\sqrt{\frac{I_2}{I_1}}\right)^2}{\left(1+\sqrt{\frac{I_2}{I_1}}\right)^2+\left(1-\sqrt{\frac{I_2}{I_1}}\right)^2}$$

$$=\frac{(1+2)^2-(1-2)^2}{(1+2)^2+(1-2)^2}=\frac{8}{10}=\frac{4}{5}$$

103. (D) Let us say, n^{th} minima of 400 nm coincides with m^{th} minima of 600 nm.

$$\Rightarrow\left(n+\frac{1}{2}\right)400\times\frac{D}{d}=\left(m+\frac{1}{2}\right).600\times\frac{D}{d}$$

$$\Rightarrow 400\,n=600m+100.$$

$$\Rightarrow n=\frac{6m+1}{4}$$

= (some integer or non-integer) + 0.25

Hence n can never be an integer. So no minima of 600 nm coincides with any minima of 400 nm.

104. (C) **105. (B)**

106. (A) At B; DP = 4l (maxima) (mfPp"B)

At $x=\infty$; $\Delta P=0$ (maxima)

Hence in between; the point at which path difference is either λ, or 2λ or 3λ → they will be maximas. Hence 3 maximas.

107. (A)

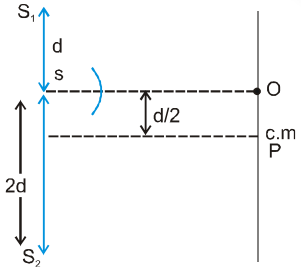
108. (B) The 2 sources are.

As O is a maxima,

Hence OP = β.

$$\Rightarrow\frac{d}{2}=\frac{\lambda.D}{(3d)};$$

get $\lambda=\dfrac{3d^2}{2D}$



109. (C)

EXERCISE - 3

P-1 (Matrix Match)

1. A → Q,R,S ; B → P,Q,R,S; C → Q,R,S; D → P,Q,R,S

Initially at a distance x from central maxima on screen is

$$I=I_0+4I_0+2\sqrt{I_0}\sqrt{4I_0}\cos\frac{2\pi x}{\beta},$$

where $\beta=\dfrac{D\lambda}{d}$ $I_{max}=9I_0$ and $I_{min}=I_0$

(A) At points where intensity is $\frac{1}{9}$ th of maximum intensity, minima is formed

∴ Distance between such points is β, 2β, 3β, 4β, ...

(B) At points where intensity is $\frac{3}{9}$ th of maximum intensity, $\cos\dfrac{2\pi x}{\beta}=-\dfrac{1}{2}$ or $x=\dfrac{\beta}{3}$.

∴ Distance between such points is

$$\frac{\beta}{3},\frac{2\beta}{3},\beta,\beta+\frac{\beta}{3},\beta+\frac{2\beta}{3},2\beta,.....$$

(C) $\cos\dfrac{2\pi x}{\beta}=0$ or $x=\dfrac{\beta}{4}$.

∴ Distance between such points is

$$\frac{\beta}{2},\beta,\beta+\frac{\beta}{2},2\beta,.....$$

(D) $\cos\dfrac{2\pi x}{\beta}=\dfrac{1}{2}$ or $x=\dfrac{\beta}{6}$.

∴ Distance between such points is $\dfrac{\beta}{3},\dfrac{2\beta}{3}$,

$$\beta,\beta+\frac{\beta}{3},\beta+\frac{2\beta}{3},2\beta,.....$$

2. A → T ; B → R ; C ; S → D → P

Additional path difference by introducing the thin sheet is given by (μ–1)t

Resultant path difference at P = Geometrical path difference + Optical path difference

3. A → R,S ; B → P,Q,S ; C → P,Q,S ; D → R,S

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EXERCISE - 3

P-2 (Assertion & Reason)

1. E **2.** A **3.** B **4.** A **5.** B **6.** D
7. A **8.** A

9. **(D)** When a light wave travel from a rarer to a denser medium it loses speed, but energy carried by the wave does not depend on its speed. Instead, it depends on the amplitude of wave.

10. **(E)** A narrow pulse is made of harmonic waves with a large range of wavelength. As speed of propagation is different for different wavelengths, the pulse cannot retain its shape while travelling through the medium.

11. **(B)** When d is negligibly small, fringe width β which is proportional to 1/d may become too large. Even a single fringe may occupy the whole screen. Hence the pattern cannot be detected.

12. **(A)** The central spot of Newton's rings is dark when the medium between plano convex lens and plane glass is rarer than the medium of lens and glass. The central spot is dark because the phase change of π is introduced between the rays reflected from surfaces of denser to rarer and rarer to denser media.

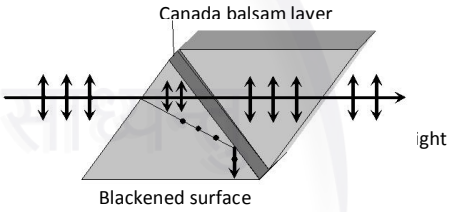
13. **(A)** For reflected system of the film, the maxima or constructive interference is $2\mu t\cos r = \frac{(2n-1)\lambda}{2}$ while the maxima for transmitted system of film is given by equation $2\mu t\cos r = n\lambda$. where t is thickness of the film and r is angle of reflection. From these two equations we can see that condition for maxima in reflected system and transmitted system are just opposite.

14. **(B)** When intensity of light emerging from two slits is equal, the intensity at minima, $I_{min} = \left(\sqrt{I_a} - \sqrt{I_b}\right)^2 = 0$, or absolute dark.It provides a better contrast.

15. **(C)** When one of slits is covered with cellophane paper, the intensity of light emerging from the slit is decreased (because this medium is translucent). Now the two interfering beam have different intensities or amplitudes. Hence intensity at minima will not be zero and fringes will become indistinct.

16. **(A)** When a polaroid is rotated in the path of unpolarised light, the intensity of light transmitted from polaroid remains undiminished (because unpolarised light contains waves vibrating in all possible planes with equal probability). However, when the polaroid is rotated in path of plane polarised light, its intensity will vary from maximum (when the vibrations of the plane polarised light are parallel to the axis of the polaroid) to minimum (when the direction of the vibrations becomes perpendicular to the axis of the crystal). Thus using polaroid we can easily verify that whether the light is polarised or not.

17. **(C)** The nicol prism is made of calcite crystal. When light is passed through calcite crystal, it breaks up into two rays (i) the ordinary ray which has its electric vector perpendicular to the principal section of the crystal and (ii) the extra ordinary ray which has its electric vector parallel to the principal section. The nicol prism is made in such a way that it eliminates one of the two rays by total internal reflection, thus produces plane polarised light. It is generally found that the ordinary ray is eliminated and only the extra ordinary ray is transmitted through the prism. The nicol prism consists of two calcite crystal cut at - 68° with its principal axis joined by a glue called Canada balsam.



18. **(B)**Doppler's effect is observed readily in sound wave due to larger wavelengths. The same is not the case with light due to shorter wavelength in every day life.

19. **(D)** In Young's experiments fringe width for dark and white fringes are same while in Young's double slit experiment when a white light as a source is used, the central fringe is white around which few coloured fringes are observed on either side.

20. **(A)** It is quite clear that the coloured spectrum is seen due to diffraction of white light on passing through fine slits made by fine threads in the muslin cloth.

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EXERCISE - 4

P-1 (NEET/AIPMT)

1. (D)

(A) Interference is a phenomenon in which two waves of same frequency superpose to give resultant intensity different from sum of their separate intensity. So, it cannot exhibit particle nature of light.

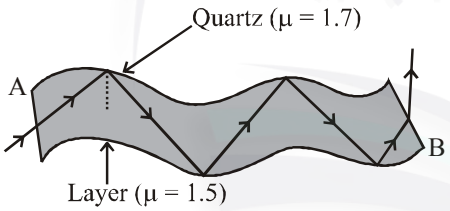
(B) Difference is a phenomenon in which light bends at sharp ends of an obstacle or a hole. So it also can't exhibit particle nature of light.

(C) Polarisation of light is a property owing to which a light ray after emerging through a crystal (a special kind like tourmaline called polaroid) have vibrations in a plane perpendicular to its direction of propagation. So, it also can't explain particle nature of light.

(D) Photoelectric effect states that light travels in the form of bundles or packets of energy, called photons. This effect is explained on the basis of quantum nature of light. So, it clearly explains the particle nature of light.

2. (D) An optical fibre is a device based on total internal reflection by which a light signal can be transferred from one place to the other with a negligible loss of energy.

It consists of a very long and thin fibre of quartz glass.



When a light ray is incident at one end A of fibre making a small angle of incidence. It suffers multiple total interna,l reflections and finally it reaches the point B.

3. (B) In any medium other than air or vacuum, the velocities of different colours are different.

Therefore, both red and green colours are refracted at different angles of refraction. Hence, afte emerging from glass slab through opposite parallel face, they appear at two different points and move in the two different parallel direction.

4. (C) Resolving limit of telescope is given by

$$\theta \propto \frac{x}{D} = \frac{\lambda}{d}$$

λ = wavelength

d = diagram of objective lens of telescope

D = Distance between object and telescope

$$\Rightarrow \quad x = \frac{\lambda D}{d}$$

Given, $\lambda = 5000\ \text{Å} = 5000 \times 10^{-10} = \text{m},$

$D = 1\ \text{km} = 1000\ \text{m},$

$d = 10\ \text{cm} = 0.1\ \text{m}$

Hence, $x = \dfrac{5000 \times 10^{-10} \times 1000}{0.1}$

$= 5 \times 10^{-3}\ \text{m} = 5\ \text{mm}$

5. (D) Angular resolution of telescope is given by

$$= \frac{1.22\lambda}{d}$$

$$= \frac{1.22 \times 5000 \times 10^{-10}}{10 \times 10^{-2}}$$

$$= 6.1 \times 10^{-6} \approx 10^{-6}\ \text{rad}$$

6. (A) Real and apparent depth are explained on the basis of refraction only. The concept of TIR is not involved here.

7. (B) Given, $\lambda_1 = 12000\ \text{Å}$ and $\lambda_2 = 10000\ \text{Å},$

$D = 2\ \text{m}$ and $d = 2\ \text{mm} = 2 \times 10^{-3}\ \text{m}.$

Fringe-width of first wavelength, $\beta_1 = \dfrac{\lambda_1 D}{d}$

$$= \frac{12000 \times 10^{-10} \times 2}{2 \times 10^{-3}} = 1.2\ \text{mm}$$

Fringe-width of second wavelength th, $\dfrac{\lambda_2 D}{d}$

$$= \frac{10000 \times 10^{-10} \times 2}{2 \times 10^{-3}} = 1\ \text{mm}$$

At 6 mm distance from central bright fringe, 5th fringe of first wavelength coincide with 6th fringe of second wavelength.

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8. **(D)** For microscope, $m = \frac{L}{f_o}\frac{D}{f_e} \Rightarrow m \propto \frac{1}{f_o}$

For telescope, $m = \frac{fo}{f_e}$

$m \propto f_o$

The magnifying power of microscope will decreases but the magnifying power of telescope will increase.

9. **(C)** For net intensity

$$I' = 4I_0 \cos^2 \frac{\phi}{2}$$

For the first case, $K = 4I_0 \cos^2[\pi]$ $\because \left(\phi = \frac{2\pi}{\lambda} \times \lambda\right)$

$K = 4\,I_0$ ...(i)

For the second case,

$$K' = 4I_0 \cos^2\left(\frac{\pi/2}{2}\right)$$

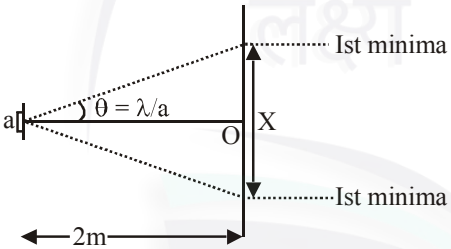
$\because$ $\left(\phi = \frac{2\pi}{\lambda} \times \frac{\lambda}{4}\right)$

$K' = 2I_0$ ...(ii)

Comparing Eqs. (i) and (ii), we get

$$K' = \frac{K}{2}$$

10. **(D)** According to question diagram is shown as



$$\tan\theta = \frac{x/2}{2}$$

For small θ and when θ is counted in rad, $\tan\theta \approx \theta$

So, $\tan\theta = \frac{x/2}{2}$

$\Rightarrow$ $\frac{\lambda}{a} = \frac{x}{4}$

$\Rightarrow$ $x = \frac{4\lambda}{a} = \frac{4 \times 600 \times 10^{-9}}{10^{-3}}$

$= 24 \times 10^{-4}$

$= 2.4 \times 10^{-3}\,m = 2.4\,mm$

11. **(B)** Given, $Y_{steel} = 2Y_{brass}$ and $L_s = L_b$ and $A_s = A_b$, such that $\Delta L_s = \Delta L_b$

As we know, Young's modulus,

$$Y = \frac{\text{stress}}{\text{strain}} = \frac{\frac{F}{A}}{\frac{\Delta L}{L}} = \frac{W\Delta L}{A\Delta L}$$

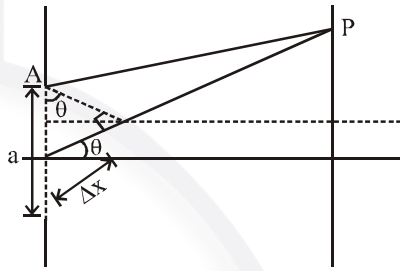
So, $W = \frac{FA\Delta L}{L} \propto Y$

i.e. $\frac{W_s}{W_b} = \frac{Y_s}{Y_b} = \frac{2Y_b}{Y_b} = \frac{2}{1}$

$\Rightarrow$ 2 : 1

Thus, weight added to the steel and brass wires must be in the ratio of 2 : 1.

12. **(C)** For first minima at P, $a \sin\theta = n\lambda$



where, $N = 1$

$\Rightarrow$ $a \sin\theta = \lambda$

So, phase difference,

$$\Delta\phi_1 = \frac{\Delta x_1}{\lambda} \times 2\pi = \frac{(a/2)\sin\theta}{\lambda} \times 2\pi$$

$$= -\frac{\lambda}{2\lambda} \times 2\pi = \pi \text{ rad}$$

13. **(A)** Given, YDSE experiment, having two slits of width are in the ratio of 1 : 25.

So, ratio of intensity,

$$\frac{I_1}{I_2} = \frac{W_1}{W_2} = \frac{1}{25} \Rightarrow \frac{I_2}{I_1} = \frac{1}{25}$$

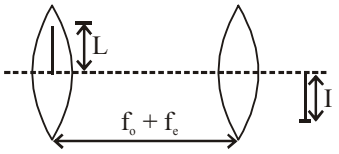
$\therefore$ $\frac{I_{max}}{I_{min}} = \frac{(\sqrt{I_2} + \sqrt{I_1})^2}{(\sqrt{I_2} - \sqrt{I_1})^2} = \left[\frac{\sqrt{\frac{I_2}{I_1}} + 1}{\sqrt{\frac{I_2}{I_1}} - 1}\right]^2$

$\Rightarrow$ $\left[\frac{5+1}{5-1}\right]^2 = \left(\frac{6}{4}\right)^2 = \frac{36}{16} = \frac{9}{4}$

Thus, $\frac{I_{max}}{I_{min}} = \frac{9}{4}$

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14. (D)



We know, magnification of telescope, we have

$$M = \frac{f_o}{f_e},$$

Here, $\frac{f_e}{f_e + u} = \frac{-I}{L}$

$$\Rightarrow \frac{f_e}{f_e - (f_o + f_e)} = \frac{-I}{L}$$

$$\Rightarrow \frac{f_e}{f_o} = \frac{I}{L}$$

i.e. $M = \frac{L}{I}$

15. (B) As, we know that $\mu = \frac{\sin\left(\frac{A + D_m}{2}\right)}{\sin\frac{A}{2}}$

$$\Rightarrow \cot\frac{A}{2} = \frac{\sin\left(\frac{A + D_m}{2}\right)}{\sin\frac{A}{2}}$$

$$\Rightarrow \frac{\cos\frac{A}{2}}{\sin\frac{A}{2}} = \frac{\sin\left(\frac{A + D_m}{2}\right)}{\sin\frac{A}{2}}$$

$$\sin\left(\frac{\pi}{2} - \frac{A}{2}\right) = \sin\left(\frac{A + D_m}{2}\right)$$

$$\Rightarrow \frac{\pi}{2} - \frac{A}{2} = \frac{A}{2} + \frac{D_m}{2}$$

$$\Rightarrow D_m = \pi - 2A$$

$$D_m = 180° - 2A$$

16. (A) Given $d = 1\text{ mm} = 1 \times 10^{-3}\text{ m}$

$D = 1\text{ m}, l = 500\text{ nm} = 5 \times 10^{-7}\text{ m}$

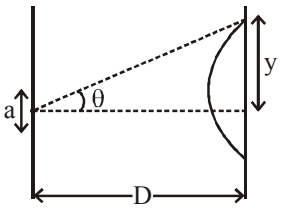
As width of central maxima = width of 10 maxima

$$\therefore \frac{2D\lambda}{a} = 10\left(\frac{\lambda D}{d}\right)$$

$$\Rightarrow a = \frac{d}{5} = \frac{10^{-3}}{5} = 0.2 \times 10^{-3}\text{ m}$$

$$a = 0.2\text{ mm}$$

17. (A) For the condition of maxima



$$\sin\theta = \frac{\lambda}{a}$$

From the geometry, $\sin\theta = \theta = \frac{Y}{D}$ (for small angle)

So, $\frac{Y}{D} = \frac{\lambda}{a}$

$$\Rightarrow Y = \frac{\lambda D}{a}$$

Hence, width of central maxima $= 2Y = \frac{2\lambda D}{a}$

18. (D) Key Idea Ist minima is formed at a distance

$$Y = \frac{\lambda D}{a}$$

For the distance of the first dark band of the diffraction pattern from the centre of the screen is given by position of Ist minima.

i.e. $Y = \frac{\lambda D}{a}$

where, λ = wavelength of parallel beams

D = focal length

$$\Rightarrow Y = \frac{(5 \times 10^{-5})(0.6)}{0.02 \times 10^{-2}} \quad \text{(given)}$$

$$\Rightarrow Y = 0.15\text{ cm}$$

19. (B) It is given that, $\frac{I_2}{I_1} = n \Rightarrow I_2 = nI_1$

$\therefore$ Ratio of intensities is given by

$$\frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{(\sqrt{I_2} + \sqrt{I_1})^2 - (\sqrt{I_2} - \sqrt{I_1})^2}{(\sqrt{I_2} + \sqrt{I_1})^2 + (\sqrt{I_2} - \sqrt{I_1})^2}$$

$$= \frac{\left(\sqrt{\frac{I_2}{I_1}} + 1\right)^2 - \left(\sqrt{\frac{I_2}{I_1}} - 1\right)^2}{\left(\sqrt{\frac{I_2}{I_1}} + 1\right)^2 + \left(\sqrt{\frac{I_2}{I_1}} - 1\right)^2}$$

$$= \frac{(\sqrt{n} + 1)^2 - (\sqrt{n} - 1)^2}{(\sqrt{n} + 1)^2 + (\sqrt{n} - 1)^2} = \frac{2\sqrt{n}}{n + 1}$$

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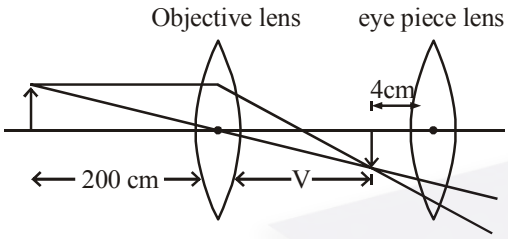
20. **(C)** According to question.

Focal length of objetive lens $(F_0) = +40$ cm

Focal length of eyepiece lens $(F_e) = 4$ cm

Objective distance for objective lens $(u_0) = -200$ cm

Applying lens formula for objective lens



$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f} \Rightarrow \frac{1}{v}-\frac{1}{-200}=\frac{1}{40}$$

$$\Rightarrow \quad \frac{1}{v}=\frac{1}{40}-\frac{1}{200}=\frac{5-1}{200}=\frac{4}{200}$$

$$\Rightarrow \quad v = 50 \text{ cm}$$

21. **(C)** As the first minimum is observed at an angle of 30° in a diffraction pattern due to single slit of width a

i.e. $n = 1, \quad \theta = 30°$

$\because$ According to Bragg's law of diffraction,

$a \sin\theta = n\lambda \Rightarrow a \sin 30° = (1)\lambda \quad (n = 1)$

$$\Rightarrow \qquad a = 2\lambda \qquad ...(i) \qquad \left\{\because \sin 30° = \frac{1}{2}\right\}$$

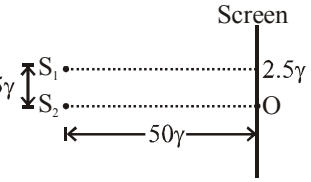
For Ist secondary maxima

$$\Rightarrow \quad a\sin\theta_1 = \frac{3\lambda}{2} \Rightarrow \sin\theta_1 = \frac{3\lambda}{2a} \qquad ...(i)$$

Substitute value of a from Eq. (i) to Eq. (ii), we get

$$\sin\theta_1 = \frac{3\lambda}{4\lambda} \Rightarrow \sin\theta_1 = \frac{3}{4} \Rightarrow \theta_1 = \sin^{-1}\left(\frac{3}{4}\right)$$

22. **(C)**



In the above figure, S_1 and S_2 are the two different slits.

Given, distance between slits S_1 and S_2, $d = 5\lambda$

distance between screen adn slits, $D = 10d = 50\lambda$

Here, λ is the wavelength of light used in the experiment.

According to question, the intensity at maximum in this Young's double slit experiment is I_0.

$$\Rightarrow \qquad I_{max} = I_0$$

$$\because \text{ Path difference} = \frac{dY_n}{D} = \frac{d\times\frac{d}{2}}{10d} = \frac{d}{20} = \frac{\lambda}{4} \quad \{\because d = 5\lambda\}$$

A path difference of λ corresponds to phase

So, for path difference $\lambda/4$, phase difference

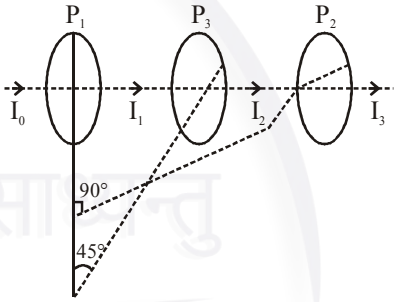
$$\phi = \frac{2\pi}{\lambda}\times\frac{\lambda}{4} = \pi/2 = 90°$$

As we know, $I = I_0\cos^2\frac{\phi}{2}$

$$\Rightarrow \quad I = I_0\cos^2\frac{90°}{2}$$

$$\Rightarrow \quad I = I_0\times\left(\frac{1}{\sqrt{2}}\right)^2 \Rightarrow I = \frac{I_0}{2}$$

23. **(C)** According to the question



From the above diagram, intensity transmitted through P_3

$$I_2 = \frac{I_0}{2}\cos^2 45° \Rightarrow I_2 = \frac{I_0}{2}\times\left(\frac{1}{\sqrt{2}}\right)^2$$

$$\Rightarrow \quad I_2 = \frac{I_0}{4}$$

Similarly, intensity transmitted through P_2,

$$I_3 = \frac{I_0}{4}\cos^2 45° \Rightarrow I_3 = \frac{I_0}{4}\times\left(\frac{1}{\sqrt{2}}\right)^2$$

$$\Rightarrow \quad I_3 = \frac{I_0}{4}\times\frac{1}{2} \Rightarrow I_3 = \frac{I_0}{8}$$

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24. **(D)** According to question,

5th dark fringe in air = 8 bright fringe in the medium

$$(2\times5-1)\frac{\lambda D}{2d}=8\frac{\lambda D}{\mu d}\Rightarrow 9\frac{\lambda D}{2d}=8\frac{\lambda D}{\mu d}$$

$$\Rightarrow \quad \frac{9}{2}=\frac{8}{\mu}\Rightarrow \mu=\frac{8\times2}{9}$$

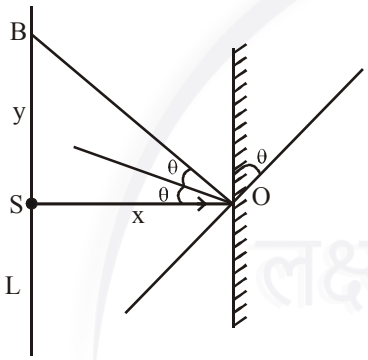
$\therefore$ Refractive index of the medium,

$$\mu=\frac{16}{9}=1.7777\approx1.78$$

25. **(A)** According to the question

L = Light source

When the light beams incident normally on the plane mirror, it is reflected back to the point from which it was coming. when the plane mirror is rotated by an angle θ, the reflected ray or beam of light must rotate by angle 2θ, from refraction at plane surface theory.



From the figure $\tan 2\theta=\frac{BS}{SO}=\frac{y}{x}$

If the angle is small

$\tan 2\theta\approx 2\theta$

So, $\quad 2\theta=\frac{y}{x}\Rightarrow\theta=\frac{y}{2x}$

26. **(C)** As, resolving power of a microscope,

$$(RP)\propto\frac{1}{\lambda_{(wavelength)}}$$

$$\therefore \quad \frac{RP_1}{RP_2}=\frac{\lambda_2}{\lambda_1}=\frac{6000}{4000}=\frac{3}{2}$$

EXERCISE - 4

P-2 (AIIMS)

1. **(B)** It is given that the amplitudes A_1 and A_2 are in the ratio $\frac{A_1}{A_2}=\frac{3}{5}$

$\therefore$ After superposition the maximum and minimum intensities will be in the ratio

$$\frac{I_{max}}{I_{min}}=\frac{(A_1+A_2)^2}{A_2}=\frac{(3+5)^2}{(3-5)^2}=\frac{8^2}{(-2)^2}=\frac{64}{4}=\frac{16}{1}$$

2. **(C)** since white light is not monochromatic, we obtain a central white band.

3. **(B)** When a ray of light falls on sea shell, then its small amount first gets refracted (slightly polarised) and then almost gets reflected back (fully polarised.) That is why, view of sea shell is golden due to polarisation.

4. **(D)** If the waves interfere destructively, then path difference is given by $\frac{\lambda}{2},\frac{3\lambda}{2},\frac{5\lambda}{2}$ etc.

Therefore path difference of a destructive interference is $\frac{(2n+1)\lambda}{2}$ (where n = 0, 1, 2, 3, ...) etc.

5. **(C)** Wavelength $\lambda=500\text{ nm}=500\times10^{-9}$ m

Thickness of the film, $t=2\ \mu m=2\times10^{-6}$ m

Refractive index $\mu=1.5$

When there is no thin film placed in the path of any one of the two beams, the path difference between them is given by yd/D (considering the two beams meeting at a point P). In case we put a thin film in the path of one of the beams, then the optical path of that beam gets longer.

Now for the central maximum, path difference in absence of the film is $\Delta x=0$. But when we put the film, the path difference becomes

$\Delta x=\mu t-t=(\mu-1)t$

$=(1.5-1)\times2\times10^{-6}=10^{-6}\text{ m}=1\ \mu m.$

Now, $\Delta x=\frac{yd}{D}\Rightarrow y=\frac{D}{d}\Delta x=\frac{D}{d}\times1\ \mu m$

And the fringe width is given by

$$W=\frac{D\lambda}{d}=\frac{D}{d}\times500\times10^{-9}\text{ m}=\frac{D}{d}\times0.5\times1\ \mu m$$

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$\therefore \quad y = \frac{D}{d} \times 1\ \mu m = 2 \times \frac{D}{d} \times \frac{1}{2} \times 1\mu m = 2W.$

As the film is placed in the path of the upper beam, the central maximum will shift upward by nearly two fringes.

6. **(C)** The presence of thin mica in the path of one of the interfering beams changes only the path difference between the beams due to which the pattern shifts upwards. But the fringe width remains the same. As monochromatic light is used, one cannot make out which one is the central shift as all the fringes are having the same colour and intensity.

7. **(B)** In compact disc colour results due to phenomenon of diffraction, in which small ripples on the surface of it break up white light into the colour of rainbow.

8. **(A)** The colour in the oil film is formed due to interference of sunlight where the colour of the film will depend upon the thickness and the angle of inclination.

9. **(B)** The magnitude of electric field vector varies periodically with time because it is the form of electromagnetic wave.

10. **(A)** Hubble's law is a statement of a direct correlation between the distance (r) to a galaxy and its recessional velocity as determined by the red shift (Z). It is stated as $Z = H_0 r$,

where Z = recessional velocity

H_0 = Hubble constant and r = distance.

11. **(B)** By superposition of two perpendicular waves polarised and having a phase difference of $\pi/2$ will result in circular polarisation of light.

12. **(D)** Fringe width, $\beta = \frac{\lambda D}{d}$

From question, $d' = 3d$

$\therefore \quad$ New fringe width, $\beta' = \frac{\lambda D}{d'}$

$\therefore \quad \beta' = \frac{\lambda D}{3d} = \frac{\beta}{3}.$

13. **(D)** Angle of first order diffraction $(\theta_1) = 32°$. We know that the angle of diffraction for the *n*th order (θ_n) is given by $d \sin \theta_n = n\lambda$.

For first order diffraction we get

$d \sin 32° = 1 \times \lambda \quad$ or, $\quad \lambda = d \sin 32°.$

Now for second order diffraction,

$d \sin \theta_2 = 2 \times \lambda \quad$ or, $\quad d \sin \theta_2 = 2 \times d \sin 32°$

or $\sin \theta_2 = 2 \times \sin 32° = 2 \times 0.529 = 1.06.$

Since the sine of any angle cannot be greater than 1, therefore there is no second order diffraction.

14. **(D)**

15. **(A)** When sources are coherent, intensity at mid point is

$I_{max} = (a + a)^2 = 4a^2$

When sources are incoherent, no interference occurs. Intensity at mid point is

$I = I_1 + I_2 = a^2 + a^2 = 2a^2$

$\therefore \quad \frac{I_{max}}{I} = \frac{4a^2}{2a^2} = 2:1$

16. **(C)** Resultant intensity,

$I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos\phi$

Here, $I_1 = I$, $I_2 = 4I$, $\phi_1 = \frac{\pi}{2}$ and $\phi_2 = \pi$

At A intensity,

$I_A = I + 4I + 2\sqrt{4I^2} \cos\frac{\pi}{2} = 5I$

At B intensity,

$I_B = I + 4I + 2\sqrt{4I^2} \cos\pi = 5I - 4I = I$

Therefore, difference between intensities is

$I_A - I_B = 5I - I = 4I$

17. **(C)**

18. **(A)** The fringe width is given by

$$\beta = \frac{\lambda D}{d}$$

Here D is the separation between screen and slits and d is the separation between slits.

19. **(B)**

20. **(A)** Polaroid glass is used in sun glasses because it reduces the light intensity to half on account of polarisation.

21. **(B)**

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22. (C) As, $\phi = \frac{2\pi}{\lambda}\Delta x \Rightarrow \phi = \frac{2\pi}{\lambda}\lambda = 2\pi$

$\therefore \quad I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi = I' + I' + 2I'\cos 2\pi$

$I = 2I' + 2I' = 4I'$

when $\Delta x = \frac{\lambda}{6}$, then

$\phi = \frac{2\pi}{\lambda} \times \frac{\lambda}{6} = \frac{2\pi}{6}$

$\therefore \quad I_1 = I' + I' + 2\sqrt{I'I'}\cos\frac{2\pi}{6}$

$I_1 = 2I' + 2I'(1/2) = 3I'$

$\therefore \quad \frac{I_1}{I} = \frac{3I'}{4I'} = \frac{3}{4}$ or $I_1 \frac{3}{4} I$

23. (A) RP of a reflecting microscope $= \frac{2\mu\sin\theta}{\lambda}$

24. (A) Fringe width, $\beta = \frac{\lambda D}{d}$

Since D and d are unaltered, $\beta \propto \lambda$.

$\therefore \quad \frac{\beta'}{\beta} = \frac{\lambda'}{\lambda}$

or $\beta' = \beta \times \frac{\lambda'}{\lambda} = 1 \times \frac{6000}{5000} = 1.2$ mm

25. (C) Slit width = d

$\lambda = 5500\ \text{Å} = 5.5 \times 10^{-7}$ m, $\theta_n = 30°$

For first secondary minima, $d\sin\theta_n = \lambda$

$d = \frac{\lambda}{\sin\theta_n} = \frac{5.5\times10^{-7}}{\sin 30°} = 11\times10^{-7}$ m

For first secondary maxima, $d\sin\theta_n = \frac{3\lambda}{2}$

i.e. $\sin\theta_n = \frac{3\lambda}{2d} = \frac{3\times5.5\times10^{-7}}{2\times11\times10^{-7}}$

$\sin\theta_n = \frac{3}{4}$ or $\theta_n = \sin^{-1}(3/4)$

26. (B) $\frac{I_{max}}{I_{min}} = \frac{(a+b)^2}{(a-b)^2}$

$\frac{9}{1} = \frac{(a+b)^2}{(a-b)^2}$

or $\frac{3}{1} = \frac{a+b}{a-b}$ or $3a - 3b = a + b$

or $2a = 4b$ or $a = 2b$

$\therefore \quad \frac{I_1}{I_2} = \frac{a^2}{b^2} = \frac{4}{1}$

27. (A) $\frac{I_1}{I_2} = \frac{a^2}{b^2} = \beta$ $\quad \therefore \quad \frac{a}{b} = \sqrt{\beta}$

Fringe visibility is given by

$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{(a+b)^2 - (a-b)^2}{(a+b)^2 + (a-b)^2}$

$= \frac{4ab}{2(a^2+b^2)} = \frac{2(a/b)}{\left(\frac{a^2}{b^2}+1\right)} = \frac{2\sqrt{\beta}}{\beta+1}$

28. (B)

29. (C) The waves diffracted from the edges of circular obstacle, placed in the path of light, interfere constructively at the centre of the shadow resulting in the formation of a bright spot.

30. (A) The coloured spectrum is due to diffraction of white light on passing through fine slits made by fine threads in the muslin cloth.

31. (C) The beautiful colours are seen on account of interference of light reflected from the upper and the lower surfaces of the thin film. As conditions for constructive and destructive interference depend upon the wavelength of light, coloured interference fringes are observed.

32. (C) The extremely fine lamellated scales covering the Morpho's wings reflect incident light repeatedly at successive layers leading to interference effect that depends on both the wavelengths and angle of incidence. Thus the colours produced very with viewing angle.

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33. **(C)** The clouds consists of dust particles and water droplets. Their size is very large as compared to the wavelength of the incident light from the sun. So there is very little scattering of light. Hence the light which we receive through the clouds has all the colours of light. As a result of this, we receive almost white light. Therefore, the cloud are generally white.

34. **(A)** Resolving power of telescope $= \frac{D}{1.22\lambda}$ where D is the diameter of the objective lens and λ is the wavelength of the light used.

With increase in D, resolving power of telescope increases. A telescope will have large light gathering power if the diameter of the objective lens is large. Hence a bright image will be formed by the telescope.

35. **(A)** Wavelength of X-rays is of the order of 0.01 Å to 0.1 Å. The grating spacing is not of this order. Hence it is not suitable for X-ray wavelength.

36. **(D)** Light reflected (in the rarer medium) is completely polarised. The intensity of light does not change in polarisation.

37. **(D)**

38. **(A)** Resolving power of telescope

$$R = \frac{1}{\Delta\theta} = \frac{a}{1.22\lambda}$$

Here a is the diameter of the objective of the telescope.

39. **(B)** Frequency of light depends on the source of its generation.

40. **(C)** Fringe width is given by, $\beta = \frac{D\lambda}{d}$

where, D = distance between slit and screen,

d = distance between coherent sources of light and

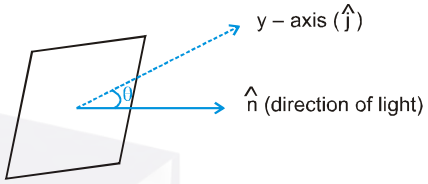
λ = wavelength of incident light.

41. **(B)** Resolving Power, $R.P. \propto \frac{1}{\lambda}$. An electron microscope has extremely high resolving power because the electronic beams have wavelength 10^5 times shorter than visible light.

MOCK TEST

1. **(B)** $I \propto A^2 \ \therefore \ \frac{I_1}{I_2} = \frac{2^2}{3^2} = 4/9$

2. **(B)** $x + 2y + 3z = c$ represents a plane.



Now angle θ is given by :

$$\cos\theta = \frac{\hat{n}\,.\,\hat{j}}{|\,\hat{n}\,||\,\hat{j}\,|} = \frac{b}{\sqrt{a^2+b^2+c^2}} \Rightarrow \theta = \cos^{-1}\left(\frac{2}{\sqrt{14}}\right)$$

where $\hat{n} = a\hat{i} + b\hat{j} + c\hat{k} = \hat{i} + 2\hat{j} + 3\hat{k}$.

3. **(B)** $\frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{\left(\sqrt{I_1}+\sqrt{I_2}\right)^2 - \left(\sqrt{I_1}-\sqrt{I_2}\right)^2}{\left(\sqrt{I_1}+\sqrt{I_2}\right)^2 + \left(\sqrt{I_2}-\sqrt{I_2}\right)^2}$

$$= \frac{I_1}{I_1} \times \frac{\left(1+\sqrt{\frac{I_2}{I_1}}\right)^2 - \left(1-\sqrt{\frac{I_2}{I_1}}\right)^2}{\left(1+\sqrt{\frac{I_2}{I_1}}\right)^2 + \left(1-\sqrt{\frac{I_2}{I_1}}\right)^2}$$

$$= \frac{(1+2)^2-(1-2)^2}{(1+2)^2+(1-2)^2} = \frac{8}{10} = \frac{4}{5}$$

4. **(D)** In cases I, II, III, IV the path differences are respectively

$$\frac{\lambda}{2}, \lambda, \frac{\lambda}{4} \text{ and } \frac{3\lambda}{4}$$

$\Rightarrow$ phase differences are respectively

$\pi, 2\pi, \pi/2, 3\pi/2$

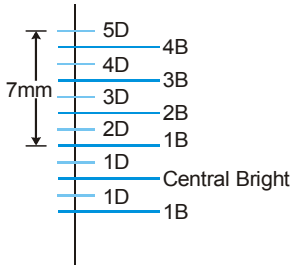
and $I = I_0 \cos^2\left(\frac{\phi}{2}\right)$

$\therefore$ the intensity in the four cases are

$0, I_0, \frac{I_0}{2}, \frac{I_0}{2}$ respetively.

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5. **(A)** There are three and a half fringes from first maxima to fifth minima as shown.



$\Rightarrow \beta = \frac{7mm}{3.5} = 2mm \Rightarrow \lambda = \frac{\beta D}{d} = 600\ nm.$

6. **(B)** For 100th max.

$d \sin\theta = 100\lambda$

$$\sin\theta = \frac{100 \times 5000 \times 10^{-9}}{1 \times 10^{-3}} = \frac{5 \times 10^{-4}}{10^{-3}} = 0.5 = \frac{1}{2}$$

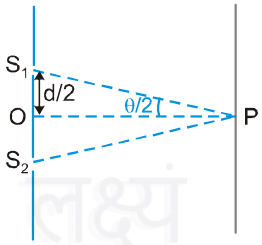
$\therefore y = D\tan\theta = 1 \times \tan 30 = \frac{1}{\sqrt{3}}$

7. **(A)** In ΔS_1PO

$$\tan\frac{\theta}{2} = \frac{d/2}{D}$$

As $D >> d$

$\therefore$ θ is very small.



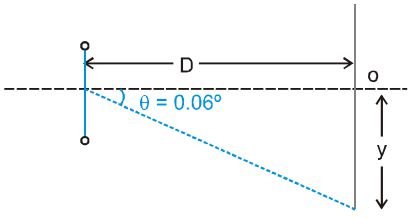
$\Rightarrow \tan\frac{\theta}{2} \approx \frac{\theta}{2}$

$\Rightarrow \frac{\theta}{2} = \frac{d}{2D} \Rightarrow \frac{D}{d} = \frac{1}{\theta} \Rightarrow$ Fringe width $= \frac{\lambda D}{d} = \frac{\lambda}{\theta}$

8. Say 'n' fringes are present in the region shown by 'y'

$\Rightarrow y = n\beta = \frac{n\lambda D}{d}$

$\Rightarrow \frac{y}{D} \approx \tan(0.06°) \approx \frac{0.06 \times \pi}{180} = \frac{n\lambda}{d}$



$\Rightarrow n = \frac{10^3 \times \pi}{180} \times 0.06 = \frac{\pi}{3} > 1.$

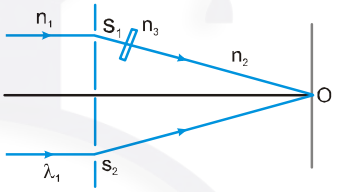
Hence; only one maxima above and below point O. So total 3 bright spots will be present (including point 'O' i.e. the central maxima).

9. **(C)** At path difference $\frac{\lambda}{6}$, phase difference is $\frac{\pi}{3}$

$I = I_O + I_O + 2I_O\cos\frac{\pi}{3} = 3I_O \qquad I_{max} = 4I_0$

So the required ratio is $\frac{3I_0}{4I_0} = 0.75$

10. **(A)**



light wavelength in medium n_1 is $= \lambda_1$

$\Rightarrow$ Wavelength in vaccum $= \lambda_0 = n_1\lambda_1$

The path difference between the lights waves reaching point O = $(n_3 - n_2)$ t = extra path which the light from S_1 travelled compared to the path from S_2.

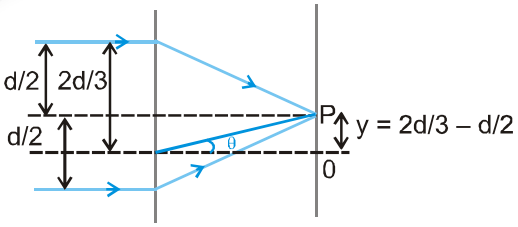
Corresponding phase difference $= \frac{2\pi}{\lambda_0}$ (path difference)

$= \frac{2\pi}{n_1\lambda_1}(n_3 - n_2)\,t$

11. **(C)** Here path difference will be :

$\Delta x = (\mu_2 - \mu_1)t \Rightarrow \delta = \frac{2\pi}{\lambda}(\mu_2 - \mu_1)t$

12. **(D)**



we know that P will be the central maxima (at which path difference is zero)

Now $OP = \frac{d}{2} - \frac{d}{3} = \frac{d}{6}$

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13. (B) When light passes through a medium of refractive index μ, the optical path it travels is (μt).

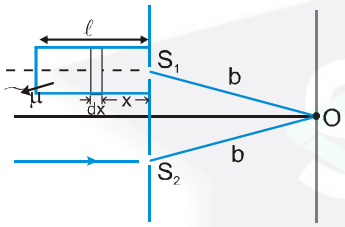
Therefore, before reaching O light through S_1 travels $(\mu\lambda + b)$ distance while that through S_2 travels a distance $(\lambda + b)$

i.e. : path difference $= (\mu\lambda + b) - (\lambda + b) = (\mu - 1)\lambda$.

For a small element 'dx' path difference $\Delta x = [(1 + ax) - 1]$ $dx = ax\,dx$

For the whole length ;

$$\Delta x = \int_0^{\ell} ax\,dx = \frac{a\ell^2}{2}$$



For a minima to be at 'O'.

$$\Delta x = (2n+1)\frac{\lambda}{2}$$

i.e. : $\frac{a\ell^2}{2} = (2n+1)\frac{\lambda}{2}$.

For minimum 'a'; $n = 0$

$$\Rightarrow \frac{a\ell^2}{2} = \frac{\lambda}{2} \Rightarrow a = \frac{\lambda}{\ell^2}$$ **Ans.**

14. (D) Shift of fringe pattern $= (\mu - 1)\frac{tD}{d}$

$$\therefore \frac{30\ D\ (4800\times10^{-10})}{d} = (0.6)\,t\,\frac{D}{d}$$

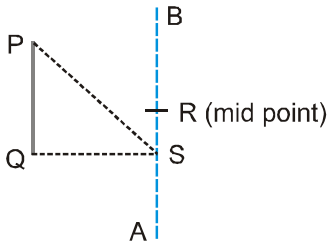
$$30 \times 4800 \times 10^{-10} = 0.6\,t$$

$$t = \frac{30 \times 4800 \times 10^{-10}}{0.6} = \frac{1.44 \times 10^{-5}}{0.6} = 24 \times 10^{-6}$$

15. (C) Lets take any general point S on the line AB.

Clearly: for any position of S on line AB; we have for Δ PQS:

PQ + QS > PS {in any triangle sum of 2 sides is more then the third side}



$\Rightarrow$ PS – QS < 3λ.

As PS – QS represents the path difference at any point on AB

$\Rightarrow$ it can never be more than 3λ. Now minimas occur at.

$\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}$ only.

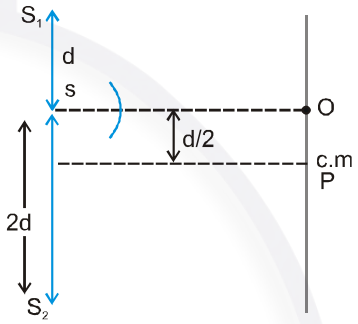
So 3 minimas below R (mid point of AB) and 3 also above R.

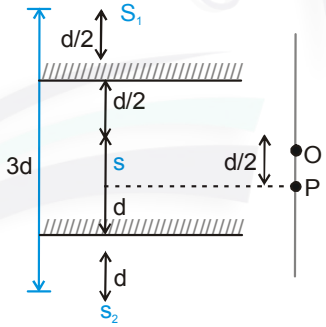
16. (B) The 2 sources are.

As O is a maxima, Hence OP = β.

$$\Rightarrow \frac{d}{2} = \frac{\lambda.D}{(3d)} \text{ ; get } \lambda = \frac{3d^2}{2D}$$

$$= \frac{3d.d}{2D} = n\lambda \Rightarrow \lambda = \frac{3d^2}{2nD} \Rightarrow \lambda = \frac{3d^2}{2d}, \frac{3d^2}{4d}$$





17. (B) Ray N undergoes reflection at surface II with phase change of π

$\Rightarrow$ $n_3 > n_2$

Ray Q undergoes a phase-change of π at II, but there is no phase change when it is reflected from surface I.

$\Rightarrow$ $n_1 < n_2$

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18. **(B)** Eq. of path diff. for maxima in tansmission (or weak reflection);

$$\Delta P_{opt} = 2n_2L = \frac{\lambda_{vacuum}}{2}, \frac{3\lambda_{vacuum}}{2} .....$$

$$\Rightarrow \quad 2\left(\frac{n_2}{n_1}\right)L = \frac{\lambda}{2}, \frac{3\lambda}{2}, ... \Rightarrow L = \frac{\lambda n_1}{4n_2} .$$

(notice that λ = wavelength in medium is related to λ_{vacuum} as, $\lambda_{vacuum} = n_1\lambda$)

19. **(B)** Constructive interference happens when $2t = (m - 1/2)\lambda$. The minimum value of m is m = 1; the maximum value is the integer portion of $\frac{2t}{\lambda} + \frac{1}{2}$ =

$$\frac{2 \times 0.034 \times 10^{-3}}{680 \times 10^{-9}} + \frac{1}{2}$$

$$= 100.5$$

$$m_{max} = 100$$

20. **(AC)** Path difference $= \sqrt{D^2 + d^2} - D = 1$ cm

Also ; $\left[\sqrt{D^2 + d^2} - D\right] = (2n - 1)\frac{\lambda}{2} \Rightarrow \lambda = \frac{2(1)}{2n - 1}$

For n = 1,2,3,.....

$\lambda = 2\text{cm}, \frac{2}{3}\text{cm}, \frac{2}{5}\text{cm},.....$

21. **(ACD)** $I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2 = \left(\sqrt{I} + \sqrt{\frac{I}{2}}\right)^2 < 4I$

$$I_{min} = \left(\sqrt{I} - \sqrt{\frac{I}{2}}\right)^2 > 0 \Rightarrow \beta = \frac{\lambda D}{d}$$

becuase λ D.d. are unchanged so β also remain unchanged.

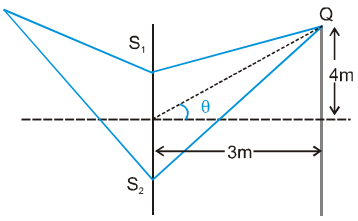
22. **(AC)** As d << D, $\Rightarrow$ path difference = d sinθ (at 0) = 1mm × sin 30° = 0.5 mm

if it is a maxima $\Rightarrow 10^{-3} \times 0.5 = (5000 \times 10^{-10})\text{m} \times (n)$

n must be integer. get n = 1000.

Hence O is a maxima of intensity $4I_0$

Now

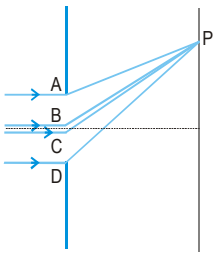


Now path difference at Q = d sinθ only $QS_1 \approx QS_2$.

d sin θ = 1 × 1/2 = 0.5 mm = integer multiple of λ . Hence maxima.

23. **(B)**

24. **(D)** $\left.\begin{matrix}\phi_A - \phi_B = \pi \\ \phi_C - \phi_D = \pi\end{matrix}\right\}$



for first dark fringe at P

also $\phi_C \sim \phi_B$

$\phi_A - \phi_D = 2\pi$

25. **A → R, B → R, C → S, D → P**

By using $(\mu - 1)t = n\lambda$, we can find value of n, that is order of the fringe produced at P, if that particular strip has been placed over any of the slit. If two strips are used in conjuction (over each other), path difference due to each is added to get net path difference created. If two strips are used over different slits, their path differences are subtracted to get net path difference.

Now, $n_1 = \frac{(\mu_1 - 1)t_1}{\lambda} = 5$

$n_2 = 4.5$

and $n_3 = 0.5$

For (a), order of the fringe is 4.5 i.e. 5th dark.

for (b), net order is

5 – 0.5 = 4.5

i.e. fifth dark.

for (c) net order is

5 – (0.5 + 4.5) = 0

i.e. it is central bright again at P.

for (d) net order is

(5 + 0.5) – (4.5) = 1

i.e. first bright



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26. $A \rightarrow P,R$; $B \rightarrow P,S$; $C \rightarrow Q,S$; $D \rightarrow S,T$

(A) When d = 99.4 λ, 398 points of maximum intensity are formed on periphery of circle and 396points of minimum intensity are formed on periphery of circle

(B) When d = 99.6 λ, 398 points of maximum intensity are formed on periphery of circle and 400 points of minimum intensity are formed on periphery of circle

(C) When d = 100 λ, 400 points of maximum intensity are formed on periphery of circle and 400 points of minimum intensity are formed on periphery of circle

(D) When d = 100.4 λ, 402 points of maximum intensity are formed on periphery of circle and 400 points of minimum intensity are formed on periphery of circle

27. (D) If maximum intensity is observed at P then for maximum intensity to be also observed at Q, S_1 and S_2 must have phase difference of $2m\pi$ (where m is an integer).

28. (D) Statement 1 is false because constructive interference can be obtained if phase difference of sources is $2\pi, 4\pi, 6\pi$, etc.

29. (D)

30. (C)

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CHAPTER 09

MODERN PHYSICS

In its efforts to learn as much as possible about nature, modern physics has found that certain things can never be "known" with certainty. Much of our knowledge must always remain uncertain. The most we can know is in terms of probabilities.

"RICHARD FEYNMAN"

INTRODUCTION

Structure of matter always been an interesting area of research for physicists. Till 20th century it was assumed that matter consists of indivisible small tiny particles called "atoms". But with the study and research it was found that the atom is divisible and made of other small partiicles called electron, proton and Neutron. So may physicists tried to explain the structure of atom but finally it was Neils Bohr whose explanation about the structure was well accepted. For simplicity they have taken hydrogen atom and then it can be extended to other H-like atoms too. Some of the historical modles are also explained and them drawbacks.

ATOMIC STRUCTURE

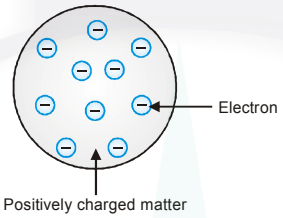
VARIOUS MODELS FOR STRUCTURE OF ATOM

Dalton's Theory

Every material is composed of minute particles known as atom. Atom is indivisible i.e. it cannot be subdivided. It can neither be created nor be destroyed. All atoms of same element are identical physically as well as chemically, whereas atoms of different elements are different in properties. The atoms of different elements are made up of hydrogen atoms. (The radius of the heaviest atom is about 10 times that of hydrogen atom and its mass is about 250 times that of hydrogen). The atom is stable and electrically neutral.

Thomson's Atom Model

The atom as a whole is electrically neutral because the positive charge present on the atom (sphere) is equal to the negative charge of electrons present in the sphere. Atom is a positively charged sphere of radius 10^{-10} m in which electrons are embedded in between. The positive charge and the whole mass of the atom is uniformly distributed throughout the sphere.



Shortcomings of Thomson's model

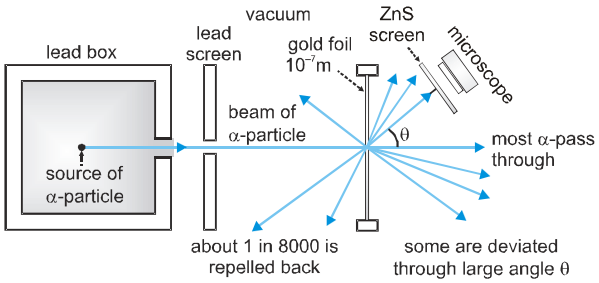
(i) The spectrum of atoms cannot be explained with the help of this model

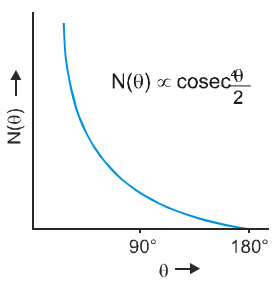
(ii) Scattering of α–particles cannot be explained with the help of this model

RUTHERFORD ATOM MODEL

Rutherford experiments on scattering of α – particles by thin gold foil

The experimental arrangement is shown in figure. α–particles are emitted by some radioactive material (polonium), kept inside a thick lead box. A very fine beam of α–particles passes through a small hole in the lead screen. This well collimated beam is then allowed to fall on a thin gold foil. While passing through the gold foil, α–particles are scattered through different angles. A zinc sulphide screen was placed out the other side of the gold foil. This screen was movable, so as to receive the α–particles, scattered from the gold foil at angles varying from 0 to 180°. When an α–particle strikes the screen, it produces a flash of light and it is observed by the microscope. It was found that :





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(i) Most of the α – particles went straight through the gold foil and produced flashes on the screen as if there were nothing inside gold foil. Thus the atom is hollow.

(ii) Few particles collided with the atoms of the foil which have scattered or deflected through considerable large angles. Few particles even turned back towards source itself.

(iii) The entire positive charge and almost whole mass of the atom is concentrated in small centre called a nucleus.

(iv) The electrons could not deflected the path of a α – particles i.e. electrons are very light.

(v) Electrons revolve round the nucleus in circular orbits. So, Rutherford 1911, proposed a new type of model of the atom. According to this model, the positive charge of the atom, instead of being uniformly distributed throughout a sphere of atomic dimension is concentrated in a very small volume (Less than 10^{-13}m is diameter) at it centre. This central core, now called nucleus, is surrounded by clouds of electron makes.

The entire atom electrically neutral. According to Rutherford scattering formula, the number of α – particle scattered at an angle θ by a target are given by $N_\theta = \frac{N_0 nt(2Ze^2)^2}{16(4\pi\varepsilon_0)^2 r^2 (mv_0^2)^2} \times \frac{1}{\sin^4 \frac{\theta}{2}}$

Where N_0 = number of α – particles that strike the unit area of the scatter

n = Number of target atom per m^3

t = Thickness of target

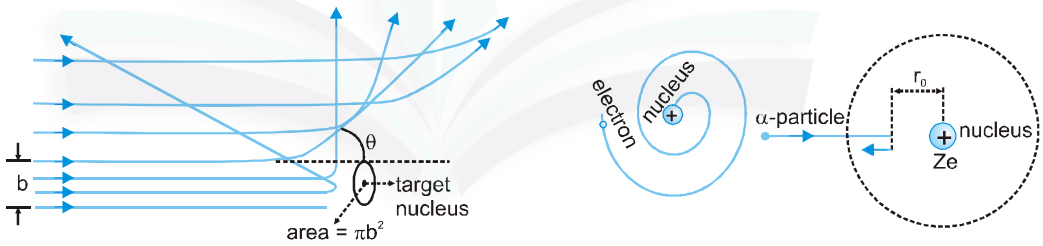
Ze = Charge on the target nucleus

$2e$ = Charge on α – particle

r = Distance of the screen from target

v_0 = Velocity of α – particles at nearer distance of approach the size of a nucleus or the distance of nearer approach is given by

$$r_0 = \frac{1}{4\pi\varepsilon_0} \times \frac{(2Ze)^2}{\left[\frac{1}{2}mv_0^2\right]} = \frac{1}{4\pi\,\epsilon_0} \frac{(2Ze)^2}{E_K}$$ where E_K = K.E. of α–particle



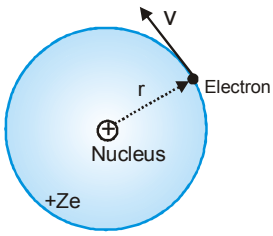
Bohr's Atomic Model

In 1913 Neils Bohr, a Danish Physicist, introduced a revolutionary concept i.e., the quantum concept to explain the stability of an atom. He made a simple but bold statement that "The old classical laws which are applicable to bigger bodies cannot be directly applied to the sub–atomic particles such as electrons or protons.

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Bohr incorporated the following new ideas now regarded as postulates of Bohr's theory.

1. The centripetal force required for an encircling electron is provided by the electrostatic attraction between the nucleus and the electron i.e. $\frac{1}{4\pi\varepsilon_0}\frac{(Ze)e}{r^2} = \frac{mv^2}{r}$ ...**(i)**



ε_0 = Absolute permittivity of free space = $8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$

m = Mass of electron

v = Velocity (linear) of electron

r = Radius of the orbit in which electron is revolving.

Z = Atomic number of hydrogen like atom.

2. Electrons can revolve only in those orbits in which angular momentum of electron about nucleus is an integral multiple of $\frac{h}{2\pi}$. i.e., $mvr = \frac{nh}{2\pi}$ ...**(ii)**

n = Principal quantum number of the orbit in which electron is revolving.

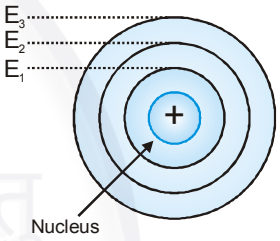
3. Electrons in an atom can revolve only in discrete circular orbits called stationary energy levels (shells). An electron in a shell is characterised by a definite energy, angular momentum and orbit number. While in any of these orbits, an electron does not radiate energy although it is accelerated.

4. Electrons in outer orbits have greater energy than those in inner orbits. The orbiting electron emits energy when it jumps from an outer orbit (higher energy states) to an inner orbit (lower energy states) and also absorbs energy when it jumps from an inner orbit to an outer orbit. $E_n - E_m = h\nu_{n,m}$

where, E_n = Outer energy state

E_m = Inner energy state

$\nu_{n,m}$ = Frequency of radiation



5. The energy absorbed or released is always in the form of electromagnetic radiations.

MATHEMATICAL ANALYSIS OF BOHR'S THEORY

From above equation **(i)** and **(ii)** i.e., $\frac{1}{4\pi\varepsilon_0}\frac{(Ze)e}{r^2} = \frac{mv^2}{r}$ and $mvr = \frac{nh}{2\pi}$ ...**(ii)**

We get the following results.

1. **Velocity of Electron in n^{th} Orbit :** By putting the value of mvr in equation **(i)** from **(ii)** we get

$$\frac{1}{4\pi\varepsilon_0}Ze^2 = \left(\frac{nh}{2\pi}\right) \times v \Rightarrow v = \frac{Z}{n}\left[\frac{e^2}{2\varepsilon_0 h}\right] = \frac{Z}{n}v_0 \quad \text{....(iii)}$$

Where, $v_0 = \frac{(1.6 \times 10^{-19})^2}{2 \times 8.85 \times 10^{-12} \times 6.625 \times 10^{-34}} = 2.189 \times 10^6\ ms^{-1} = \frac{c}{137} = 2.2 \times 10^6\ m/s$

where $c = 3 \times 10^8$ m/s = speed of light in vacuum

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2. Radius of the n^{th} orbit : From equation **(iii)**, putting the value of v in equation **(ii)**, we get

$$m\left(\frac{Z}{n}\times\frac{e^2}{2\varepsilon_0 h}\right)r=\frac{nh}{2\pi}\Rightarrow r=\frac{n^2}{Z}\left[\frac{\varepsilon_0 h^2}{\pi m e^2}\right]=\frac{n^2}{Z}r_0 \qquad ...(iv)$$

where $r_0=\dfrac{8.85\times10^{-12}\times\left(6.625\times10^{-34}\right)^2}{3.14\times9.11\times10^{-31}\times\left(1.6\times10^{-19}\right)^2}=0.529\times10^{-10}\,m\approx0.53\text{Å}$

3. Total energy of electron in n^{th} orbit :

From equation **(i)** $KE=\frac{1}{2}mv^2=\frac{Ze^2}{8\pi\varepsilon_0 r}$ and $PE=\frac{1}{4\pi\varepsilon_0}\frac{(Ze)(-e)}{r}=-2K.E.$ $\therefore |PE|=2\,KE$

Total energy of the system $E=KE+PE=-2KE+KE=-KE=\dfrac{-Ze^2}{8\pi\varepsilon_0 r}$

By putting the value of r from the equation **(iv)**, we get $E=\frac{Z^2}{n^2}\left(-\frac{me^4}{8\varepsilon_0^2h^2}\right)=\frac{Z^2}{n^2}\cdot E_0$ ...(v)

where $E_0=\dfrac{-\left(9.11\times10^{-3}\right)\left(1.6\times10^{-19}\right)^4}{8\times\left(8.85\times10^{-12}\right)^2\times\left(6.625\times10^{-34}\right)^2}=-13.6\ eV$

4. Time period of revolution of electron in n^{th} orbit : $T=\dfrac{2\pi r}{v}$

By putting the values of r and v, from **(iii)** and **(iv)** $T=\frac{n^3}{Z^2}\times\left(\frac{4\varepsilon_0^2h^3}{me^4}\right)=\frac{n^3}{Z^2}\cdot T_0$

where, $T_0=\dfrac{4\times\left(8.85\times10^{-12}\right)^2\times\left(6.625\times10^{-34}\right)^3}{9.11\times10^{-31}\times\left(1.6\times10^{-19}\right)^4}=1.51\times10^{-16}$ second

5. Frequency of revolution in n^{th} orbit :

$f=\frac{1}{T}=\frac{Z^2}{n^3}\times\frac{me^4}{4\varepsilon_0^2h^3}=\frac{Z^2}{n^3}\cdot f_0$ where, $f_0=\dfrac{9.11\times10^{-31}\times\left(1.6\times10^{-19}\right)^4}{4\times\left(8.85\times10^{-12}\right)^2\left(6.625\times10^{-34}\right)^3}=6.6\times10^{15}\,Hz$

6. Wavelength of photon

$$\Delta E=E_{n_2}-E_{n_1}=\frac{me^4}{8\varepsilon_0^2h^2}\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]Z^2=13.6\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]Z^2\Rightarrow\Delta E=\frac{hc}{\lambda}\Rightarrow\frac{1}{\lambda}=\bar{\nu}=\frac{me^4}{8\varepsilon_0^2h^3c}\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]Z^2$$

$$=R_\infty\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]Z^2$$ where, $\bar{\nu}$ is called wave number.

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$R_\infty = R_H$ = Rydberg constant

$$= \frac{9.11\times10^{-31}\times\left(1.6\times10^{-19}\right)^4}{8\times\left(8.85\times10^{-12}\right)^2\left(6.625\times10^{-34}\right)^3\times3\times10^8} = 1.097\times10^7\ m^{-1} = 1.097\times10^{-3}\ \text{Å}^{-1}$$ (for stationary nucleus).

If nucleus is not stationary (i.e., mass of nucleus is not much greater than the mass of the revolving particle like electron), then $R = \frac{R_\infty}{1+m/M}$ where, m = mass of revolving particle and M = mass of nucleus

HYDROGEN LIKE ATOMS

The Bohr model of hydrogen can be extended to hydrogen like atoms, i.e., one electron atoms, the nuclear charge is +ze, where z is the atomic number, equal to the number of protons in the nucleus.

The effect in the previous analysis is to replace e^2 every where by ze^2. Thus, the equations for, r_n, v_n and E_n are altered as under:

$$r_n = \frac{\varepsilon_0 n^2h^2}{nmze^2} = \frac{n^2}{z}a_0 \quad \text{or} \quad r_n \propto \frac{n^2}{z} \qquad \text{....(i)}$$

where $a_0 = 0.529$ Å (radius of first orbit of H)

$$v_n = \frac{ze^2}{2\varepsilon_0 nh} = \frac{z}{n}v_1 \quad \text{or} \quad v_n \propto \frac{z}{n} \qquad \text{....(ii)}$$

where $v_1 = 2.19\times10^6$ m/s (speed of electron in first orbit of H)

$$E_n = -\frac{mz^2e^4}{8\varepsilon_0^2n^2h^2} = \frac{z^2}{n^2}E_1 \text{ or } \quad E_n \propto \frac{z^2}{n^2} \qquad \text{....(iii)}$$

where $E_1 = -13.60$ eV (energy of atom in first orbit of H)

Defination Valid for Single Electron System

(1) **Ground state :** Lowest energy state of any atom or ion is called ground state of the atom.

Ground state energy of H atom = –13.6 eV

Ground state energy of He^+ Ion = –54.4 eV

Ground state energy of Li^{++} Ion = –122.4 eV

(2) **Excited State :** State of atom other than the ground state are called its excited states.

n = 2	first excited state
n = 3	second excited state
n = 4	third excited state
$n = n_0 + 1$	n_0^{th} excited state

(3) **Ionisation energy (I.E.) :** Minimum energy required to move an electron from ground state to n = ∞ is called ionisation energy of the atom or ion

Ionisation energy of H atom = 13.6 eV

Ionisation energy of He^+ Ion = 54.4 eV

Ionisation energy of Li^{++} Ion = 122.4 eV

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(4) **Ionisation potential (I.P.) :** Potential difference through which a free electron must be accelerated from rest such that its kinetic energy becomes equal to ionisation energy of the atom is called ionisation potential of the atom.

I.P of H atom = 13.6 V

I.P. of He^+ Ion = 54.4 V

(5) **Excitation energy :** Energy required to move an electron from ground state of the atom to any other exited state of the atom is called excitation energy of that state.

Energy in ground state of H atom = –13.6 eV

Energy in first excited state of H-atom = –3.4 eV

I^{st} excitation energy = 10.2 eV.

(6) **Excitation Potential :** Potential difference through which an electron must be accelerated from rest so that its kinetic energy becomes equal to excitation energy of any state is called excitation potential of that state.

I^{st} excitation energy = 10.2 eV.

I^{st} excitation potential = 10.2 V.

(7) **Binding energy or Seperation energy :** Energy required to move an electron from any state to $n = \infty$ is called binding energy of that state. or energy released during formation of an H-like atom/ion from $n = \infty$ to some particular n is called binding energy of that state.

Binding energy of ground state of H-atom = 13.6 eV

Ex. First excitation potential of a hypothetical hydrogen like atom is 15 volt. Find third excitation potential of the atom.

Sol. Let energy of ground state = E_0

$$E_0 = -13.6\,Z^2\ \text{eV} \quad \text{and} \quad E_n = \frac{E_0}{n^2}$$

$$n = 2,\ E_2 = \frac{E_0}{4}$$

$$\text{given} \quad \frac{E_0}{4} - E_0 = 15 \Rightarrow -\frac{3E_0}{4} = 15$$

$$\text{for} \quad n = 4,\ E_4 = \frac{E_0}{16}$$

$$\text{third exicitation energy} = \frac{E_0}{16} - E_0 = -\frac{15}{16}E_0 = -\frac{15}{16}\cdot\left(\frac{-4\times 15}{3}\right) = \frac{75}{4}\ \text{eV}$$

$\therefore$ third excitation potential is $\frac{75}{4}$ V

SPECTRAL SERIES OF HYDROGEN ATOM

It has been shown that the energy of the outer orbit is greater than the energy of the inner ones. When the Hydrogen atom is subjected to external energy, the electron jumps from lower energy state i.e. the hydrogen atom is excited. The excited state is unstable hence the electron return to its ground state in about 10^{-8} sec. The excess of energy is now radiated in the form of radiations of different wavelength. The different wavelength constitute spectral series. Which are characteristic of atom emitting, then the wave length of different members of series can be found from the following relations

$$\bar{\nu} = \frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

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This relation explains the complete spectrum of hydrogen. A detailed account of the important radiations are listed below.

(i) **Lyman Series** : The series consist of wavelength which are emitted when electron jumps from an outer orbits to the first orbit i. e., the electronic jumps to K orbit give rise to lyman series. Here $n_1 = 1$ & $n_2 = 2, 3, 4, ...\infty$

The wavelengths of different members of Lyman series are :

(ii) **First member** : In this case $n_1 = 1$ and $n_2 = 2$ hence $\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{2^2}\right] = \frac{3R}{4}$

$$\Rightarrow \lambda = \frac{4}{3R} \Rightarrow \lambda = \frac{4}{3 \times 10.97 \times 10^6} = 1216 \times 10^{-10}\,m = 1216Å$$

(iii) **Second member** : In this case $n_1 = 1$ and $n_2 = 3$ hence $\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{3^2}\right] = \frac{8R}{9}$

$$\Rightarrow \lambda = \frac{9}{8R} \Rightarrow \lambda = \frac{9}{8 \times 10.97 \times 10^6} = 1026 \times 10^{-10}\,m = 1026Å$$

Similarly the wavelength of the other members can be calculated.

(iv) **Limiting members** : In this case $n_1 = 1$ and $n_2 = \infty$, hence $\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{\infty^2}\right] = R$

$$\Rightarrow \lambda = \frac{1}{R} \Rightarrow \lambda = \frac{1}{10.97 \times 10^6} = 912 \times 10^{-10} m = 912Å$$

This series lies in ultraviolet region.

(v) **Balmer Series** : This series is consist of all wave lengths which are emitted when an electron jumps from an outer orbit to the second orbit i. e., the electron jumps to L orbit give rise to Balmer series.

Here $n_1 = 2$ and $n_2 = 3, 4, 5 .....\infty$ The wavelength of different members of Balmer series.

(vi) **First member** : In this case $n_1 = 2$ and $n_2 = 3$, hence $\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{3^2}\right] = \frac{5R}{36}$

$$\Rightarrow \lambda = \frac{36}{5R} \Rightarrow \lambda = \frac{36}{5 \times 10.97 \times 10^6} = 6563 \times 10^{-10} m = 6563Å$$

(vii) **Second member** : In this case $n_1 = 2$ and $n_2 = 4$, hence $\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{4^2}\right] = \frac{3R}{16}$

$$\Rightarrow \lambda = \frac{16}{3R} \Rightarrow \lambda = \frac{16}{3 \times 10.97 \times 10^6} = 4861 \times 10^{-10} m = 4861Å$$

(viii) **Limiting members :** In this case $n_1 = 2$ and $n_2 = \infty$, hence $\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{\infty}\right] = \frac{R}{4} \Rightarrow \lambda = \frac{4}{R} = 3646Å$

This series lies in visible and near ultraviolet region.

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(ix) Paschen Series : This series consist of all wavelength are emitted when an electron jumps from an outer orbit to the third orbit i. e., the electron jumps to M orbit give rise to paschen series. Here n_1=3 & n_2= 4, 5, 6 .....∞.

The different wavelengths of this series can be obtained from the formula $\frac{1}{\lambda} = R\left[\frac{1}{3^2} - \frac{1}{n_2^2}\right]$

where $n_2 = 4, 5, 6 ...\infty$

For the first member, the wavelengths is 18750Å. This series lies in infra–red region.

(x) Bracket Series : This series is consist of all wavelengths which are emitted when an electron jumps from an outer orbits to the fourth orbit i. e., the electron jumps to N orbit give rise to Brackett series.

Here $n_1 = 4$ & $n_2 = 5, 6, 7, ...\infty$.

The different wavelengths of this series can be obtained from the formula $\frac{1}{\lambda} = R\left[\frac{1}{4^2} - \frac{1}{n_2^2}\right]$

where $n_2 = 5, 6, 7 .....\infty$

This series lies in infra–red region of spectrum.

(xi) Pfund series : The series consist of all wavelengths which are emitted when an electron jumps from an outer orbit to the fifth orbit i. e., the electron jumps to O orbit give right to Pfund series.

Here $n_1 = 5$ and $n_2 = 6, 7, 8 .....\infty$.

The different wavelengths of this series can be obtained from the formula $\frac{1}{\lambda} = R\left[\frac{1}{5^2} - \frac{1}{n_2^2}\right]$

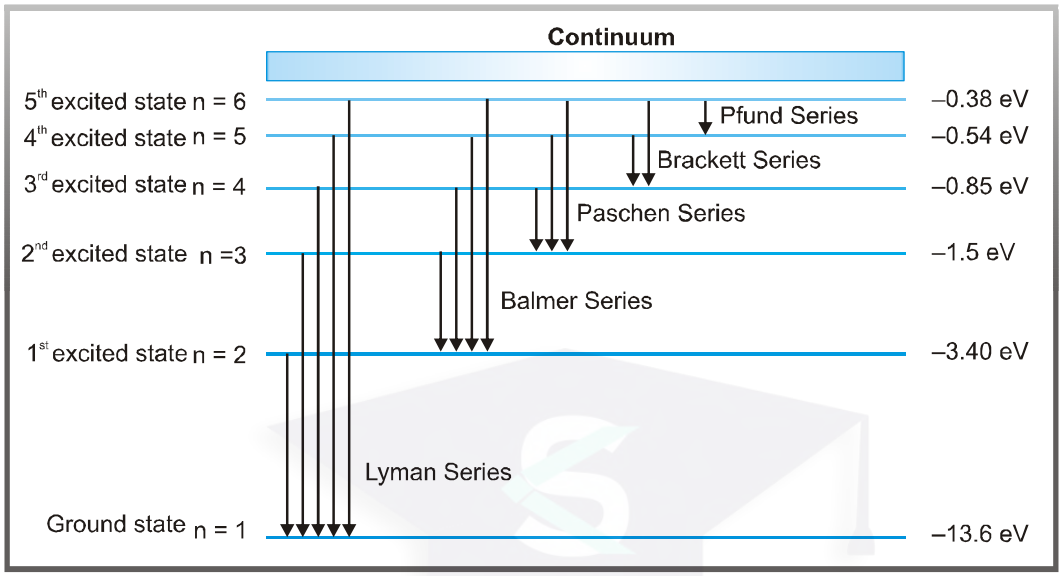
where $n_2 = 6, 7, 8 .....\infty$

This series lies in infra–red region of spectrum.

The Result are Tabulated Below

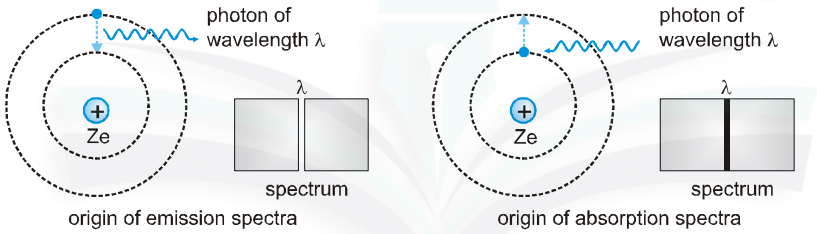
S. No.	Series Observed	Value of n_1	Value of n_2	Position in the Spectrum
1.	Lyman Series	1	2,3,4...∞	Ultra Violet
2.	Balmer Series	2	3,4,5...∞	Visible
3.	Paschen Series	3	4,5,6....∞	Infra–red
4.	Brackett Series	4	5,6,7....∞	Infra–red
5.	Pfund Series	5	6,7,8....∞	Infra–red

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EXCITATION AND IONISATION OF ATOMS

Consider the case of simplest atom i. e., hydrogen atom, this has one electron in the innermost orbit i.e., (n = 1) and is said to be in the unexcited or normal state. If by some means, sufficient energy is supplied to the electron. It moves to higher energy states. When the atom is in a state of a high energy it is said to be excited. The process of raising or transferring the electron from lower energy state is called excitation. When by the process of excitation, the electron is completely removed from the atom. The atom is said to be ionized. Now the atom has left with a positive charge. Thus the process of raising the atom from the normal state to the ionized state is called ionisation. The process of excitation and ionisation both are absorption phenomena. The excited state is not stationary state and lasts in a very short interval of time (10^{-8} sec) because the electron under the attractive force of the nucleus jumps to the lower permitted orbit. This is accompanied by the emission of radiation according to BOHR'S frequency condition.



The energy necessary to excite an atom can be supplied in a number of ways. The most commonly kinetic energy (Wholly or partly) of the electrons is transferred to the atom. The atom is now in a excited state. The minimum potential V required to accelerate the bombarding electrons to cause excitation from the ground state is called the resonance potential. The various values of potential to cause excitation of higher state called **excitation potential**. The potential necessary to accelerate the bombarding electrons to cause ionisation is called the **ionization potential**. The term critical potential is used to include the resonance, excitation and ionisation potential. We have seen that the energy required to excite the electron from first to second state is 13.6 – 3.4 = 10.2 eV from first to third state is 13.6 – 1.5 = 12.1 eV., and so on. The energy required to ionise hydrogen atom is 0 – (– 13.6) = 13.6 eV. Hence ionization potential of hydrogen atom is 13.6 volt.

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Successes and Limitations

Bohr showed that Planck's quantum ideas were a necessary element of the atomic theory. He introduced the idea of quantized energy levels and explained the emission or absorption of radiations as being due to the transition of an electron from one level to another. As a model for even multielectron atoms, the Bohr picture is still useful. It leads to a good, simple, rational ordering of the electrons in larger atoms and quantitatively helps to predict a greater deal about chemical behavior and spectral detail.

Bohr's theory is unable to explain the following facts :

(i) The spectral lines of hydrogen atom are not single lines but each one is a collection of several closely spaced lines.

(ii) The structure of multielectron atoms is not explained.

(iii) No explanation for using the principles of quantization of angular momentum.

(iv) No explanation for Zeeman effect. If a substance which gives a line emission spectrum is placed in a magnetic field, the lines of the spectrum get splitted up into a number of closely spaced lines. This phenomenon is known as Zeeman effect.

Ex. A hydrogen like atom of atomic number Z is in an excited state of quantum number 2n. It can emit a maximum energy photon of 204 eV. If it makes a transition to quantum state n, a photon of energy 40.8 eV is emitted. Find n, Z and the ground state energy (in eV) for this atom. Also, calculate the minimum energy (in eV) that can be emitted by this atom during de–excitation. Ground state energy of hydrogen atom is –13.6 eV.

Sol. The energy released during de–excitation in hydrogen like atoms is given by : $E_{n_2} - E_{n_1} = \frac{me^4}{8\varepsilon_0^2 h^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]Z^2$

Energy released in de–excitation will be maximum if transition takes place from nth energy level to ground state i.e.,

$$E_{2n} - E_1 = 13.6\left[\frac{1}{1^2} - \frac{1}{(2n)^2}\right]Z^2 = 204\text{ eV} \quad ...\textbf{(i)}$$ & also $$E_{2n} - E_n = 13.6\left[\frac{1}{n^2} - \frac{1}{(2n)^2}\right]Z^2 = 40.8\text{ eV} \quad ...\textbf{(ii)}$$

Taking ratio of **(i)** to **(ii)**, we will get $\frac{4n^2 - 1}{3} = 5 \Rightarrow n^2 = 4 \Rightarrow n = 2$

Putting n=2 in equation **(i)** we get $Z^2 = \frac{204 \times 16}{13.6 \times 15} \Rightarrow Z = 4$

$\because$ $E_n = -13.6\frac{Z^2}{n^2} \Rightarrow E_1 = -13.6 \times \frac{4^2}{1^2} = -217.6\text{ eV} = \text{ground state energy}$

ΔE is minimum if transition will be from 2n to 2n–1 i.e. between last two adjacent energy levels.

$\therefore$ $\Delta E_{min} = E_{2n} - E_{2n-1} = 13.6\left[\frac{1}{3^2} - \frac{1}{4^2}\right]4^2 = 10.57\text{ eV}$

is the minimum amount of energy released during de–excitation.

Ex. A single electron orbits around a stationary nucleus of charge +Ze where Z is a constant and e is the magnitude of electronic charge. It requires 47.2 eV to excite the electron from the second orbit to third orbit. Find

(i) The value of Z.

(ii) The energy required to excite the electron from the third to the fourth Bohr orbit.

(iii) The wavelength of electronic radiation required to remove the electron from first Bohr orbit to infinity.

(iv) Find the K.E., P.E. and angular momentum of electron in the 1st Bohr orbit.

[The ionization energy of hydrogen atom = 13.6 eV, Bohr radius = 5.3×10^{-11} m, Velocity of light = 3×10^8 m/s, Planck's constant = 6.6×10^{-34} J–s]

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Sol. The energy required to excite the electron from n_1 to n_2 orbit revolving around the nucleus with charge +Ze is given by $E_{n_2} - E_{n_1} = \frac{me^4}{8\varepsilon_0^2 h^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]Z^2 \Rightarrow E_{n_2} - E_{n_1} = Z^2 \times (13.6)\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

(i) Since 47.2 eV energy is required to excite the electron from $n_1 = 2$ to $n_2 = 3$ orbit

$$47.2 = Z^2 \times 13.6\left[\frac{1}{2^2} - \frac{1}{3^2}\right] \Rightarrow Z^2 = \frac{47.2 \times 36}{13.6 \times 5} = 24.988 \approx 25 \Rightarrow Z = 5$$

(ii) The energy required to excite the electron from $n_1 = 3$ to $n_2 = 4$ is given by

$$E_4 - E_3 = 13.6\, Z^2 = 5\left[\frac{1}{3^2} - \frac{1}{4^2}\right] = \frac{25 \times 13.6 \times 7}{144} = 16.53\ \text{eV}$$

(iii) The energy required to remove the electron from the first Bohr orbit to infinity (∞) is given by

$$E_\infty - E_3 = 13.6 \times Z^2\left[\frac{1}{1^2} - \frac{1}{\infty^2}\right] = 13.6 \times 25\,\text{eV} = 340\,\text{eV}$$

In order to calculate the wavelength of radiation, we use Bohr's frequency relation

$$hf = \frac{hc}{\lambda} = 13.6 \times 25 \times (1.6 \times 10^{-19})\text{J} \Rightarrow \lambda = \frac{(6.6 \times 10^{-34}) \times 10^8 \times 3}{13.6 \times 25 \times (1.6 \times 10^{-19})} = 36.397\text{Å}$$

(iv) $\text{K.E.} = \frac{1}{2}mv_1^2 = \frac{1}{2} \times \frac{Ze^2}{4\pi g\, \in_0 r_1} = 543.4 \times 10^{-19}\,\text{J}$ $\quad \text{P.E.} = -2 \times \text{K.E.} = -1086.8 \times 10^{-19}\,\text{J}$

$$\text{Angular momentum} = mv_1 r_1 = \frac{h}{2\pi} = 1.05 \times 10^{-34}\,\text{Js}$$

The radius r_1 of the first Bohr orbit is given by

$$r_1 = \frac{\varepsilon_0 h^2}{\pi m e^2} \cdot \frac{1}{Z} = \frac{0.53 \times 10^{-10}}{5} \left(\because \frac{\varepsilon_0 h^2}{\pi m e^2} = 0.53 \times 10^{-10}\,\text{m}\right) = 1.106 \times 10^{-10}\,\text{m} = 0.106\,\text{Å}$$

Ex. An isolated hydrogen atom emits a photon of 10.2 eV.

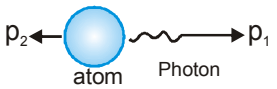
(i) Determine the momentum of photon emitted

(ii) Calculate the recoil momentum of the atom

(iii) Find the kinetic energy of the recoil atom [Mass of proton= $m_p = 1.67 \times 10^{-27}$ kg]

Sol. **(i)** Momentum of the photon is $p_1 = \frac{E}{c} = \frac{10.2 \times 1.6 \times 10^{-19}}{3 \times 10^8} = 5.44 \times 10^{-27}$ kg–m/s

(ii) Applying the momentum conservation $p_2 = p_1 = 5.44 \times 10^{-27}$ kg–m/s



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(iii) $K = \frac{1}{2}mv^2$ (v = recoil speed of atom, m = mass of hydrogen atom) $K = \frac{1}{2}m\left(\frac{p}{m}\right)^2 = \frac{p^2}{2m}$

Substituting the value of the momentum of atom, we get $K = \frac{\left(5.44\times10^{-27}\right)^2}{2\times1.67\times10^{-27}} = 8.86\times10^{-27}J$

Physical quantity	Formula	Ratio Formulae of hydrogen atom
Radius of Bohr orbit (r_n)	$r_n = \frac{n^2h^2}{4\pi^2mkZe^2}$; $r_n = 0.53\frac{n^2}{Z}$ Å	$r_1 : r_2 : r_3 ... r_n = 1:4:9...n^2$
Velocity of electron in n^{th} Bohr orbit (v_n)	$v_n = \frac{2\pi kZe^2}{nh}$; $v_n = 2.2\times10^6\frac{Z}{n}$	$v_1 : v_2 : v_3 ... v_n = 1 : \frac{1}{2} : \frac{1}{3} ... \frac{1}{n}$
Momentum of electron (p_n)	$p_n = \frac{2\pi mke^2z}{nh}$; $p_n \propto \frac{Z}{n}$	$p_1 : p_2 : p_3 ... \ p_n = 1 : \frac{1}{2} : \frac{1}{3} ... \frac{1}{n}$
Angular velocity of electron(ω_n)	$\omega_n = \frac{8\pi^3k^2Z^2mc^4}{n^3h^3}$; $\omega_n \propto \frac{Z^2}{n^3}$	$\omega_1 : \omega_2 : \omega_3 ... \omega_n = 1 : \frac{1}{8} : \frac{1}{27} ... \frac{1}{n^3}$
Time Period of electron (T_n)	$T_n = \frac{n^3h^3}{4\pi^2k^2Z^2me^4}$; $T_n \propto \frac{n^3}{Z^2}$	$T_1 : T_2 : T_3 ... T_n = 1:8:27: ... :n^3$
Frequency (f_n)	$f_n = \frac{4\pi^2k^2Z^2e^4m}{n^3h^3}$; $f_n \propto \frac{Z^2}{n^3}$	$f_1 : f_2 : f_3 ... f_n = 1 : \frac{1}{8} : \frac{1}{27} ... \frac{1}{n^3}$
Orbital current (I_n)	$I_n = \frac{4\pi^2k^2Z^2me^5}{n^3h^3}$; $I_n \propto \frac{Z^2}{n^3}$	$I_1 : I_2 : I_3 ... I_n = 1 : \frac{1}{8} : \frac{1}{27} ... \frac{1}{n^3}$
Angular momentum (J_n)	$J_n = \frac{nh}{2\pi}$; $J_n \propto n$	$J_1 : J_2 : J_3 ... J_n = 1 : 2 : 3 ... n$
Centripetal acceleration (a_n)	$a_n = \frac{16\pi^4k^3Z^3me^6}{n^4h^4}$; $a_n \propto \frac{Z^3}{n^4}$	$a_1 : a_2 : a_3 ... a_n = 1 : \frac{1}{16} : \frac{1}{81} ... \frac{1}{n^4}$
Kinetic energy (E_{K_n})	$E_{K_n} = \frac{RchZ^2}{n^2}$; $E_{K_n} \propto \frac{Z^2}{n^2}$	$E_{K_1} : E_{K_2} ... E_{K_n} = 1 : \frac{1}{4} : \frac{1}{9} ... \frac{1}{n^2}$
Potential energy (U_n)	$U_n = \frac{-2RchZ^2}{n^2}$; $U_n \propto \frac{Z^2}{n^2}$	$U_1 : U_2 : U_3 ... U_n = 1 : \frac{1}{4} : \frac{1}{9} ... \frac{1}{n^2}$
Total energy (E_n)	$E_n = \frac{-RchZ^2}{n^2}$; $E_n \propto \frac{Z^2}{n^2}$	$E_1 : E_2 : E_3 ... E_n = 1 : \frac{1}{4} : \frac{1}{9} ... \frac{1}{n^2}$

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Ex. Calculate **(a)** the wavelength and **(b)** the frequency of the H_β line of the Balmer series for hydrogen.

Sol. **(a)** H_β line of Balmer series corresponds to the transition from n = 4 to n = 2 level. The corresponding wavelength for H_β line is,

$$\frac{1}{\lambda} = (1.097\times10^7)\left(\frac{1}{2^2}-\frac{1}{4^2}\right) = 0.2056\times10^7 \qquad \therefore\ \lambda = 4.9\times10^{-7}\,\text{m}\ \textbf{Ans.}$$

(b) $\nu = \frac{c}{\lambda} = \frac{3.0\times10^8}{4.9\times10^{-7}} = 6.12\times10^{14}\,\text{Hz}$ **Ans.**

Ex. Find the largest and shortest wavelengths in the Lymen series for hydrogen. In what region of the electromagnetic spectrum does each series lie?

Sol. The transition equation for Lymen series is given by,

$$\frac{1}{\lambda} = R\left[\frac{1}{(1)^2}-\frac{1}{n^2}\right] \qquad n = 2, 3, ...$$

for largest wavelength, $n = 2$

$$\frac{1}{\lambda_{max}} = 1.097\times10^7\left(\frac{1}{1}-\frac{1}{4}\right) = 0.823\times10^7$$

$\therefore$ $\lambda_{max} = 1.2154\times10^{-7}\,\text{m} = 1215\,\text{Å}$ **Ans.**

The shortest wavelength corresponds to $n = \infty$

$\therefore$ $$\frac{1}{\lambda_{max}} = 1.097\times10^7\left(\frac{1}{1}-\frac{1}{\infty}\right)$$

or $\lambda_{min} = 0.911\times10^{-7}\,\text{m} = 911\,\text{Å}$ **Ans.**

Both of these wavelengths lie in ultraviolet (UV) region of electromagnetic spectrum.

Ex. How may different wavelengths may be observed in the spectrum from a hydrogen sample if the atoms are excited to states with principal quantum number n ?

Sol. From the nth state, the atom may go to (n – 1)th state, ..., 2nd state or 1st state. So there are (n – 1) possible transitions starting from the nth state. The atoms reaching (n – 1)th state may make (n – 2) different transitions. Similarly for other lower states. The total number of possible transitions is

$$(n-1)+(n-2)+(n-3)+.....2+1$$

$$= \frac{n(n-1)}{2} \qquad \textbf{(Remember)}$$

Ex. **(a)** Find the wavelength of the radiation required to excite the electron in Li^{++} from the first to the third Bohr orbit.

(b) How many spectral linea are observed in the emission spectrum of the above excited system?

Sol. **(a)** The energy in the first orbit = $E_1 = Z^2 E_0$ where $E_0 = -13.6$ eV is the energy of a hydrogen atom in ground state thus for Li^{++},

$$E_1 = 9E_0 = 9\times(-13.6\,\text{eV}) = -122.4\,\text{eV}$$

The energy in the third orbit is

$$E_3 = \frac{E_1}{n^2} = \frac{E_1}{9} = -13.6\,\text{eV}$$

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Thus, $E_3 - E_1 = 8 \times 13.6\,eV = 108.8\,eV.$

Energy required to excite Li^{++} from the first orbit to the third orbit is given by

$$E_3 - E_1 = 8 \times 13.6\,eV = 108.8\,eV.$$

The wavelength of radiation required to excite Li^{++} from the first orbit to the third orbit is given by

$$\frac{hc}{\lambda} = E_3 - E_1 \quad \text{or} \quad \lambda = \frac{hc}{E_3 - E_1} = \frac{1240\,eV - nm}{108.8\,eV} \approx 11.4\,nm$$

(b) The spectral lines emitted are due to the transitions $n = 3 \rightarrow n = 2$, $n = 3 \rightarrow n = 1$ and $n = 2 \rightarrow n = 1$. Thus, there will be three spectral lines in the spectrum.

Ex. Find the kinetic energy potential energy and total energy in first and second orbit of hydrogen atom if potential energy in first orbit is taken to be zero.

Sol. $E_1 = -13.60\,eV$ $K_1 = -E_1 = 13.60\,eV$ $U_1 = 2E_1 = -27.20\,eV$

$E_2 = \frac{E_1}{(2)^2} = -3.40\,eV$ $K_2 = 3.40\,eV$ and $U_2 = -6.80\,eV$

Now $U_1 = 0$, i.e., potential energy has been increased by 27.20 eV while kinetic energy will remain unchanged. So values of kinetic energy, potential energy and total energy in first orbit are 13.60 eV, 0, 13.60 respectively and for second orbit these values are 3.40 eV, 20.40 eV and 23.80 eV.

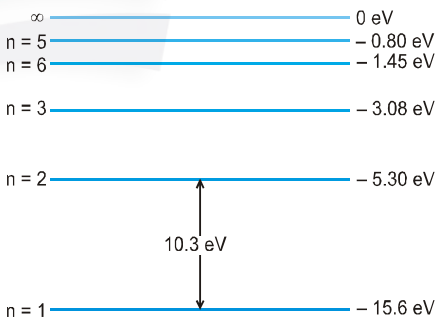
Ex. A lithium atom has three electrons, Assume the following simple picture of the atom. Two electrons move close to the nucleus making up a spherical cloud around it and the third moves outside this cloud in a circular orbit. Bohr's model can be used for the motion of this third electron but n = 1 states are not available to it. Calculate the ionization energy of lithium in ground state using the above picture.

Sol. In this picture, the third electron moves in the field of a total charge + 3e – 2e = + e. Thus, the energies are the same as that of hydrogen atoms. The lowest energy is :

$$E_2 = \frac{E_1}{4} = \frac{-13.6\ eV}{4} = -3.4\,eV$$

Thus, the ionization energy of the atom in this picture is 3.4 eV.

Ex. The energy levels of a hypothetical one electron atom are shown in the figure.



(a) Find the ionization potential of this atom.

(b) Find the short wavelength limit of the series terminating at n = 2

(c) Find the excitation potential for the state n = 3.

(d) Find wave number of the photon emitted for the transition n = 3 to n = 1.

(e) What is the minimum energy that an electron will have after interacting with this atom in the ground state if the initial kinetic energy of the electron is

(i) 6 eV **(ii)** 11 eV

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Sol. **(a)** Ionization potential = 15.6 V

(b) $\lambda_{min} = \dfrac{12400}{5.3} = 2340\ \text{Å}$

(c) $\Delta E_{31} = -3.08 - (-15.6) = 12.52\ \text{eV}$

Therefore, excitation potential for state n = 3 is 12.52 volt.

(d) $\dfrac{1}{\lambda_{31}} = \dfrac{\Delta E_{31}}{12400}$ $\quad \text{Å}^{-1} = \dfrac{12.52}{12400}\ \text{Å}^{-1} \approx 1.01 \times 10^7\ \text{m}^{-1}$

(e) **(i)** $E_2 - E_1 = 10.3\ \text{eV} > 6\ \text{eV}$.

Hence electron cannot excite the atoms. So, $K_{min} = 6\ \text{eV}$.

(ii) $E_2 - E_1 = 10.3\ \text{eV} < 11\ \text{eV}$.

Hence electron can excite the atoms. So, $K_{min} = (11 - 10.3) = 0.7\ \text{eV}$.

Ex. A small particle of mass m moves in such a way that the potential energy U = ar^2 where a is a constant and r is the distance of the particle from the origin. Assuming Bohr's model of quantization of angular momentum and circular orbits, find the radius of n^{th} allowed orbit.

Sol. The force at a distance r is,

$$F = -\frac{dU}{dr} = -2ar$$

Suppose r be the radius of nth orbit. The necessary centripetal force is provided by the above force. Thus,

$$\frac{mv^2}{r} = 2ar$$

Further, the quantization of angular momentum gives,

$$mvr = \frac{nh}{2\pi}$$

Solving Eqs. **(i)** and **(ii)** for r, we get

$$r = \left(\frac{n^2h^2}{8am\pi^2}\right)^{1/4}$$ **Ans.**

Ex. An imaginary particle has a charge equal to that of an electron and mass 100 times the mass of the electron. It moves in a circular orbit around a nucleus of charge + 4e. Take the mass of the nucleus to be infinite. Assuming that the Bohr's model is applicable to the system.

(a) Derive and expression for the radius of n^{th} Bohr orbit.

(b) Find the wavelength of the radiation emitted when the particle jumps from fourth orbit to the second.

Sol. **(a)** We have $\dfrac{m_p v^2}{r_n} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{ze^2}{r_n^2}$ .....**(i)**

The quantization of angular momentum gives,

$$m_p\, vr_n = \frac{nh}{2\pi}$$ .....**(ii)**

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Solving Eqs. **(i)** and **(ii)**, we get

$$r = \frac{n^2h^2\varepsilon_0}{z\pi m_p e^2}$$

Substituting $m_p = 100\,m$

where m = mass of electron and z = 4

we get, $r_n = \frac{n^2h^2\varepsilon_0}{400\,\pi me^2}$ **Ans.**

(b) As we know,

Energy of hydrogen atom in ground state $= -13.60$ eV

and $E_n \propto \left(\frac{z^2}{n^2}\right)m$

For the given particle, $E_4 = \frac{(-13.60)(4)^2}{(4)^2} \times 100 = -1360\,eV$

and $E_2 = \frac{(-13.60)(4)^2}{(2)^2} \times 100 = -5440\,eV$

$$DE = E_4 - E_2 = 4080\,eV$$

$\therefore$ $\lambda\,(\text{in Å}) = \frac{12400}{4080} = 3.0$ Å **Ans.**

Ex. A particle known as μ-meason, has a charge equal to that of an electron and mass 208 times the mass of the electron. It moves in a circular orbit around a nucleus of charge +3e. Take the mass of the nucleus to be infinite. Assuming that the Bohr's model is applicable to this system, **(a)** derive an expression for the radius of the nth Bohr orbit, **(b)** find the value of n for which the radius of the orbit is approximately the same as that of the first Bohr orbit for a hydrogen atom and **(c)** find the wavelength of the radiation emitted when the μ–meson jumps from the third orbit to the first orbit.

Sol. **(a)** We have,

$$\frac{mv^2}{r} = \frac{Ze^2}{4\pi\varepsilon_0 r^2}$$

or, $v^2r == \frac{Ze^2}{4\pi\varepsilon_0 m}$ ...**(i)**

The quantization rule is $vr = \frac{nh}{2\pi m}$

The radius is $r = \frac{(vr)^2}{v^2r} = \frac{4\pi\varepsilon_0 m}{Ze^2}$

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$$= \frac{n^2h^2\varepsilon_0}{Z\pi me^2} \qquad \text{....(ii)}$$

For the given system, Z = 3 and m = 208 m_e.

Thus $$r_\mu = \frac{n^2h^2\varepsilon_0}{624\pi m_e e^2}$$

(b) From **(ii)**, the radius of the first Bohr orbit for the hydrogen atom is

$$r_h = \frac{h^2\varepsilon_0}{\pi m_e e^2}$$

For $r_\mu = r_h$, $$\frac{n^2h^2\varepsilon_0}{624\pi m_e e^2} = \frac{h^2\varepsilon_0}{\pi m_e e^2}$$

or, $n^2 = 624$

or, $n = 25$

(c) From **(i)**, the kinetic energy of the atom is

$$\frac{mv^2}{2} = \frac{Ze^2}{8\pi\varepsilon_0 r}$$

and the potential energy is $-\frac{Ze^2}{4\pi\varepsilon_0 r}$

The total energy is $E_n = \frac{Ze^2}{8\pi\varepsilon_0 r}$

Using **(ii)**, $$E_n = -\frac{Z^2\pi me^4}{8\pi\varepsilon_0^2 n^2h^2} = -\frac{9\times 208 m_e^4}{8\varepsilon_0^2 n^2h^2} = \frac{1872}{n^2}\left(-\frac{m_e e^4}{8\varepsilon_0^2 h^2}\right)$$

But $\left(-\frac{m_e e^4}{8\varepsilon_0^2 h^2}\right)$ is the ground state energy of hydrogen atom and hence is equal to – 13.6 eV.

From **(iii)**, $E_n = -\frac{1872}{n^2}\times 13.6\,\text{eV} = \frac{-25459.2\,\text{eV}}{n^2}$

Thus, $E_1 = -25459.2$ eV and $E_3 = \frac{E_1}{9} = -2828.8$ eV. The energy difference is $E_3 - E_1 = 22630.4$eV.

The wavelength emitted is

$$\lambda = \frac{hc}{\Delta E} = \frac{1240\,\text{eV}-\text{nm}}{22630.4\,\text{eV}} = 55\,\text{pm}.$$

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Ex. A gas of hydrogen like atoms can absorb radiations of 68 eV. Consequently, the atoms emit radiations of only three different wavelength. All the wavelengths are equal or smaller than that of the absorbed photon.

(a) Determine the initial state of the gas atoms.

(b) Identify the gas atoms.

(c) Find the minimum wavelength of the emitted radiations.

(d) Find the ionization energy and the respective wavelength for the gas atoms.

Sol. **(a)** $\frac{n(n-1)}{2}=3$

$\therefore \quad n=3$

i.e., after excitation atom jumps to second excited state.

Hence $n_f=3$. So n_i can be 1 or 2

If $n_i=1$ then energy emitted is either equal to, greater than or less than the energy absorbed.

Hence the emitted wavelength is either equal to, less than or greater than the absorbed wavelength.

Hence $n_i \neq 1$.

If $n_i=2$, then $E_e \geq E_a$. Hence $\lambda_e \leq \lambda_0$

(b) $E_3-E_2=68\ eV$

$\therefore \quad (13.6)(Z^2)\left(\frac{1}{4}-\frac{1}{9}\right)=68$

$\therefore \quad Z=6$

(c) $\lambda_{min}=\frac{12400}{E_3-E_1}=\frac{12400}{(13.6)(6)^2\left(1-\frac{1}{9}\right)}=\frac{12400}{435.2}=28.49$ **Ans.**

(d) Ionization energy $=(13.6)(6)^2=489.6\ eV$ **Ans.**

$\lambda=\frac{12400}{489.6}=25.33\ Å$ **Ans.**

Ex. An electron is orbiting in a circular orbit of radius r under the influence of a constant magnetic field of strength B. Assuming that Bohr's postulate regarding the quantisation of angular momentum holds good for this electron, find

(a) the allowed values of the radius 'r' of the orbit.

(b) the kinetic energy of the electron in orbit

(c) The potential energy of interaction between the magnetic moment of the orbital current due to the electron moving in its orbit and the magnetic field B.

(d) The total energy of the allowed energy levels.

Sol. **(a)** radius of circular path

$r=\frac{mv}{Be}$ ....**(i)**

$mvr=\frac{nh}{2\pi}$ ....**(ii)**

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Solving these two equations, we get

$$r = \sqrt{\frac{nh}{2\pi Be}} \quad \text{and} \quad v = \sqrt{\frac{nhBe}{2\pi m^2}}$$

(b) $K = \frac{1}{2}mv^2 = \frac{nhBe}{4\pi m}$ **Ans.**

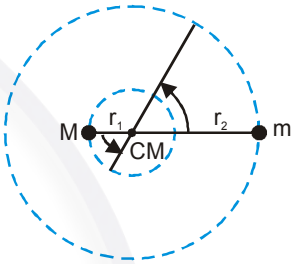
(c) $M = iA = \left(\frac{e}{T}\right)(\pi r^2) = \frac{evr}{2} = \frac{e}{2}\sqrt{\frac{nh}{2\pi Be}}\sqrt{\frac{nhBe}{2\pi m^2}} = \frac{nhe}{4\pi m}$

Now potential energy $U = -M.B = \frac{nheB}{4\pi m}$

(d) $E = U + K = \frac{nheB}{2\pi m}$

EFFECT OF NUCLEUS MOTION ON ENERGY OF ATOM

Let both the nucleus of mass M, charge Ze and electron of mass m, and charge e revolve about their centre of mass (CM) with same angular velocity (ω) but different linear speeds. Let r_1 and r_2 be the distance of CM from nucleus and electron. Their angular velocity should be same then only their separation will remain unchanged in an energy level.



Let r be the distance between the nucleus and the electron. Then

$$Mr_1 = mr_2$$

$$r_1 + r_2 = r$$

$$\therefore \quad r_1 = \frac{mr}{M+m} \quad \text{and} \quad r_2 = \frac{Mr}{M+m}$$

Centripetal force to the electron is provided by the electrostatic force.

So, $$mr_2\omega^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r^2}$$

or $$m\left(\frac{Mr}{M+m}\right)\omega^2 = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Ze^2}{r^2} \quad \text{or} \quad \left(\frac{Mm}{M+m}\right)r^3\omega^2 = \frac{Ze^2}{4\pi\varepsilon_0}$$

or $$\mu r^3\omega^2 = \frac{e^2}{4\pi\varepsilon_0}$$

where $$\frac{Mm}{M+m} = \mu$$

Moment of inertia of atom about CM,

$$I = Mr_1^2 + mr_2^2 = \left(\frac{Mm}{M+m}\right)r^2 = \mu r^2$$

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According to Bohr's theory, $\frac{nh}{2\pi} = I\omega$ or $\mu r^2\omega = \frac{nh}{2\pi}$

Solving above equations for r, we get

$$r = \frac{\varepsilon_0 n^2 h^2}{\pi \mu e^2 Z} \quad \text{and} \quad \mathbf{r = (0.529\ \text{Å})}\ \frac{n^2}{n} \cdot \frac{n}{\mu}$$

Further electrical potential energy of the system,

$$U = \frac{-Ze^2}{4\pi\varepsilon_0 r} \qquad U = \frac{-Z^2 e^4 \mu}{4\varepsilon_0^2 n^2 h^2}$$

and kinetic energy, $K = \frac{1}{2} I\omega^2 = \frac{1}{2} \mu r^2 \omega^2$ and $K = \frac{1}{2} \mu v^2$

v-speed of electron with respect to nucleus. ($v = r\omega$)

here $\omega^2 = \frac{Ze^2}{4\pi\varepsilon_0\ \mu r^3}$

$\therefore$ $K = \frac{Ze^2}{8\pi\varepsilon_0 r} = \frac{Z^2 e^4 \mu}{8\pi\varepsilon_0^2 n^2 h^2}$

$\therefore$ Total energy of the system $E_n = K + U \Rightarrow E_n = -\frac{\mu e^4}{8\varepsilon_0^2 n^2 h^2}$

this expression can also be written as

$$E_n = -(13.6\ \text{eV})\ \frac{Z^2}{n^2} \cdot \left(\frac{\mu}{m}\right)$$

The expression for E_n without considering the motion of proton is $E_n = -\frac{me^4}{8\varepsilon_0^2 n^2 h^2}$, i.e., m is replaced by μ while considering the motion of nucleus.

Ex. A positronium 'atom' is a system that consists of a positron and an electron that orbit each other. Compare the wavelength of the spectral lines of positronium with those of ordinary hydrogen.

Sol. Here the two particle have the same mass m, so the reduced mass is

$$\mu = \frac{mM}{m+M} = \frac{m^2}{2m} = \frac{m}{2}$$

where m is the electron mass. We know that $E_n \propto m$

$\therefore$ $\frac{E'_n}{E_n} = \frac{\mu}{m} = \frac{1}{2}$ energy of each level is halved. $\therefore$ Their difference will also be halved.

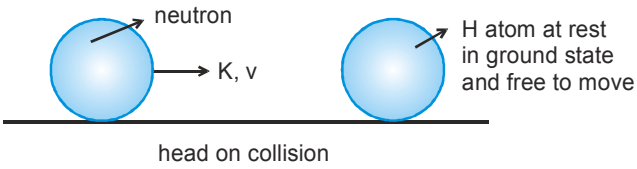
Hence $\lambda'_n = 2\lambda_n$

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ATOMIC COLLISION

In such collisions assume that the loss in the kinetic energy of system is possible only if it can excite or ionise.

Ex.



What will be the type of collision, if K = 14eV, 20.4 eV, 22 eV, 24.18 eV

(elastic/inelastic/perectly inelastic)

Sol. Loss in energy (ΔE) during the collision will be used to excite the atom or electron from one level to another.

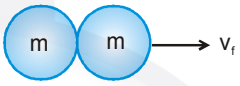
According to quantum Mechanics, for hydrogen atom.

$\Delta E = \{0, 10.2\ eV, 12.09\ eV, ..., 13.6\ eV)$

According to Newtonion mechanics

minimum loss = 0. (elastic collsion)

for maximum loss collision will be perfectly inelastic



if neutron collides perfectly inelastically

then, Applying momentum conservation

$$mv_0 = 2mv_f$$

$$v_f = \frac{v_0}{2}$$

Final $\quad K.E. = \frac{1}{2} \times 2m \times \frac{v_0^2}{4} = \frac{\frac{1}{2}mv_0^2}{2} = \frac{K}{2}$

maximum loss $= \frac{K}{2}$

According to classical mechanics $(\Delta E) = [0, \frac{K}{2}]$

(a) If $K = 14\ eV$, According to quantum mechanics

$(\Delta E) = \{0, 10.2eV, 12.09\ eV\}$

According to classical mechanics

$\Delta E = [0, 7\ eV]$

loss = 0, hence it is elastic collision speed of particle changes.

(b) If $K = 20.4\ eV$

According to classical mechanics

loss = [0, 10.2 eV]

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According to quantum mechanics

loss = {0, 10.2eV, 12.09eV,.....}

loss = 0 elastic collision.

loss = 10.2eV perfectly inelastic collision

(c) If K = 22 eV

Classical mechanics $\Delta E = [0, 11]$

Quantum mechanics $\Delta E = \{0, 10.2eV, 12.09eV, ...\}$

loss = 0 elastic collision

loss = 10.2 eV inelastic collsion

(d) If K = 24.18 eV

According to classical mechanics $\Delta E = [0, 12.09eV]$

According to quantum mechanics $\Delta E = \{0, 10.2eV, 12.09eV, ... 13.6eV\}$

loss = 0 elastic collision

loss = 10.2 eV inelastic collision

loss = 12.09 eV perfectly inelastic collision

Ex. A He^+ ion is at rest and is in ground state. A neutron with initial kinetic energy K collides head on with the He^+ ion. Find minimum value of K so that there can be an inelastic collision between these two particle.

Sol. Here the loss during the collision can only be used to excite the atoms or electrons.

So according to quantum mechanics

loss = {0, 40.8eV, 48.3eV, ..., 54.4eV} ....(1)

$E_n = -13.6 \frac{Z^2}{n^2}$ eV



Now according to newtonion mechanics

Minimum loss = 0

maximum loss will be for perfectly inelastic collision.

let v_0 be the initial speed of neutron and v_f be the final common speed.

so by momentum conservation $mv_0 = mv_f + 4mv_f$ $v_f = \frac{v_0}{5}$

where m = mass of Neutron

$\therefore$ mass of He^+ ion = 4m

So final kinetic energy of system

$$K.E. = \frac{1}{2} m v_f^2 + \frac{1}{2} 4m v_f^2 = \frac{1}{2}.(5m).\frac{v_0^2}{25} = \frac{1}{5}.(\frac{1}{2}mv_0^2) = \frac{K}{5}$$

maximum loss $= K - \frac{K}{5} = \frac{4K}{5}$

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So loss will be $\left[0, \frac{4K}{5}\right]$ ....(2)

For inelastic collision there should be at least one common value other than zero in set (1) and (2)

$$\therefore \quad \frac{4K}{5} > 40.8 \text{ eV}$$

$$K > 51 \text{ eV}$$

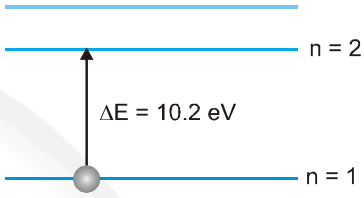
minimum value of K = 51 eV.

Ex. A moving hydrogen atom makes a head on collision with a stationary hydrogen atom. Before collision both atoms are in ground state and after collision they move together. What is the minimum value of the kinetic energy of the moving hydrogen atom, such that one of the atoms reaches one of the excitation state.

Sol. Let K be the kinetic energy of the moving hydrogen atom and K', the kinetic energy of combined mass after collision.

From conservation of linear momentum,

$$p = p' \text{ or } \sqrt{2Km} = \sqrt{2K'(2m)}$$



or $K = 2K'$ ....(i)

From conservation of energy, $K = K' + \Delta E$ ....(ii)

Solving Eqs. (i) and (ii), we get $\Delta E = \frac{K}{2}$

Now minimum value of ΔE for hydrogen atom is 10.2 eV.

or $\Delta E \geq 10.2 \text{ eV}$

$$\therefore \quad \frac{K}{2} \geq 10.2$$

$$\therefore \quad K \geq 20.4 \text{ eV}$$

Therefore, the minimum kinetic energy of moving hydrogen is 20.4 eV **Ans.**

Ex. A neutron moving with speed v makes a head-on collision with a hydrogen atom in ground state kept at rest. Find the minimum kinetic energy of the neutron for which inelastic (completely or partially) collision may take place. The mass of neutron = mass of hydrogen = 1.67×10^{-27} kg.

Sol. Suppose the neutron and the hydrogen atom move at speed v_1 and v_2 after the collision. The collision will be inelastic if a part of the kinetic energy is used to excite the atom. Suppose an energy ΔE is used in this way. Using conservation of linear momentum and energy.

$$mv = mv_1 + mv_2 \quad \text{....(i)}$$

and $$\frac{1}{2} mv^2 = \frac{1}{2} mv_1^2 + \frac{1}{2} mv_2^2 + \Delta E \quad \text{....(ii)}$$

From (i), $v^2 = v_1^2 + v_2^2 + 2v_1v_2$,

From (ii), $$v^2 = v_1^2 + v_2^2 + \frac{2\Delta E}{m}$$

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Thus, $2v_1v_2 = \frac{2\Delta E}{m}$

Hence, $(v_1 - v_2)^2 - 4v_1v_2 = v^2 - \frac{4\Delta E}{m}$

As $v_1 - v_2$ must be real, $v^2 - \frac{4\Delta E}{m} \geq 0$

or, $\frac{1}{2}mv^2 > 2\Delta E.$

The minimum energy that can be absorbed by the hydrogen atom in ground state to go in an excited state is 10.2 eV. Thus, the minimum kinetic energy of the neutron needed for an inelastic collision is

$$\frac{1}{2}mv_{min}^2 = 2 \times 10.2\,eV = 20.4\,eV$$

Ex. How many head-on, elastic collisions must a neutron have with deuterium nucleus to reduce its energy from 1 MeV to 0.025 eV.

Sol. Let mass of neutron = m and mass of deuterium = 2m

initial kinetic energy of neutron = K_0

Let after first collision kinetic energy of neutron and deuterium be K_1 and K_2.

Using C.O.L.M. along direction of motion

$$\sqrt{2mK_0} = \sqrt{2mK_1} + \sqrt{4mK_2}$$

velocity of seperation = velocity of approach

$$\frac{\sqrt{4mK_2}}{2m} - \frac{\sqrt{2mK_1}}{m} = \frac{\sqrt{2mK_0}}{m}$$

Solving equaiton **(i)** and **(ii)** we get

$$K_1 = \frac{K_0}{9}$$

Loss in kinetic eneryg after first collision

$$\Delta K_1 = K_0 - K_1$$

$$\Delta K_1 = \frac{8}{9}K_0 \qquad \text{..... (1)}$$

After second collision

$$\Delta K_2 = \frac{8}{9}K_1 = \frac{8}{9} \cdot \frac{K_0}{9}$$

$\therefore$ Total energy loss

$$\Delta K = \Delta K_1 + \Delta K_2 + ... + \Delta K_n$$

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As, $\Delta K = \frac{8}{9}K_0 + \frac{8}{9^2}K_0 + \ldots\ldots\ldots + \frac{8}{9^n}K_0$

$$\Delta K = \frac{8}{9}K_0\left(1 + \frac{1}{9} + \ldots\ldots\ldots + \frac{1}{9^{n-1}}\right)$$

$$\frac{\Delta K}{K_0} = \frac{8}{9}\left[\frac{1-\frac{1}{9^n}}{1-\frac{1}{9}}\right] = 1 - \frac{1}{9^n}$$

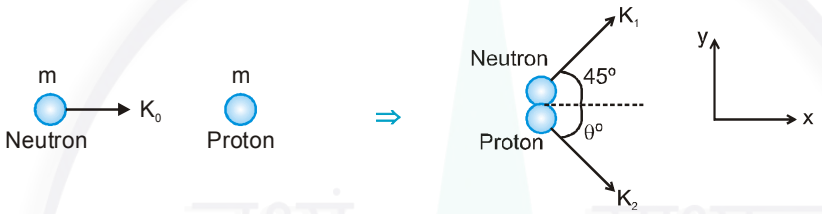
Here, $K_0 = 10^6$ eV, $\Delta K = (10^6 - 0.025)$ eV

$\therefore$ $\frac{1}{9^n} = \frac{K_0 - \Delta K}{K_0} = \frac{0.025}{10^6}$ or $9^n = 4 \times 10^7$

Taking log both sides and solving, we get $n = 8$

Ex. A neutron with an energy of 4.6 MeV collides with protons and is retarded. Assuming that upon each collision neutron is deflected by 45° find the number of collisions which will reduce its energy to 0.23 eV.

Sol. Mass of neutron $\approx$ mass of proton = m



From conservation of momentum in y-direction

$$\sqrt{2mK_1}\sin 45° = \sqrt{2mK_2}\sin\theta \quad \ldots.(i)$$

In x-direction $\sqrt{2mK_0} - \sqrt{2mK_1}\cos 45° = \sqrt{2mK_2}\cos\theta \quad \ldots.(ii)$

Squaring and adding equation **(i)** and **(ii)**, we have

$$K_2 = K_1 + K_0 - \sqrt{2K_0K_1} \quad \ldots.(iii)$$

From conservation of energy

$$K_2 = K_0 - K_1 \quad \ldots.(iv)$$

Solving equations **(iii)** and **(iv)**, we get

$$K_1 = \frac{K_0}{2}$$

i.e., after each collision energy remains half. Therefore, after n collisions,

$$K_n = K_0\left(\frac{1}{2}\right)^n$$

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$$\therefore \qquad 0.23 = (4.6 \times 10^6)\left(\frac{1}{2}\right)^n \qquad 2^n = \frac{4.6 \times 10^6}{0.23}$$

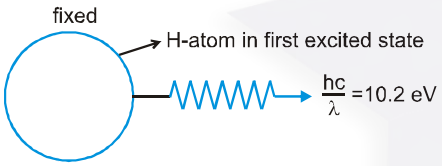
Taking log and solving, we get

$$n \approx 24 \quad \textbf{Ans.}$$

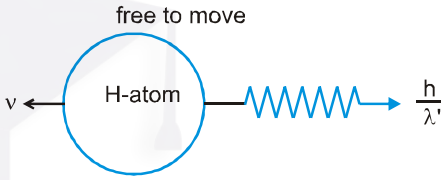
Calculation of Recoil Speed of Atom on Emission of a Photon

$$\text{Momentum of Photon} = mc = \frac{h}{\lambda}$$

(a)



(b)



m - mass of atom

According to momentum conservation

$$mv = \frac{h}{\lambda'} \qquad \text{.... (i)}$$

According to energy conservation

$$\frac{1}{2}mv^2 + \frac{hc}{\lambda'} = 10.2\,eV$$

Since mass of atom is very large than photon

hence $\frac{1}{2}mv^2$ can be neglected

$$\frac{hc}{\lambda'} = 10.2\,eV \quad \Rightarrow \quad \frac{h}{\lambda} = \frac{10.2}{c}\,eV$$

$$mv = \frac{10.2}{c}eV \quad \Rightarrow \quad v = \frac{10.2}{cm}$$

$$\text{recoil speed of atom} = \frac{10.2}{cm}$$

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X-RAY

What are X - Rays

X-rays are electromagnetic radiation of very short wavelength 0.1 Å and 100 Å) and high energy which are emitted when fast moving electrons or cathode rays strike a target of high atomic mass.

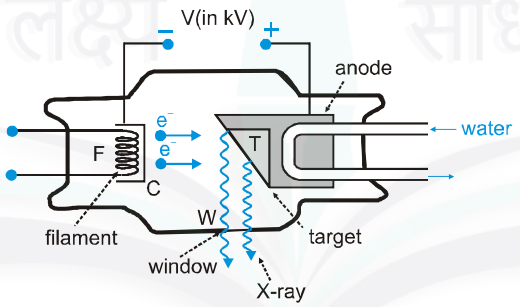
The X-Rays extends from the ultraviolet band to gamma rays band. Although their is very thin line between the X-ray and gamma rays but they are distinguished by the source of their generation. In the older days the X-Rays were distinguished from gamma rays by the wavelength and frequency but with time it has been observed that their exists X-Rays and gamma rays overlapping band and hence it is then understood that the distinction between them is source of generation.

Historical background

On Nov. 1895, Wilhelm Conrad Rontgen (accidentally) discovered an image cast from his cathode ray generator, projected far beyond the possible range of the cathode rays (now known as an electron beam). Further investigation showed that the rays were generated at the point of contact of the cathode ray beam on the interior of the vacuum tube, that they were not deflected by magnetic fields, and they penetrated many kinds of matter. Rontgen named the new form of radiation X-radiation (X standing for "Unknown").

COOLIDGE METHOD

Coolidge developed thermoionic vacuum X–ray tube in which electron are produced by thermoionic emission method. Due to high potential difference electrons (emitted due to thermoionic method) move towards the target and strike from the atom of target due to which X–ray are produced. Experimentally it is observed that only 1% or 2% kinetic energy of electron beam is used to produce X–ray. Rest of energy is wasted in form of heat.



Characteristics of Target

(a) Must have high atomic number to produce hard X–rays.

(b) High melting point to withstand high temperature produced.

(c) High thermal conductivity to remove the heat produced

(d) Tantalum, platinum, molybdenum and tungsten serve as target materials

Control of intensity : The intensity of X–ray depends on number of electrons striking the target and number of electron depend on temperature of filament which can be controlled by filament current.

Thus intensity of X–ray depends on current flowing through filament.

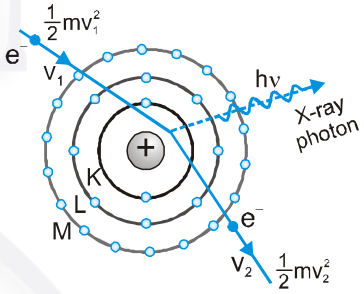
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Control of Penetrating Power: The Penetrating power of X–ray depends on the energy of incident electron. The energy of electron can be controlled by applied potential difference. Thus penetrating power of X–ray depend on applied potential difference. Thus the intensity of X–ray depends on current flowing through filament while penetrating power depends on applied potential difference

	Soft X–ray	Hard X–ray
Wavelength	10 Å to 100 Å	0.1 Å – 10 Å
Energy	$\frac{12400}{\lambda}$ eV–Å	$\frac{12400}{\lambda}$ eV–Å
Penetrating power	Less	More
Use	Radio photography	Radio therapy

Continuous spectrum of X–ray :

When high speed electron collides from the atom of target and passes close to the nucleus. There is coulomb attractive force due to this electron is deaccelerated i.e. energy is decreased. The loss of energy during deacceleration is emitted in the form of X–rays. X–ray produced in this way are called Braking or Bremstralung radiation and form continuous spectrum. In continuous spectrum of X–ray all the wavelength of X–ray are present but below a minimum value of wavelength there is no X–ray. It is called cut off or threshold or minimum wavelength of X–ray. The minimum wavelength depends on applied potential.

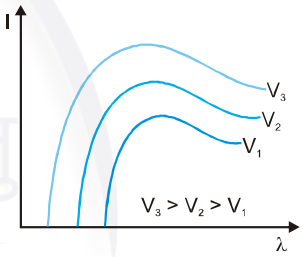


Loss in Kinetic Energy

$\frac{1}{2}mv_1^2 - \frac{1}{2}mv_2^2 = h\nu$ + heat energy if $v_2 = 0$, $v_1 = v$ (In first collision, heat = 0)

$\frac{1}{2}mv^2 = h\nu_{max}$ ...**(i)**

$\frac{1}{2}mv^2 = eV$ ...**(ii)** [here V is applied potential]

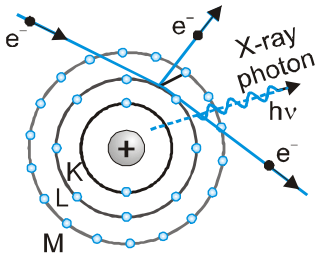


from **(i)** and **(ii)** $h\nu_{max} = eV \Rightarrow \frac{hc}{\lambda_{min}} = eV \Rightarrow \lambda_{min} = \frac{12400}{V} \times \text{volt} = \frac{12400}{V} \times 10^{-10}\,\text{m} \times \text{volt}$

Continuous X–rays also known as white X–ray. Minimum wavelength of these spectrum only depends on applied potential and doesn' t depend on atomic number.

Characteristic Spectrum of X–ray

When the target of X–ray tube is collide by energetic electron it emits two type of X–ray radiation. One of them has a continuous spectrum whose wavelength depend on applied potential while other consists of spectral lines whose wavelength depend on nature of target. The radiation forming the line spectrum is called characteristic X–rays. When highly accelerated electron strikes with the atom of target then it knockout the electron of orbit, due to this a vacancy is created. To fill this vacancy electron jumps from higher energy level and electromagnetic radiation are emitted which form characteristic spectrum of X–ray. Whose wavelength depends on nature of target and not on applied potential.



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From Bohr Model

$n_1 = 1$, $n_2 = 2, 3, 4$.....K series

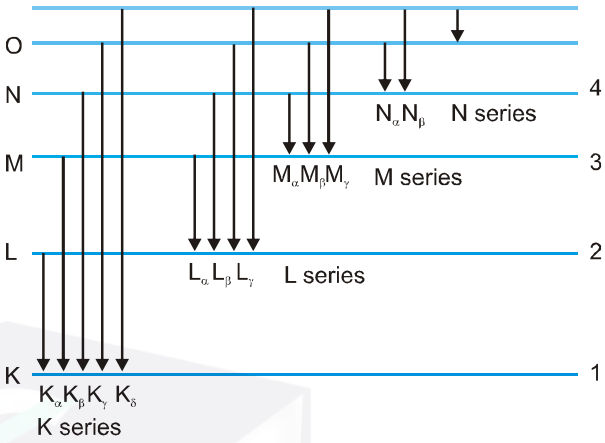
$n_1 = 2$, $n_2 = 3, 4, 5$.....L series

$n_1 = 3$, $n_2 = 4, 5, 6$.....M series

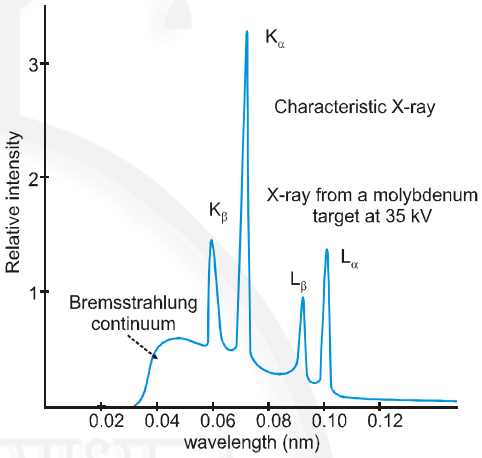
First line of series = α

Second line of series = β

Third line of series = γ



Transition	Wave–length	Energy difference	Energy	Wavelength
$L \to K$	$\lambda_{K\alpha}$	$h\nu_{K\alpha}$	$-(E_K - E_L)$	$\lambda_{K\alpha} = \frac{hc}{(E_K - E_L)}$
$(2 \to 1)$		$= h\nu_{K\alpha}$		$= \frac{12400}{(E_K - E_L)}$ eVÅ
$M \to K$	$\lambda_{K\beta}$	$h\nu_{K\beta}$	$-(E_K - E_M)$	$\lambda_{K\beta} = \frac{hc}{(E_K - E_M)}$
$(3 \to 1)$		$= h\nu_{K\beta}$		$= \frac{12400}{(E_K - E_M)}$ eVÅ
$M \to L$	$\lambda_{L\alpha}$	$h\nu_{L\alpha}$	$-(E_L - E_M)$	$\lambda_{L\alpha} = \frac{hc}{(E_L - E_M)}$
$(3 \to 2)$		$= h\nu_{L\alpha}$		$= \frac{12400}{(E_L - E_M)}$ eVÅ



MOSELEY'S LAW

Moseley studied the characteristic spectrum of number of many elements and observed that the square root of the frequency of a K– line is closely proportional to atomic number of the element. This is called Moseley's law.

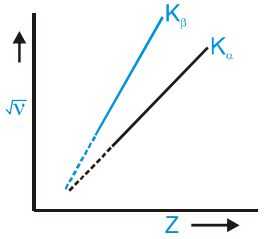
$$\sqrt{\nu} \propto (Z - b) \Rightarrow \nu \propto (Z - b)^2 \Rightarrow \nu = a(Z - b)^2 \quad \text{...(i)}$$

Z = atomic number of target

ν = frequency of characteristic spectrum

b = screening constant (for K– series b=1, L series b=7.4)

a = proportionality constant



From Bohr Model $\nu = RcZ^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ ...(ii)

Comparing (i) and (ii) $a = Rc\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

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❖ Thus proportionality constant 'a' does not depend on the nature of target but depend on transition.

	Bohr model		Moseley's correction
1.	For single electron species	1.	For many electron species
2.	$\Delta E = 13.6Z^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$ eV	2.	$\Delta E = 13.6\,(Z-1)^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$ eV
3.	$\nu = RcZ^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$	3.	$\nu = Rc(Z-1)^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$
4.	$\frac{1}{\lambda} = RZ^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$	4.	$\frac{1}{\lambda} = R\,(Z-1)^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$

❖ For X–ray production, Moseley formulae are used because heavy metal are used.

When target is same $\lambda \propto \frac{1}{\frac{1}{n_1^2}-\frac{1}{n_2^2}}$ When transition is same $\lambda \propto \frac{1}{(Z-b)^2}$

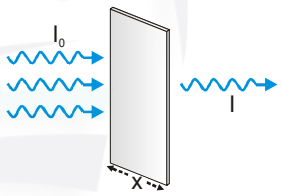
ABSORPTION OF X–RAY

When X–ray passes through x thickness then its intensity $I = I_0 e^{-\mu x}$

I_0 = Intensity of incident X–ray

I = Intensity of X–ray after passing through x distance

μ = absorption coefficient of material



❖ Intensity of X–ray decrease exponentially.

❖ Maximum absorption of X–ray $\rightarrow$ Lead

❖ Minimum absorption of X–ray $\rightarrow$ Air

HALF THICKNESS ($x_{1/2}$)

The distance travelled by X–ray when intensity become half the original value $x_{1/2} = \frac{\ell n_2}{\mu}$

Ex. When X–rays of wavelength 0.5Å pass through 10 mm thick Al sheet then their intensity is reduced to one sixth. Find the absorption coefficient for Aluminium .

Sol. $\mu = \frac{2.303}{x}\log\left(\frac{I_o}{I}\right) = \frac{2.303}{10}\log_{10} 6 = \frac{2.303 \times 0.7781}{10} = 0.1752/\text{mm}$

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DIFFRACTION OF X–RAY

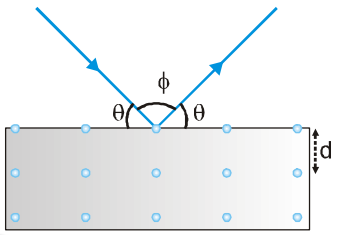
Diffraction of X–ray is possible by crystals because the interatomic spacing in a crystal lattice is order of wavelength of X–rays it was first verified by Lauve.

Diffraction of X–ray take place according to Bragg's law $2d \sin\theta = n\lambda$

d = spacing of crystal plane or lattice constant or distance between adjacent atomic plane

θ = Bragg's angle or glancing angle

ϕ = Diffracting angle n = 1, 2, 3 .....



For Maximum Wavelength

$\sin\theta = 1, n = 1 \Rightarrow \lambda_{max} = 2d$

so if $\lambda > 2d$ diffraction is not possible i.e. solution of Bragg's equation is not possible.

PROPERTIES OF X–RAY

(i) X–ray always travel with the velocity of light in straight line because X–rays are em waves

(ii) X–ray is electromagnetic radiation it show particle and wave both nature

(iii) In reflection, diffraction, interference, refraction X–ray shows wave nature while in photoelectric effect it shows particle nature.

(iv) There is no charge on X–ray thus these are not deflected by electric field and magnetic field.

(v) X–ray are invisible.

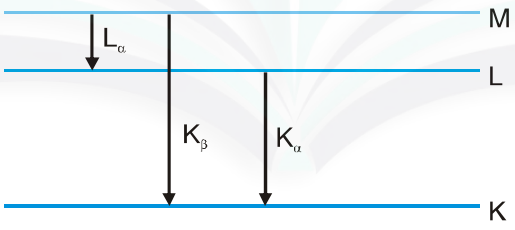
(vi) X–ray affects the photographic plate

(vii) When X–ray incidents on the surface of substance it exerts force and pressure and transfer energy and momentum

(viii) Characteristic X–ray can not obtained from hydrogen because the difference of energy level in hydrogen is very small.

Ex. Show that the frequency of K_β X–ray of a material is equal to the sum of frequencies of K_α and L_α X–rays of the same material.

Sol. The energy level diagram of an atom with one electron knocked out is shown above.



Energy of K_α X–ray is $E_{K\alpha} = E_L - E_K$

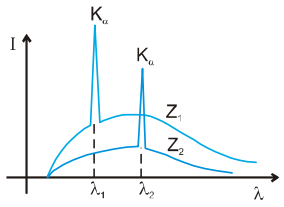
and of K_β X–ray is $E_{K\beta} = E_M - E_K$

and of L_α X–rays is $E_{L\alpha} = E_M - E_L$

thus $E_{K\beta} = E_{K\alpha} + E_{L\alpha}$ or $\nu_{K\beta} = \nu_{K\alpha} + \nu_{L\alpha}$

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Ex.



Find in Z_1 and Z_2 which one is greater.

Sol. $\because \sqrt{\nu} \equiv \sqrt{cR\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)}\ .(Z-b)$

If Z is greater then ν will be greater, λ will be less

$\therefore \quad \lambda_1 < \lambda_2 \quad \therefore \quad Z_1 > Z_2.$

Ex. A cobalt target is bombarded with electrons and the wavelength of its characteristic spectrum are measured. A second, fainter, characteristic spectrum is also found because of an impurity in the target. The wavelength of the K_α lines are 178.9 pm (cobalt) and 143.5 pm (impurity). What is the impurity?

Sol. Using Moseley's law and putting c/λ for ν (and assuming b = 1), we obtain

$$\sqrt{\frac{c}{\lambda_{c_0}}} = aZ_{c_0} - a \qquad \text{and} \qquad \sqrt{\frac{c}{\lambda_x}} = aZ_x - a$$

Dividing yields $\sqrt{\frac{\lambda_{c_0}}{\lambda_x}} = \frac{Z_x - 1}{Z_{c_0} - 1}$

Substituting gives us $\sqrt{\frac{178.9\,pm}{143.5\,pm}} = \frac{Z_x - 1}{27 - 1}.$

Solving for the unknown, we find $Z_x = 30.0$; the impurity is zinc.

Ex. Find the constants a and b in Moseley's equation $\sqrt{\nu} = a(Z-b)$ from the following data.

Element	Z	Wavelength of K_α X-ray
Mo	42	71 pm
Co	27	178.5 pm

Sol. Moseley's equation is

$$\sqrt{\nu} = a(Z-b)$$

Thus, $\sqrt{\frac{c}{\lambda_1}} = a(Z_1 - b)$ ....**(i)** and $\sqrt{\frac{c}{\lambda_2}} = a(Z_2 - b)$ ....**(ii)**

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From (i) and (ii) $\sqrt{c}\left(\frac{1}{\sqrt{\lambda_1}}-\frac{1}{\sqrt{\lambda_2}}\right)=a(Z_1-Z_2)$ or, $a=\frac{\sqrt{c}}{(Z_1-Z_2)}\left(\frac{1}{\sqrt{\lambda_1}}-\frac{1}{\sqrt{\lambda_2}}\right)$

$$=\frac{(3\times10^8 m/s)^{1/2}}{42-27}\left[\frac{1}{(71\times10^{-12}m)^{1/2}}-\frac{1}{(178.5\times10^{-12}m)^{1/2}}\right]=5.0\times10^7\,(Hz)^{1/2}$$

Dividing (i) by (ii),

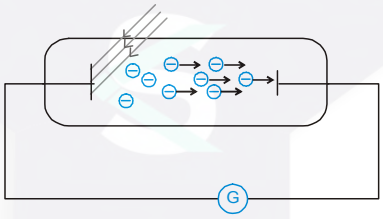
$$\sqrt{\frac{\lambda_2}{\lambda_1}}=\frac{Z_1-b}{Z_2-b} \quad \text{or,} \quad \sqrt{\frac{178.5}{71}}=\frac{42-b}{27-b} \quad \text{or,} \quad b=1.37$$

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PHOTOELECTRIC EFFECT

INTRODUCTION

The photoelectric effect or photoemission is the production of electrons or other free corners when light is shone onto a material. Electrons emitted in this manner can be called photoelectrons. It was discovered by manner can be called photoelectrons. It was discovered by Hertz in 1887. He found that when negative plate of on electronic discharge tube was illuminated with ultraviolet light. The electric discharge took place more readily. Further experiments carried out by Hallwachs confirmed that certain negatively charge particles are emitted, whenb a Zn plate is illuminated with ultraviolet light. These particles were identified as electrons.

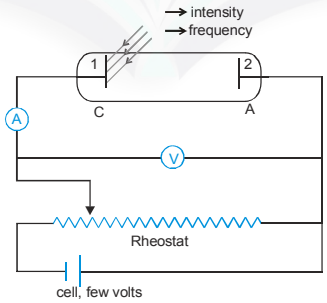


1. **Photoelectron :** The electron emitted in photoelectric effect is called photoelectron.
2. **Photoelectric current :** If current passes through the circuit in photoelectric effect then the current is called photoelectric current.
3. **Work function :** The minimum energy required to make an electron free from the metal is called work function. It is constant for a metal and denoted by ϕ or W. It is the minimum for Cesium. It is relatively less for alkali metals.

WORK FUNCTIONS OF SOME PHOTOSENSITIVE METALS

Metal	Work function (ev)	Metal	Work function (eV)
Cesium	1.9	Calcium	3.2
Potassium	2.2	Copper	4.5
Sodium	2.3	Silver	4.7
Lithium	2.5	Platinum	5.6

To produce photo electric effect only metal and light is necessary but for observing it, the circuit is completed. Figure shows an arrangement used to study the photoelectric effect.



Here the plate (1) is called emitter or cathode and other plate (2) is called collector or anode.

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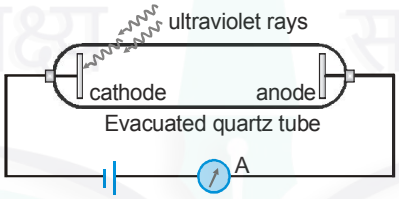
1. **Saturation Current :** When all the photo electrons emitted by cathode reach the anode then current flowing in the circuit at that instant is known as saturated current, this is the maximum value of photoelectric current.
2. **Stopping Potential :** Minimum magnitude of negative potential of anode with respect to cathode for which current is zero is called stopping potential. This is also known as cutoff voltage. This voltage is independent of intensity.
3. **Retarding Potential :** Negative potential of anode with respect to cathode which is less than stopping potential is called retarding potential.

EXPLANATION OF PHOTOELECTRIC EFFECT

1. **On the basis of wave theory :** According to wave theory, light is an electromagnetic radiation consisting of oscillating electric field vectors and magnetic field vectors. When electromagnetic radiations are incident on a metal surface, the free electrons [free electrons means the electrons which are loosely bound and free to move inside the metal] absorb energy from the radiation. This occurs by the oscillations of electron under the action of electric field vector of electromagnetic radiation. When an electron acquires sufficiently high energy so that it can overcome its binding energy, it comes out from the metal.
2. **On the basis of photon theory:** According to photon theory of light, light consists of particles (called photons). Each particle carries a certain amount of energy with it. This energy is given by $E=h\nu$, where h is the Plank's constant and ν is the frequency. When the photons are incident on a metal surface, they collide with electrons. In some of the collisions, a photon is absorbed by an electron. Thus an electron gets energy $h\nu$. If this energy is greater than the binding energy of the electron, it comes out of the metal surface. The extra energy given to the electron becomes its kinetic energy.

EXPERIMENTS

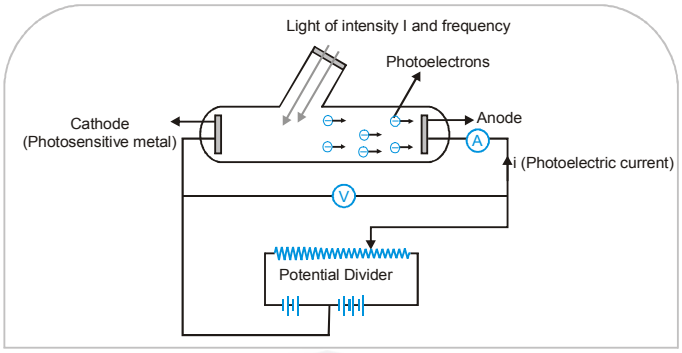
1. **Hertz Experiment :** Hertz observed that when ultraviolet rays are incident on negative plate of electric discharge tube then conduction takes place easily in the tube.



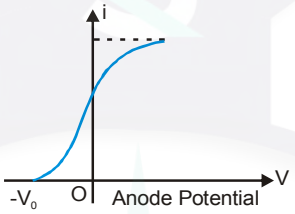
2. **Hallwach Experiment :** Hallwach observed that if negatively charged Zn plate is illuminated by U.V. light, its negative charge decreases and it becomes neutral and after some time it gains positive charge. It means in the effect of light, some negative charged particles are emitted from the metal.
3. **Lenard Explanation :** He told that when ultraviolet rays are incident on cathode, electrons are ejected. These electrons are attracted by anode and circuit is completed due to flow of electrons and current flows. When U.V. rays incident on anode, electrons are ejected but current does not flow.

   For the photo electric effect the light of short wavelength (or high frequency) is more effective than the light of long wavelength (or low frequency)
4. **Experimental study of photoelectric Effect :** When light of frequency ν and intensity I falls on the cathode, electrons are emitted from it. The electrons are collected by the anode and a current flows in the circuit. This current is called photoelectric current. This experiment is used to study the variation of photoelectric current with different factors like intensity, frequency and the potential difference between the anode and cathode.

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(i) Variation of photoelectric current with potential difference : With the help of the above experimental setup, a graph is obtained between current and potential difference. The potential difference is varied with the help of a potential divider. The graph obtained is shown below.



The main points of observation are :

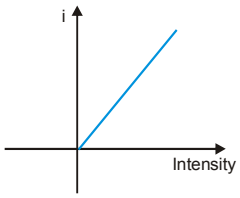
(a) At zero anode potential, a current exists. It means that electrons are emitted from cathode with some kinetic energy.

(b) As anode potential is increased, current increases. This implies that different electrons are emitted with different kinetic energies.

(c) After a certain anode potential, current acquires a constant value called saturation current. Current acquires a saturation value because the number of electrons emitted 7 per second from the cathode are fixed.

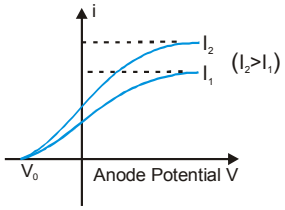
(d) At a certain negative potential, the photoelectric current becomes zero. This is called stopping potential (V_0). Stopping potential is a measure of maximum kinetic energy of the emitted electrons. Let KE_{max} be the maximum kinetic energy of an emitted electron, then $KE_{max} = eV_0$.

(ii) Variation of current with intensity



The photoelectric current is found to be directly proportional to intensity of incident radiation.

(iii) Effect of intensity on saturation current and stopping potential

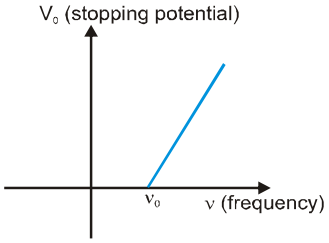


(a) Saturation current increases with increase in intensity.

(b) Stopping potential (and therefore maximum kinetic energy) is independent of intensity.

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(iv) Effect of frequency



(a) Stopping potential is found to vary with frequency of incident light linearly. Greater the frequency of incident light, greater the stopping potential.

(b) There exists a certain minimum frequency ν_0 below which no stopping potential is required as no emission of electrons takes place. This frequency is called threshold frequency. For photoelectric emission to take place, $\nu > \nu_0$.

(i) Photo electric effect is an instantaneous process, as soon as light is incident on the metal, photo electrons are emitted.

(ii) Stopping potential does not depend on the distance between cathode and anode.

(iii) The work function represented the energy needed to remove the least tightly bounded electrons from the surface. It depends only on nature of the metal and independent of any other factors.

1. Failure of wave theory of light

(i) According to wave theory when light incident on a surface, energy is distributed continuously over the surface. So that electron has to wait to gain sufficient energy to come out. But in experiment there is no time lag. Emission of electrons takes place in less than 10^{-9} s. This means, electron does not absorb energy. They get all the energy once.

(ii) When intensity is increased, more energetic electrons should be emitted. So that stopping potential should be intensity dependent. But it is not observed.

(iii) According to wave theory, if intensity is sufficient then, at each frequency, electron emission is possible. It means there should not be existence of threshold frequency.

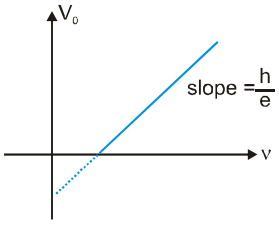
2. Einstein's Explanation of Photoelectric Effect

Einstein explained photoelectric effect on the basis of photon–electron interaction. The energy transfer takes place due to collisions between an electrons and a photon. The electrons within the target material are held there by electric force. The electron needs a certain minimum energy to escape from this pull. This minimum energy is the property of target material and it is called the work function. When a photon of energy E=hν collides with and transfers its energy to an electron, and this energy is greater than the work function, the electron can escape through the surface.

3. Einstein's Photoelectric Equation $h\nu = \phi + KE_{max}$

Here hν is the energy transferred to the electron. Out of this, ϕ is the energy needed to escape.

The remaining energy appears as kinetic energy of the electron.



Now $KE_{max} = eV_0$ (where V_0 is stopping potential)

$$\therefore h\nu = \phi + eV_0 \Rightarrow V_0 = \left(\frac{h}{e}\right)\nu - \frac{\phi}{e}$$

Thus, the stopping potential varies linearly with the frequency of incident radiation.

Slope of the graph obtained is $\frac{h}{e}$. This graph helps in determination of Planck's constant.

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(i) Einstein's Photo Electric equation is based on conservation of energy.

(ii) Einstein explained P.E.E. on the basis of quantum theory, for which he was awarded noble prize.

(iii) According to Einstein one photon can eject one e^- only. But here the energy of incident photon should greater or equal to work function.

(iv) In photoelectric effect all photoelectrons do not have same kinetic energy. Their KE range from zero to E_{max} which depends on frequency of incident radiation and nature of cathode.

(v) The photo electric effect takes place only when photons strike bound electrons because for free electrons energy and momentum conservations do not hold together.

Ex. In an experiment on photo electric emission, following observations were made;

(i) Wavelength of the incident light = 1.98×10^{-7} m;

(ii) Stopping potential = 2.5 volt.

Find : **(a)** Kinetic energy of photoelectrons with maximum speed.

(b) Work function and

(c) Threshold frequency;

Sol. **(a)** Since $v_s = 2.5$ V, $K_{max} = eV_s$ So, $K_{max} = 2.5$ eV

(b) Energy of incident photon

$$E = \frac{12400}{1980} eV = 6.26 \text{ eV} \qquad W = E - K_{max} = 3.76 \text{ eV}$$

(c) $h\nu_{th} = W = 3.76 \times 1.6 \times 10^{-19}$ J $\quad \therefore \quad \nu_{th} = \dfrac{3.76 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}} \approx 9.1 \times 10^{14}$ Hz

Ex. A beam of light consists of four wavelength 4000 Å, 4800 Å, 6000 Å and 7000 Å, each of intensity 1.5×10^{-3} Wm^{-2}. The beam falls normally on an area 10^{-4} m^2 of a clean metallic surface of work function 1.9 eV. Assuming no loss of light energy (i.e. each capable photon emits one electron) calculate the number of photoelectrons liberated per second.

Sol. $E_1 = \dfrac{12400}{4000} = 3.1$ eV, $\quad E_2 = \dfrac{12400}{4800} = 2.58$ eV $\quad E_3 = \dfrac{12400}{6000} = 2.06$ eV

and $\quad E_4 = \dfrac{12400}{7000} = 1.77$ eV

Therefore, light of wavelengths 4000 Å, 4800 Å and 6000 Å can only emit photoelectrons.

$\therefore$ Number of photoelectrons emitted per second = No. of photons incident per second)

$$= \frac{I_1 A_1}{E_1} + \frac{I_2 A_2}{E_2} + \frac{I_3 A_3}{E_3} = IA\left(\frac{1}{E_1} + \frac{1}{E_2} + \frac{1}{E_3}\right)$$

$$= \frac{(1.5 \times 10^{-3})(10^{-4})}{1.6 \times 10^{-19}} \qquad \left(\frac{1}{3.1} + \frac{1}{2.58} + \frac{1}{2.06}\right)$$

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Ex. Calculate the possible velocity of a photoelectron if the work function of the target material is 1.24 eV and wavelength of light is 4.36×10^{-7} m. What retarding potential is necessary to stop the emission of electrons?

Sol. As $KE_{max} = h\nu - \phi \Rightarrow \frac{1}{2}mv_{max}^2 = h\nu - \phi = \frac{hc}{\lambda} - \phi$

$$v_{max} = \sqrt{\frac{2\left(\frac{hc}{\lambda} - \phi\right)}{m}} = \sqrt{\frac{2\left(\frac{6.63\times10^{-34}\times3\times10^{8}}{4.36\times10^{-7}} - 1.24\times1.6\times10^{-19}\right)}{9.11\times10^{-31}}} = 7.523\times10^{5}\ \text{m/s}$$

$\therefore$ The speed of a photoelectron can be any value between 0 and 7.43×10^5 m/s

If V_0 is the stopping potential, then $eV_0 = \frac{1}{2}mv_{max}^2$

$$\Rightarrow V_0 = \frac{1}{2}\frac{mv_{max}^2}{e} = \frac{hc}{e\lambda} - \frac{\phi}{e} = \frac{12400}{4360} - 1.24 = 1.60\ \text{V} \qquad \left[\because \frac{hc}{e} = 12400\times10^{-10}\ \text{V}-\text{m}\right]$$

Ex. The surface of a metal of work function ϕ is illuminated by light whose electric field component varies with time as $E = E_0[1 + \cos\omega t]\sin\omega_0 t$. Find the maximum kinetic energy of photoelectrons emitted from the surface.

Sol. The given electric field component is $E = E_0 \sin\omega_0 t + E_0 \sin\omega_0 t\cos\omega t = E_0 \sin\omega_0 t + \frac{E_0}{2}[\sin(\omega_0+\omega)t + \sin(\omega_0-\omega)t]$

$\therefore$ The given light comprises three different frequencies viz. ω, $\omega_0 + \omega$, $\omega_0 - \omega$

The maximum kinetic energy will be due to most energetic photon.

$$\therefore KE_{max} = h\nu - \phi = \frac{h(\omega+\omega_0)}{2\pi} - \phi \quad \left(\because \omega = 2\pi\nu \text{ or } \nu = \frac{\omega}{2\pi}\right)$$

Ex. When light of wavelength λ is incident on a metal surface, stopping potential is found to be x. When light of wavelength $n\lambda$ is incident on the same metal surface, stopping potential is found to be $\frac{x}{n+1}$. Find the threshold wavelength of the metal.

Sol. Let λ_0 is the threshold wavelength. The work function is $\phi = \frac{hc}{\lambda_0}$.

Now, by photoelectric equation $ex = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$ ...(i) $\frac{ex}{n+1} = \frac{hc}{n\lambda} - \frac{hc}{\lambda_0}$ ...(ii)

From (i) and (ii) $\frac{hc}{\lambda} - \frac{hc}{\lambda_0} = (n+1)\frac{hc}{n\lambda} - (n+1)\frac{hc}{\lambda_0} \Rightarrow \frac{nhc}{\lambda_0} = \frac{hc}{n\lambda} \Rightarrow \lambda_0 = n^2\lambda$

PHOTON THEORY OF LIGHT

According to Plank's Quantum Theory light consist of photon as energy packets having following properties :

(i) Each photon i.e. of energy

$E = h\nu = hc/\lambda$ where h is plank's constant

(ii) A photon is a particle of light moving with speed 299792458 m/s in vacuum.

(iii) The speed of a photon is independent of frame of reference. This is the basic postulate of theory of relativity.

(iv) The rest mass of a photon is zero. i.e. photons do not exist at rest.

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(v) Effective mass of photon $m = \frac{E}{c^2} = \frac{hc}{c^2\lambda} = \frac{h}{c\lambda}$ i.e. $m \propto \frac{1}{\lambda}$

So mass of violet light photon is greater than the mass of red light photon. ($\because \lambda_R > \lambda_V$)

(vi) According to Planck the energy of a photon is directly proportional to the frequency of the radiation.

$E \propto \nu$ or $E = h\nu$

$E = \frac{hc}{\lambda}$ joule ($\because c = \nu\lambda$) or $E = \frac{hc}{\lambda e} = \frac{12400}{\lambda}$ eV – Å $\left[\because \frac{hc}{e} = 12400(\text{Å} - eV)\right]$

Here E = energy of photon, c = speed of light, h = Planck's constant, e = charge of electron

$h = 6.62 \times 10^{-34}$ J–s, ν = frequency of photon, λ = wavelength of photon

(vii) Linear momentum of photon $p = \frac{E}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$

(viii) A photon can collide with material particles like electron. During these collisions, the total energy and total momentum remain constant.

(ix) Energy of light passing through per unit area per unit time is known as intensity of light.

Intensity of light $I = \frac{E}{At} = \frac{P}{A}$ ...**(i)**

Here P = power of source, A = Area, t = time taken

E = energy incident in t time = Nhν, N = number of photon incident in t time

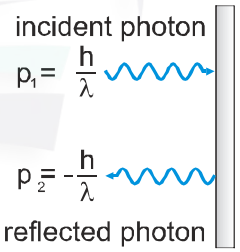
Intensity $I = \frac{N(h\nu)}{At} = \frac{n(h\nu)}{A}$ ...**(ii)** $\left[\because n = \frac{N}{t} = \text{no. of photon per sec.}\right]$

From equation **(i)** and **(ii)**, $\frac{P}{A} = \frac{n(h\nu)}{A} \Rightarrow n = \frac{P}{h\nu} = \frac{P\lambda}{hc} = 5 \times 10^{24}\,J^{-1}m^{-1} \times P \times \lambda$

(x) When photons fall on a surface, they exert a force and pressure on the surface. This pressure is called radiation pressure.

(xi) **Force exerted on perfectly reflecting surface**

Let 'N' photons are there in time t,



Momentum before striking the surface $(p_1) = \frac{Nh}{\lambda}$

Momentum after striking the surface $(p_2) = -\frac{Nh}{\lambda}$

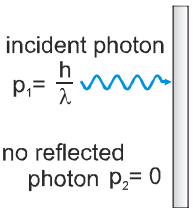
Change in momentum of photons $= p_2 - p_1 = \frac{-2Nh}{\lambda}$

But change in momentum of surface = $\Delta p = \frac{2Nh}{\lambda}$; So that force on surface $F = \frac{2Nh}{t\lambda} = n\left[\frac{2h}{\lambda}\right]$ but $n = \frac{P\lambda}{hc}$

$\therefore F = \frac{2h}{\lambda} \times \frac{P\lambda}{hc} = \frac{2P}{c}$ and Pressure $= \frac{F}{A} = \frac{2P}{cA} = \frac{2I}{c}$ $\left[\because I = \frac{P}{A}\right]$

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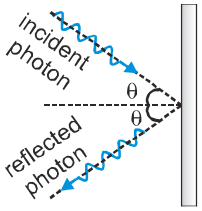
(xii) Force exerted on perfectly absorbing surface



$$F = \frac{p_1 - p_2}{t} = \frac{\frac{Nh}{\lambda} - 0}{t} = \frac{Nh}{t\lambda} = n\frac{h}{\lambda} \; ; \; F = \frac{P}{c} \left(\because \; n = \frac{P\lambda}{hc} \right)$$

and Pressure $= \frac{F}{A} = \frac{P}{Ac} = \frac{I}{c}$

(xiii) When a beam of light is incident at angle θ on perfectly reflector surface



$$F = \frac{2P}{c}\cos\theta = n\left[\frac{2h}{\lambda}\right]\cos\theta = \frac{2IA\cos\theta}{c} \; ; \text{ Pressure} = \frac{F}{A} = \frac{2I\cos\theta}{c}$$

Ex. Violet light $(\lambda = 4000\ \text{Å})$ of entensity 4 watt/m^2 falls normally on a surface of area 10 cm × 20 cm.

Find

(a) the energy received by the surface per second.

(b) the number of photons hitting the surface per second.

(c) If surface is tiled such that plane of the surface makes an angle 30° with light beam, find the number of photons hitting the surface per second.

Sol. **(a)** Energy received per second per unit area

$E = I A \cos\theta = 4 \times 0.02\ J \times \cos 0° = 0.08\ J$

(b) $n\,h\,(c/\lambda) = E$

$$\Rightarrow \quad n = \frac{0.08 \times 4000 \times 10^{-10}}{6.63 \times 10^{-34} \times 3 \times 10^8} = \frac{32 \times 10^{17}}{19.89} = 1.699 \times 10^{17}$$

(c) $$n = \frac{IA\cos 60° \times \lambda}{hc} = \frac{1}{2} \times \frac{32 \times 10^{17}}{19.89} = 0.805 \times 10^{17}$$

Ex. The intensity of sunlight on the surface of earth is 1400 W/m^2. Assuming the mean wavelength of sunlight to be 6000 Å, calculate:–

(a) The photon flux arriving at 1 m^2 area on earth perpendicular to light radiations and

(b) The number of photons emitted from the sun per second (Assuming the average radius of Earth's orbit to be 1.49×10^{11} m)

Sol. **(a)** Energy of a photon $E = \frac{hc}{\lambda} = \frac{12400}{6000} = 2.06\ eV = 3.3 \times 10^{-19}\ J$

Photon flux $= \frac{IA}{E} = \frac{1400 \times 1}{3.3 \times 10^{-19}} = 4.22 \times 10^{21}$ photons/sec.

(b) Number of photons emitted per second $n = \frac{P}{E} = \frac{IA}{E} = \frac{1400 \times 4\pi \times (1.49 \times 10^{11})^2}{3.3 \times 10^{-19}} = 1.18 \times 10^{45}$

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Ex. In a photoelectric setup, a point source of light of power 3.2×10^{-3} W emits monochromatic photons of energy 5.0 eV. The source is located at a distance 0.8 m from the centre of a stationary metallic sphere of work function 3.0 eV and radius 8×10^{-3} m. The efficiency of photoelectron emission is one for every 10^6 incident photons. Assuming that the sphere is isolated and initially neutral and that photoelectrons are instantly swept away after emission, Find **(i)** the number of photoelectrons emitted per second. **(ii)** the time t after light source is switched on, at which photoelectron emission stops.

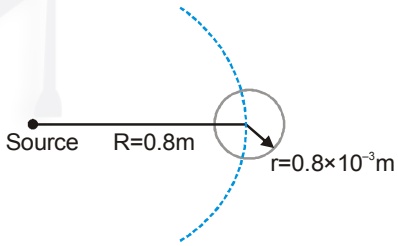
Sol. Energy of a single photon $E = 5.0 \text{ eV} = 8 \times 10^{-19}$ J

Power of source $P = 3.2 \times 10^{-3}$ W

$\therefore$ number of photons emitted per second $n = \frac{P}{E} = \frac{3.2 \times 10^{-3}}{8 \times 10^{-19}} = 4 \times 10^{15}$/s

The number of photons incident per second on metal surface is $n_0 = \frac{n}{4\pi R^2} \times \pi r^2$

$$n_0 = \frac{4 \times 10^{15}}{4\pi (0.8)^2} \times \pi \left(8 \times 10^{-3}\right)^2 = 1.0 \times 10^{11} \text{ photon/s}$$



Number of electrons emitted $= \frac{1.0 \times 10^{11}}{10^6} = 10^5$ /s

$KE_{max} = h\nu - \phi = 5.0 - 3.0 = 2.0$ eV

The photoelectron emission stops, when the metallic sphere acquires stopping potential.

As $KE_{max} = 2.0$ eV $\Rightarrow$ Stopping potential $V_0 = 2$V $\Rightarrow 2 = \frac{q}{4\pi\varepsilon_0 r} \Rightarrow q = 1.78 \times 10^{-12}$C

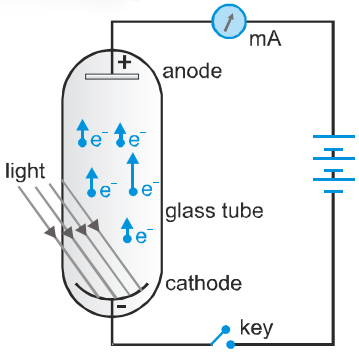
Now charge q = (number of electrons/second) × t× e $\Rightarrow t = \frac{1.78 \times 10^{-12}}{10^5 \times 1.6 \times 10^{-19}} = 111$s

PHOTO CELL

A photo cell is a practical application of the phenomenon of photo electric effect, with the help of photo cell light energy is converted into electrical energy.

1. **Construction :** A photo cell consists of an evacuated sealed glass tube containing anode and a concave cathode of suitable emitting material such as Cesium (Cs).

2. **Working:** When light of frequency greater than the threshold frequency of cathode material falls on the cathode, photoelectrons emitted are collected by the anode and an electric current starts flowing in the external circuit. The current increase with the increase in the intensity of light. The current would stop, if the light does not fall on the cathode.



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3. Application

(i) In television camera.

(ii) In automatic door

(iii) Burglar's alarm

(iv) Automatic switching of street light and traffic signals.

1, 2, 3..... represents the I, II & III line of Lymen, Balmer, Paschen series.

The hydrogen spectrum (some selected lines)

(c) $\Delta E_{31} = -3.08 - (-15.6) = 12.52$ eV

Therefore, excitation potential for state n = 3 is 12.52 volt.

(d) $\frac{1}{\lambda_{31}} = \frac{\Delta E_{31}}{12400}$ Å^{-1} $= \frac{12.52}{12400}$ Å^{-1}

$\approx 1.01 \times 10^{7}$ m^{-1}

(e) **(i)** $E_2 - E_1 = 10.3$ eV > 6 eV.

Hence electron cannot excite the atoms. So, $K_{min} = 6$ eV.

(ii) $E_2 - E_1 = 10.3$ eV < 11 eV.

Hence electron can excite the atoms. So, $K_{min} = (11 - 10.3) = 0.7$ eV.

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MATTER WAVES

DUAL NATURE OF LIGHT

Experimental phenomena of light reflection, refraction, interference, diffraction are explained only on the basis of wave theory of light. These phenomena verify the wave nature of light. Experimental phenomena of light photoelectric effect and Crompton effect, pair production and positron inhalational can be explained only on the basis of the particle nature of light. These phenomena verify the particle nature of light.

It is inferred that light does not have any definite nature, rather its nature depends on its experimental phenomenon. This is known as the dual nature of light. The wave nature and particle nature both can not be possible simultaneously.

De-Broglie HYPOTHESIS

De Broglie imagined that as light possess both wave and particle nature, similarly matter must also posses both nature, particle as well as wave. De Broglie imagined that despite particle nature of matter, waves must also be associated with material particles. Wave associated with material particles, are defined as matter waves.

(i) De Broglie wavelength associated with moving particles

If a particle of mass m moving with velocity v

Kinetic energy of the particle $E = \frac{1}{2}mv^2 = \frac{p^2}{2m}$ momentum of particle $p = mv = \sqrt{2mE}$ the wave length associated with the particles is $\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE}}$ $\lambda \propto \frac{1}{p} \Rightarrow \lambda \propto \frac{1}{v} \Rightarrow \lambda \propto \frac{1}{\sqrt{E}}$

The order of magnitude of wave lengths associated with macroscopic particles is 10^{-24} Å.

The smallest wavelength whose measurement is possible is that of γ – rays ($\lambda \simeq 10^{-5}$ Å). This is the reason why the wave nature of macroscopic particles is not observable.

The wavelength of matter waves associated with the microscopic particles like electron, proton, neutron, α – particle, atom, molecule etc. is of the order of 10^{-10} m, it is equal to the wavelength of X–rays, which is within the limit of measurement. Hence the wave nature of these particles is observable.

(ii) De Broglie wavelength associated with the charged particles

Let a charged particle having charge q is accelerated by potential difference V.

Kinetic energy of this particle $E = \frac{1}{2}mv^2 = qV$ Momentum of particle $p = mv = \sqrt{2mE} = \sqrt{2mqV}$

The De Broglie wavelength associated with charged particle $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}}$

(iii) For an Electron $m_e = 9.1 \times 10^{-31}$ kg, $q = 1.6 \times 10^{-19}$ C, $h = 6.62 \times 10^{-34}$ J–s

De Broglie wavelength associated with electron $\lambda = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} V}}$

$\lambda = \frac{12.27 \times 10^{-10}}{\sqrt{V}}$ meter $= \frac{12.27}{\sqrt{V}}$ Å So $\lambda \propto \frac{1}{\sqrt{V}}$

Potential difference required to stop an electron of wavelength λ is $V = \frac{150.6}{\lambda^2}$ volt $(Å)^2$

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(iv) For Proton $m_p = 1.67 \times 10^{-27}$ kg

De Broglie wavelength associated with proton

$$\lambda_p = \frac{6.62\times10^{-34}}{\sqrt{2\times1.67\times10^{-27}\times1.6\times10^{-19}\,V}}\,;\lambda_p = \frac{0.286\times10^{-10}}{\sqrt{V}}\text{ meter} = \frac{0.286}{\sqrt{V}}\,\text{Å}$$

(v) For Deuteron $m_d = 2\times1.67\times10^{-27}$ kg, $q_d = 1.6\times10^{-19}$ C

$$\lambda_d = \frac{6.62\times10^{-34}}{\sqrt{2\times2\times1.67\times10^{-27}\times1.6\times10^{-19}\,V}} = \frac{0.202}{\sqrt{V}}\,\text{Å}$$

(vi) For α Particles $q_\alpha = 2\times1.6\times10^{-19}$ C, $m_\alpha = 4\times1.67\times10^{-27}$ kg

$$\therefore\quad \lambda_\alpha = \frac{6.62\times10^{-34}}{\sqrt{2\times4\times1.67\times10^{-27}\times2\times1.6\times10^{-19}\,V}} = \frac{0.101}{\sqrt{V}}\,\text{Å}$$

De Broglie Wavelength Associated with Uncharged Particles

(i) Kinetic energy of uncharged particle $E = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

m = mass of particle, v = velocity of particle, p = momentum of particle.

(ii) Velocity of uncharged particle $v = \sqrt{\frac{2E}{m}}$

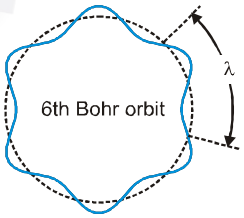
(iii) Momentum of particle $p = mv = \sqrt{2mE}$

wavelength associated with the particle $\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE}}$

Kinetic energy of the particle in terms of its wavelength $E = \frac{h^2}{2m\lambda^2} = \frac{h^2}{2m\lambda^2\times1.6\times10^{-19}}\text{eV}$

For a neutron $m_n = 1.67\times10^{-27}$ kg $\therefore\ \lambda = \frac{6.62\times10^{-34}}{\sqrt{2\times1.67\times10^{-27}\times E}} = \frac{0.286\times10^{-10}}{\sqrt{E}}\text{meter}\sqrt{eV} = \frac{0.286}{\sqrt{E}}\,\text{Å}\sqrt{eV}$

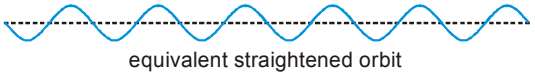
EXPLANATION OF BOHR QUANTIZATION CONDITION



According to De Broglie electron revolves round the nucleus in the form of stationary waves (i. e. wave packet) in the similar fashion as stationary waves in a vibrating string. Electron can stay in those circular orbits whose circumference is an integral multiple of De–Broglie wavelength associated with the electron, $2\pi r = n\lambda$

$\because\ \lambda = \frac{h}{mv}$ and $2\pi r = n\lambda$ $\qquad\therefore\ mvr = \frac{nh}{2\pi}$

This is the Bohr quantizations condition.



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Ex. Find the initial momentum of electron if the momentum of electron is changed by p_m and the De Broglie wavelength associated with it changes by 0.50 %

Sol. $\frac{d\lambda}{\lambda}\times 100 = 0.5 \Rightarrow \frac{d\lambda}{\lambda} = \frac{0.5}{100} = \frac{1}{200}$ and $\Delta p = p_m$

$\because p = \frac{h}{\lambda}$, differentiating $\frac{dp}{d\lambda} = -\frac{h}{\lambda^2} = -\frac{h}{\lambda}\times\frac{1}{\lambda} = -\frac{p}{\lambda} \Rightarrow \frac{|dp|}{p} = \frac{d\lambda}{\lambda} \therefore \frac{p_m}{p} = \frac{1}{200} \Rightarrow p = 200\, p_m$

Ex. An α–particle moves in circular path of radius 0.83 cm in the presence of a magnetic field of 0.25 Wb/m^2. Find the De Broglie wavelength associated with the particle.

Sol. $\lambda = \frac{h}{p} = \frac{h}{qBr} = \frac{6.62\times10^{-34}}{2\times1.6\times10^{-19}\times0.25\times83\times10^{-4}}$ meter $= 0.01$ Å $\left[\because \frac{mv^2}{r} = qvB\right]$

Ex. A proton and an α–particle are accelerated through same potential difference. Find the ratio of their de- Broglie wavelength.

Sol. $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}}$ $[\because E = qV]$ For proton $m_p = m$, $q = e$

For α–particle $m_\alpha = 4\,m$, $q = 2e$, $\frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p q_p}{m_\alpha q_\alpha}} = \frac{1}{2\sqrt{2}}$

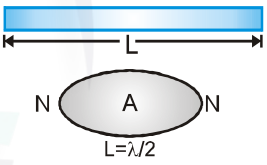
Ex. A particle of mass m is confined to a narrow tube of length L.

(a) Find the wavelengths of the de–Broglie wave which will resonate in the tube.

(b) Calculate the corresponding particle momenta, and

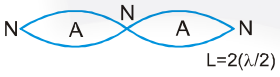
(c) Calculate the corresponding energies.

Sol. **(a)** The de–Broglie waves will resonate with a node at each end of the tube.



Few of the possible resonance forms are as follows : $\lambda_n = \frac{2L}{n}$, n=1,2,3.....

(b)



Since de–Broglie wavelengths are $\lambda_n = \frac{h}{p_n}$

$p_n = \frac{h}{\lambda_n} = \frac{nh}{2L}$, $n = 1,2,3....$



(c) The kinetic energy of the particles are $K_n = \frac{p_n^2}{2m} = \frac{n^2h^2}{8L^2m}$, $n = 1, 2, 3,....$

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NUCLEAR PHYSICS

It exists at the centre of an atom, containing entire positive charge and almost whole of mass. The electron resolve around the neuleus to form an atom. The nucleus consists of protons (+ve charge) and neutrons. A proton has positive charge equal in magnitude to that of an electron (+ 1.6×10^{-19} C) and a mass equal to 1840 C) and a mass equal to 1840 times that of an electron. A neutron has no charge and mass is approximately equal to that of proton.

PROPERTIES OF A NUCLEUS

(1) Nuclear Mass :

As we know that every nucleus contains protons and neutrons and so every nucleus has a define mass. However, since the mass of electron is negligible so atomic mass is roughly equal to nuclear mass.

Atomic masses are measured in atomic mass unit (a.m.u.) defiined as

$\Rightarrow$ $1u = 931.478\ MeV/c^2$

and its energy equivalent is 931.48 MeV

Thye number of protons is a nucleus of an atom is called as the atomic number (Z) of that atom. The number of protons plus neutrons (called as Nucleus) in a nucleus of an atom is called as mass number (A) of that atom.

A partiicular set of nucleons forming an atom is called as nuclide. It is represented as ${}_{Z}X^{A}$. The nuclides having same number of protons (Z), but different number of nucleons (A) are called as isotopes. The nuclide having same number of nucleons (A), but different number of protons (Z) are called as isobars. The nuclide having same number of neutrons (A-Z) are called as isotones.

(2) Nuclear Charge :

Since nucleus contain +vely charged protons (charge = 1.67×10^{-19} C) and neutrons (neutral) so every nucleus has a net +ve charge.

(3) Nuclear Radius :

A rough estiimate of nuclear size suggests us that the radius of the nucleus of an atom having mass number 'A' is given by

$$R = R_0 A^{1/3}$$

Where R_0 is a constant found to be equal to

$$R_0 = 1.4 \times 10^{-15}\ m = 1.4\ fm.$$

(4) Nuclear Density :

In spite of the fact that nuclear radius depends on mass number of the atom but nuclear density is independent of mass number because if neutrons are supposed to be of almost the same mass as that of protons then the total mass of a nucleus is proportional to A. If each nucleon are supposed to have a mass m then nuclear density is given by

$$\rho = \frac{mA}{\frac{4}{3}\pi R_0^3 A} = \frac{3m}{4\pi R_0^3}$$ (Which is independent of A)

(5) Nuclear spin and magnetic moment

Like orbial electrons in an atom, nucleons inside nucleus have well defined quantum states. Correspondingly they have angular momentum and hence a magnetic moment. Like electrons nucleons also have intrinsic angular momentum and 'magnetic' moment corresponding to their spin.

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NUCLEAR FORCES

If only the electrostatic and gravitattional forces existed in the nucleus, then it would be impossible to have stable nuclei composed of protons and neutrons. The gravitational forces are much too small to hold the nucleons together compared to the electrostatic forces repelling the protons. Since stable atoms of neutrons and protons do exiist, there must be another attractive force acting within the nucleus. This force is called the nuclear force.

Properties of nuclear force

(1) They are charge independent. The nuclear force between two proton is same as that between two neutrons or between a neutron and proton. This is known as charge independent character of nuclear forces.

(2) They may be repulsive may be attractive (Repulsive at exceedingly small separation between two nucleons appreciably smaller than 10^{-13} cm. i.e. 10^{-15} m.

(3) It is a short range force. Its radius of action is of the order of 10^{-13} cm.

(4) The nuclear force is of saturation character. Each nucleon in nucleus interacts with a limited number of nucleons.

(5) Nuclear force are much stronger than electromagnetic force or gravitational attrqactive forces. It is the strongest of all the forces. This is why it is called strong interaction.

(6) Nuclear force is spin dependent. If two interacting nucleons are having parallel spins then nuclear force operative betwee them is comparatively stronger and if their spins are antiparallel, nuclear interaction is comparatively weaker.

(7) Nuclear force is a non-central force. They can not be represented as directe along the st. line connecting the centers of the interacting nucleons. Its non central nature is due to the fact that it depends also on the orientation of the nucleon spins.

MASS DEFECT

It is observed that the mass of a nucleus is slightly less than the sum of the masses of constituent nucleons. Suppose a nucleus consists of 'Z' protons and 'N' neutrons. Mass of a proton, a neutron and the resulting nucleus are respectively m_p, m_n and M then mass defect of the nucleus is given by of the nucleus is given by

$$\Delta m = Zm_p + Nm_n - M$$

If A is the mass number of the nucleus

$$\Delta m = [Zm_p(A-Z)m_n - M]$$

In terms of atomic masses we may also write mass defect as

$$\Delta m = [Zm(_1^1H)Nm_n - m(_z^AX)]$$

Where $m(_1^1H)$ = mass of one hydrogen atom.

$m(_z^AX)$ = mass of atom having atomic no. Z and mass no. **A**

e.g.,

mass of $_1^1H$ = 1.00784 u

mass of neutron = 1.00874 u

Expected mass of deuterium = 2.01654 u

but measured mass = 2.0141 u

mass defect,

Δm = 0.00244 u

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NUCLEAR STABILIITY

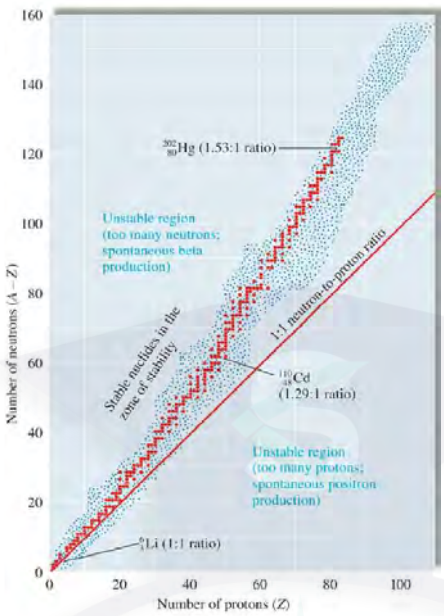


Figure shows pot of N vs Z for known nuclides. The stable nuclides are indicated by the black dots. Non-stable nuclides decay by emission of particles, or electromagnetic radiation, in a process called radioactivity.

BINDING ENERGY

To break a nucleus into its constituent nuclei some energy is required to be supplied. This energy is called Binding Energy of the given nucleus or the energy equivalent of the missing mass of a nucleus is called the binding energy of the nucleus.

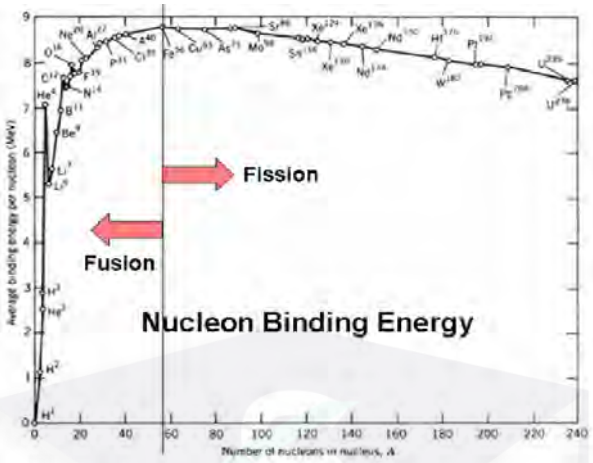
$$BE = (\Delta m)c^2 = [Zm_p + (A-Z)m_n - M]c^2$$

BE = Δm(on amu) × 931 MeV Where Δm = mass defect

Binding energy per nucleon is a measure of the stability of the nucleus. If there be n nucleons which is equal to A.

$$\frac{\text{Binding Energy}}{\text{Nucleon}} = \frac{B.E.}{A}$$

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From the plot of B.E./ nucleons Vs mass number (A), we observe that :

(1) Binding energy per nucleon has low value for both heavy and liight nuclei i.e. heavy as well as light nuclei, both are unstable. B.E./nucleons increases on an average and reaches a maximum of about 8.7 MeV for A = 50–80. For more heavy nuclei, B.E./nucleons decreases slowly as A increases. For the heaviest natural element U^{238} it drops to about 7.5 MeV. From above observation, it follows that nuclei in the region of atomic 50 – 80 are most stable.

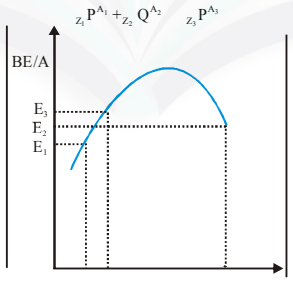
(2) The intermediate nuclei have large value of binding energy per nucleon so they are more stable.

(3) Binding energy per nucleon increases rapidly upto mass number 20 but there are peaks corresponding to $_2^4He, _6^{12}C, _8^{16}O$ which indicates that these nuclei are more stable than neighbours. The reason is that they may be considered to passes magic numbers i.e. their mass number is divisible by 4 and these nuclei may have $_2^4He$ as their constituents.

(4) The minimum value of the BE/Nucleon is in the case of deutron that is 1.11 MeV.

(5) The maximum value of the BE/Nucleon is 8.79 Mev for the nuclei $_{26}^{56}Fe$ which is therefore the most stable nucleus.

Ex. Using the following plot of BE/nucleon vs mass number, mention the condition for which the energy is absorbed or released for the reaction



Sol. Binding energy for reaction is $(xE_a + yE_b)$ and that for product is zE_c

Case - I :

$$\text{if } (A_1E_1 + A_2E_2) > A_3E_3$$

Energy is absorbed

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Case - II :

$\text{if}\,(A_1E_1 + A_2E_2) < A_3E_3$

Energy is released

Note

(i) If we split a heavy neclues into two medium sized nucleii and total binding energy of new nuclei is greater then parent nuclei, then energy is released (Nuclear fission)

(ii) If two nuclei of small mass number combine to form a single medium size nucleus for which biinding energy is greater than the constituent nuclei, then energy is released (Nuclear fusion)

NUCLEAR COLLISIONS

We can represent a nuclear collision or reaction by the following notation, which means X (a,b) Y

$$\underset{\text{(bombarding particle)}}{a} + \underset{\text{(at rest)}}{X} \rightarrow Y + b$$

We can apply :

(i) Conservation of momentum **(ii)** Conservation of charge **(iii)** Conservation of mass–energy

For any nuclear reaction

$$\underset{K_1}{a} + \underset{K_2}{X} \rightarrow \underset{K_3}{Y} + \underset{K_4}{b}$$

By mass energy conservation

(i) $K_1 + K_2 + (m_\alpha + m_x)c^2 = K_3 + K_4 + (m_Y + m_b)c^2$

(ii) Energy released in any nuclear reaction or collision is called Q value of the reaction

(iii) $Q = (K_3 + K_4) - (K_1 + K_2) = \Sigma K_P - \Sigma K_R = (\Sigma m_R - \Sigma m_P)c^2$

(iv) If Q is positive, energy is released and products are more stable in comparison to reactants.

(v) If Q is negative, energy is absorbed and products are less stable in comparison to reactants.

$$Q = \Sigma(\text{B.E.})_{\text{product}} - \Sigma(\text{B.E.})_{\text{reactants}}$$

Ex. Let us find the Q value of fusion reaction

$$^4He + {}^4He \rightarrow {}^8Be, \quad \text{if } \frac{B.E.}{A} \text{ of He} = X \text{ and } \frac{\text{B.E.}}{A} \text{ of Be} = Y \Rightarrow Q = 8Y - 8X$$

Q value for α decay

$$_ZX^A \rightarrow {}_{Z-2}Y^{A-4} + {}_2He^4 \qquad \Rightarrow \qquad Q = K_\alpha + K_Y \qquad \text{....(i)}$$

Momentum conservation, $p_Y = p_\alpha$ ...(ii)

$$K_\alpha = \frac{p^2}{2 \times m \times 4} \qquad \Rightarrow \qquad K_Y = \frac{p^2}{2m(A-4)} = \frac{4K_\alpha}{A-4}$$

$$Q = K_\alpha + \frac{4K_\alpha}{A-4} = \frac{A}{A-4}K_\alpha \qquad \Rightarrow \qquad K_\alpha = \frac{A-4}{A}Q$$

For α decay A > 210 which means maximum part of released energy is associated with K.E. of α. If Q is negative, the reaction is endoergic. The minimum amount of energy that a bombarding particle must have in order to initiate an endoergic reaction is called Threshold energy E_{th}, given by

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$$E_{th} = -Q\left(\frac{m_1}{m_2}+1\right)$$ where m_1 = mass of the projectile.

E_{th} = minimum kinetic energy of the projectile to initiate the nuclear reaction

m_2 = mass of the target

Ex. How much energy must a bombarding proton possess to cause the reaction ${}_3Li^7 + {}_1H^1 \rightarrow {}_4Be^7 + {}_0n^1$

(Mass of ${}_3Li^7$ atom is 7.01600, mass of ${}_1H^1$ atom is 1.0783, mass of ${}_4Be^7$ atom is 7.01693)

Sol. Since the mass of an atom includes the masses of the atomic electrons, the appropriate number of electron masses must be subtracted from the given values.

Reactants : Total mass $= (7.01600 - 3\,m_e) + (1.0783 - 1\,m_e) = 8.0943 - 4m_e$

Products : Total mass $= (7.01693 - 4m_e) + 1.0087 = 8.02563 - 4m_e$

The energy is supplied as kinetic energy of the bombarding proton. The incident proton must have more than this energy because the system must possess some kinetic energy even after the reaction, so that momentum is conserved with momentum conservation taken into account, the minimum kinetic energy that the incident particle must possess can be found with the formula.

where, $Q = -[(8.02563 - 4m_e) - (8.0943 - 4\,m_e)]\,931.5\,\text{MeV} = -63.96\,\text{MeV}$

$$E_{th} = -\left(1+\frac{m}{M}\right)Q = -\left(1+\frac{1}{7}\right)(-63.96) = 73.1\ \text{MeV}$$

NUCLEAR FISSION

In 1938 by Hahn and Strassmann. By attack of a particle splitting of a heavy nucleus (A > 230) into two or more lighter nuclei. In this process certain mass disappears which is obtained in the form of energy (enormous amount)

$$A + p \rightarrow \text{excited nucleus} \rightarrow B + C + Q$$

Hahn and Strassmann done the first fision of nucleus of U^{235}).

When U^{235} is bombarded by a neutron it splits into two fragments and 2 or 3 secondary neutrons and releases about 190 MeV ($\simeq$ 200 MeV) energy per fission (or from single nucleus)

Fragments are uncertain but each time energy released is almost same.

Possible reactions are

$$U^{235} + {}_0n^1 \rightarrow Ba + Kr + 3\,{}_0n^1 + 200\ \text{MeV} \quad \text{or} \quad U^{235} + {}_0n^1 \rightarrow Xe + Sr + 2\,{}_0n^1 + 200\ \text{MeV}$$

and many other reactions are possible.

(i) The average number of secondary neutrons is 2.5.

(ii) Nuclear fission can be explained by using "liquid drop model" also.

(iii) The mass defect Δm is about 0.1% of mass of fissioned nucleus

(iv) About 93% of released energy (Q) is appear in the form of kinetic energies of products and about 7% part in the form of γ – rays.

NUCLEAR CHAIN REACTION :

The equation of fission of U^{235} is $U^{235} + {}_0n^1 \rightarrow Ba + Kr + 3\,{}_0n^1 + Q$.

These three secondary neutrons produced in the reaction may cause of fission of three more U^{235} and give 9 neutrons, which in turn, may cause of nine more fission of U^{235} and so on.

Thus a continuous 'Nuclear Chain reaction' would start.

If there is no control on chain reaction then in a short time ($\simeq 10^{-6}$ sec.) a huge amount of energy will be released. (This is the principle of 'Atom bomb'). If chain is controlled then produced energy can be used for peaceful

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purposes. For example nuclear reactor (Based on fission) are generating electricity.

NATURAL URANIUM :

It is mixture of U^{235} (0.7%) and U^{238} (99.3%).

U^{235} is easily fissionable, by slow neutron (or thermal neutrons) having K.E. of the order of 0.03 eV. But U^{238} is fissionable with fast neutrons.

Note : Chain reaction in natural uranium can't occur. To improve the quality, percentage of U^{235} is increased to 3%. The proposed uranium is called 'Enriched Uranium' (97% U^{238} and 3% U^{235})

LOSSES OF SECONDARY NEUTRONS :

Leakage of neutrons from the system : Due to their maximum K.E. some neutrons escape from the system.

Absorption of neutrons by U^{238} : Which is not fissionable by these secondary neutrons.

CRITICAL SIZE (OR MASS) :

In order to sustain chain reaction in a sample of enriched uranium, it is required that the number of lost neutrons should be much smaller than the number of neutrons produced in a fission process. For it the size of uranium block should be equal or greater than a certain size called critical size.

REPRODUCTION FACTOR :

$$(K) = \frac{\text{rate of production of neutrons}}{\text{rate of loss of neutrons}}$$

(i) If size of Uranium used is 'Critical' then K = 1 and the chain reaction will be steady or sustained (As in nuclear reaction)

(ii) If size of Uranium used is 'Super critical' then K > 1 and chain reaction will accelerate resulting in a explosion (As in atom bomb)

(iii) If size of Uranium used is 'Sub Critical' then K < 1 and chain reaction will retard and will stop.

NUCLEAR REACTOR (K = 1) : Credit → To Enricho Fermi

Construction :

(i) **Nuclear Fuel :** Commonly used are U^{235} , Pu^{239}. Pu^{239} is the best. Its critical size is less than critical size of U^{235}. But Pu^{239} is not naturally available and U^{235} is used in most of the reactors.

(ii) **Moderator** : Its function is to slow down the fast secondary neutrons. Because only slow neutrons can bring the fission of U^{235}. The moderator should be light and it should not absorb the neutrons. Commonly, Heavy water (D_2O, molecular weight 20 gm.) Graphite etc. are used. These are rich of protons. Neutrons collide with the protons and interchange their energy. Thus neutrons get slow down.

(iiii) **Control rods** :They have the ability to capture the slow neutrons and can control the chain reaction at any stage. Boron and Cadmium are best absorber of neutrons.

(iv) **Coolant** : A substance which absorb the produced heat and transfers it to water for further use. Generally coolant is water at high pressure

FAST BREADER REACTORS

The atomic reactor in which fresh fissionable fuel (Pu^{239}) is produced along with energy. The amount of produced fuel (Pu^{239}) is more than consumed fuel (U^{235})

(i) **Fuel :** Natural Uranium.

(ii) **Process**: During fission of U^{235}, energy and secondary neutrons are produced. These secondary neutrons are

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absorbed by U^{238} and U^{239} is formed. This U^{239} converts into Pu^{239} after two beta decay. This Pu^{239} can be separated, its half life is 2400 years.

$$_{92}U^{238} + {}_{0}n^{1} \longrightarrow {}_{92}U^{239} \xrightarrow{2\beta^-} {}_{94}Pu^{239} \text{ (best fuel of fission)}$$

This Pu^{239} can be used in nuclear weapons because of its small critical size than U^{235}.

(iii) Moderator : Are not used in these reactors.

(iv) Coolant : Liquid sodium

NUCLEAR FUSION :

It is the phenomenon of fusing two or more lighter nuclei to form a single heavy nucleus.

$$A + B \rightarrow C + Q \text{ (Energy)}$$

The product (C) is more stable then reactants (A and B) & $m_C < (m_a + m_b)$

and mass defect $\Delta m = [(m_a + m_b) - m_c]$ amu

Energy released is $E = \Delta m\, 931$ MeV

The total binding energy and binding energy per nucleon C both are more than of A and B.

$$\Delta E = E_c - (E_a + E_b)$$

Fusion of four hydrogen nuclei into helium nucleus :

$$4({}_{1}H^{1}) \rightarrow {}_{2}He^{4} + 2\,{}_{+}\beta^{0} + 2\,\nu + 26\text{ MeV}$$

❖ Energy released per fission >> Energy released per fusion.

❖ Energy per nucleon in fission $\left[= \frac{200}{235} \simeq 0.85\text{MeV}\right]$ << energy per nucleon in fusion $\left[= \frac{24}{4} \simeq 6\text{MeV}\right]$

REQUIRED CONDITION FOR NUCLEAR FUSION

(i) High temperature :

Which provide kinetic energy to nuclei to overcome the repulsive electrostatic force between them.

(ii) High Pressure (or density) :

Which ensure frequent collision and increases the probability of fusion. The required temperature and pressure at earth (lab) are not possible. These condition exist in the sun and in many other stars. The source of energy in the sun is nuclear fusion, where hydrogen is in plasma state and there protons fuse to form helium nuclei.

HYDROGEN BOMB

It is based on nuclear fusion and produces more energy than an atom bomb.

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Pair production	Pair Annihilation
A γ–photon of energy more than 1.02 MeV, when interact with a nucleus produces pair of electron (e^-) and positron (e^+). The energy equivalent to rest mass of e^- (or e^+)=0.51 MeV. The energy equivalent to rest mass of pair ($e^- + e^+$) = 1.02 MeV. For pair production Energy of photon $\geq$ 1.02 MeV. If energy of photon is more than 1.02 MeV, the extra energy (E–1.02) MeV divides approximately in equal amount to each particle as the kinetic energy or $(KE)_{e^- \text{ or } e^+} = \left[\frac{E_{Ph} - 1.02}{2}\right]$ MeV If E < 1.02 MeV, pair will not produce.	When electron and positron combines they annihilates to each other and only energy is released in the form of two gama photons. If the energy of electron and positron are negligible then energy of each γ–photon is 0.5/MeV

Ex. In a nuclear reactor, fission is produced in 1 g for U^{235} (235.0439) in 24 hours by slow neutrons (1.0087 u). Assume that $_{35}Kr^{92}$ (91.8973 u) and $_{56}Ba^{141}$ (140.9139 amu) are produced in all reactions and no energy is lost.

(i) Write the complete reaction **(ii)** Calculate the total energy produced in kilowatt hour. Given 1u = 931 MeV.

Sol. The nuclear fission reaction is $_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_0n^1$

Mass defect $\Delta m = [(m_u + m_n) - (m_{Ba} + m_{Kr} + 3m_n)] = 256.0526 - 235.8373 = 0.2153$ u

Energy released $Q = 0.2153 \times 931 = 200$ MeV. Number of atoms in 1 g $= \frac{6.02 \times 10^{23}}{235} = 2.56 \times 10^{21}$

Energy released in fission of 1 g of U^{235} is $E = 200 \times 2.56 \times 10^{21} = 5.12 \times 10^{23}$ MeV

$= 5.12 \times 10^{23} \times 1.6 \times 10^{-13} = 8.2 \times 10^{10}$ J

$= \frac{8.2 \times 10^{10}}{3.6 \times 10^{6}}$ kWh $= 2.28 \times 10^{4}$ kWh

Ex. It is proposed to use the nuclear fusion reaction : $_1H^2 + {}_1H^2 \rightarrow {}_2He^4$ in a nuclear reactor of 200 MW rating. If the energy from above reaction is used with at 25% efficiency in the reactor, how many grams of deuterium will be needed per day. (Mass of $_1H^2$ is 2.0141 u and mass of $_2He^4$ is 4.0026 u)

Sol. Energy released in the nuclear fusion is $Q = \Delta mc^2 = \Delta m(931)$ MeV (where Δm is in amu)

$Q = (2 \times 2.0141 - 4.0026) \times 931$ MeV $= 23.834$ MeV $= 23.834 \times 10^6$ eV

Since efficiency of reactor is 25%

So effective energy used $= \frac{25}{100} \times 23.834 \times 10^6 \times 1.6 \times 10^{-19}$ J $= 9.534 \times 10^{-13}$ J

Since the two deuterium nuclei are involved in a fusion reaction,

therefore, energy released per deuterium is $\frac{9.534 \times 10^{-13}}{2}$.

For 200 MW power per day, number of deuterium nuclei required $= \frac{200 \times 10^6 \times 86400}{\frac{9.534 \times 10^{-23}}{2}} = 3.624 \times 10^{25}$

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RADIOACTIVITY

INTRODUCTION

Among about 2500 known nuclides, fewer than 300 are stable. The others are unstable structures that decay to form other nuclides by spontaneously emitting particles and electromagnetic radiation, a process called radioactivity. The time scale of these decay processes ranges from a small fraction of a microsecond to billions of years. The substances which emit these radiations are called as radioactive substances. It was discovered by Henry Becquerel for atoms of Uranium. Later iit was discovered that many naturally occurring compounds of heavy elements like radium, thorium etc. also emit radiations.

At present, it is known that all the naturally occurring elements having atomic number greater than 82 are radioactive. For example some of them are; radium, polonium, thorium, actinium, uranium, radon etc. Later on Rutherford found that emission of radiation always accompained by transformation of one element (transmutation) into another. In actual radioactivity is the result of disintegration of an unable nucleus. Rutherford studied the nature of thesed radiations and found that these mainly consist of α,β,γ particles (rays).

α-Particles : ($_2He^4$)

These carry a charge of +2e and mass equal to $4m_p$. These are nuclei of helium atoms. The energies of α-particles very form 5 Me V to 9 Me V ; theiir velocities vary from 0.01 – 0..1 times of c (velocity of light). They can be deflected by electric and magnetic field and have lower penetrating power but high ionising power.

β-Particles : ($_1e^0$)

These are fast moving electrons having charge equal to e and mass $m_e = 9.1 \times 10^{-31}$ kg. Their velocities very from 1% to 99% of the velocity of light (c). They can also be deflected by electric and magnetic fields. They have low ionising power but high penetrating power.

γ-particles : ($_0\gamma^0$)

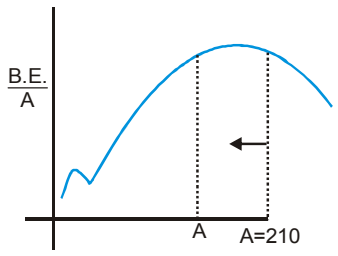
These are electro-magnetic waves of nuclear origin and of very short wavelength. They have no masss. They have maximum penetrating power and minimum ionising power. The energy released in a nuclear reaction is mainly emitted in from these γ-radiations.

RADIOACTIVE DECAYS

Generally, there are three types of radioactive decays **(i)** α decay **(ii)** β^- and β^+ decay **(iii)** γ decay

(i) α decay

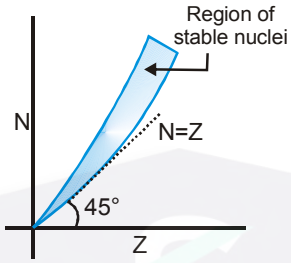
In α decay, the unstable nucleus emits an α particle. By emitting α particle, the nucleus decreases it's mass energy number and move towards stability. Nucleus having A>210 shows α decay.By releasing α particle, it can attain higher stability and Q value is positive.



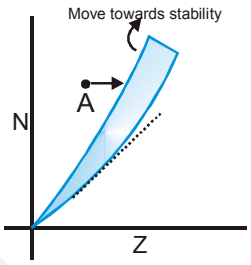
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(ii) β decay

In beta decay (N/Z) ratio of nucleus is changed. This decay is shown by unstable nuclei. In beta decay, either a neutron is converted into proton or proton is converted into neutron. For better understanding we discuss N/Z graph. There are two type of unstable nuclides



❖ A type



For A type nuclides $(N/Z)_A > (N/Z)$ stable

To achieve stability, it increases Z by conversion of neutron into proton

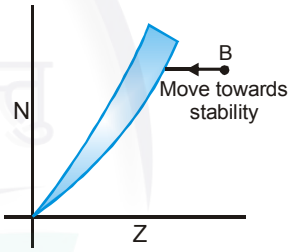
$${}_0n^1 \rightarrow {}_1p^1 + e^{-1} + \bar{\nu},\ {}_ZX^A \rightarrow {}_{Z+1}Y^A + \underset{(\beta \text{ particle})}{e^{-1}} + \bar{\nu}$$

This decay is called β^{-1} decay.

Kinetic energy available for e^{-1} and $\bar{\nu}$ is, $Q = K_\beta + K_{\bar{\nu}}$

K.E. of β satisfies the condition $0 < K_\beta < Q$

❖ B type

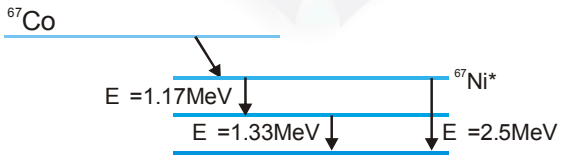


For B type nuclides $(N/Z)_B < (N/Z)$ stable

To achieve stability it decreases Z by the conversion of a proton into neutron. That is, $p \rightarrow n + \underset{(\text{positron})}{e^+} + \underset{(\text{neutrino})}{\nu}$, ${}_ZX^A \rightarrow {}_{Z-1}Y^A + \underset{(\beta^+ \text{particle})}{e^+} + \nu$

(iii) γ decay

: when an α or β decay takes place, the daughter nucleus is usually in higher energy state, such a nucleus comes to ground state by emitting a photon or photons.



Order of energy of γ photon is 100 KeV e.g. ${}^{67}_{27}Co \rightarrow \underset{(\text{higher energy state})}{{}^{67}_{28}Ni^*} + \beta^- + \bar{\nu},\ {}^{67}_{28}Ni^* \rightarrow {}^{67}_{28}Ni + \gamma$ photon

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Properties of α, β and γ rays

Features	α–particles	β–particles	γ–rays
Identity	Helium nucleus or doubly ionised helium atom ($_2He^4$)	Fast moving electrons ($_{-}\beta^0$ or β^-)	Electromagnetic wave (photons)
Charge	Twice of proton (+2e)	Electronic (– e)	Neutral
Mass	$\approx 4m_p$ (rest mass of β) m_p–mass of proton	rest mass = 0 = (rest mass of electron)	
Speed	1.4×10^7 m/s. to 2.2×10^7 m/s. (Only certain value between this range). Their speed depends on nature of the nucleus. So that it is a characteristic speed.	1% of c to 99% of c (All possible values between this range) β–particles come out with different speeds from the same type of nucleus. So that it can not be a characteristic speed.	Only $c = 3 \times 10^8$ m/s γ–photons come out with same speed from all types of nucleus. So, can not be a characteristic speed.
K.E.	≈ MeV	≈ MeV	≈ MeV
Energy spectrum	Line and discrete (or linear)	Continuous (or linear)	Line and discrete
Ionization power (α>β>γ)	10,000 times of γ–rays	100 times of γ–rays (or $\frac{1}{100}$ times of α)	1 (or $\frac{1}{100}$ times of β)
Penetration power (γ>β>α)	$\frac{1}{10000}$ times of γ–rays	$\frac{1}{100}$ times of γ–rays (100 times of α)	1(100 times of β)
Effect of electric or magnetic field	Deflection	Deflection (More than α)	No deflection
Explanation of emission	By Tunnel effect (or quantum mechanics)	By weak nuclear interactions	With the help of energy levels in nucleus

Laws of Radioactive Decay

1. The radioactive decay is a spontaneous process with the emission of α, β and γ rays. It is not influenced by external conditions such as temperature, pressure, electric and magnetic fields.
2. The rate of disintegration is directly proportional to the number of radioactive atoms present at that time i.e., rate of decay ∝ number of nuclei.

Rate of decay = λ (number of nuclei) i.e. $\frac{dN}{dt} = -\lambda N$

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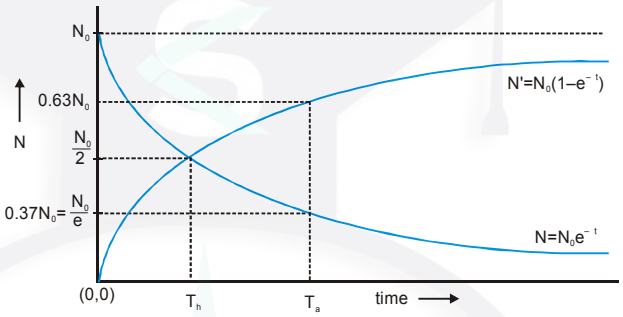
where λ is called the decay constant. This equation may be expressed in the form $\frac{dN}{N} = -\lambda dt$.

$$\int_{N_0}^{N} \frac{dN}{N} = -\lambda \int_{0}^{t} dt \Rightarrow \ell n\left(\frac{N}{N_0}\right) = -\lambda t$$

where N_0 is the number of parent nuclei at t=0. The number that survives at time t is therefore

$N=N_0e^{-\lambda t}$ and $t = \frac{2.303}{\lambda}\log_{10}\left(\frac{N_0}{N_t}\right)$ this function is plotted in figure.

Graph : Time versus N (or N')



(1) Half life (Th) : It is the time during which number of active nuclei reduce to half of initial value.

If at t = 0 no. of active nuclei N_0 then at $t = T_h$ number of active nuclei will be $\frac{N_0}{2}$

From decay equation $N = N_0e^{-\lambda t}$

$$\frac{N_0}{2} = N_0e^{-\lambda T}n \Rightarrow T_h = \frac{\ell n(2)}{\lambda} = \frac{0.693}{\lambda} \approx \frac{0.7}{\lambda}$$

(2) Mean or Average Life (Ta) : It is the average of age of all active nuclei i.e.

$$T_a = \frac{\text{sum of times of existance of all nuclei in a sample}}{\text{initial number of active nuclei in that sample}} = \frac{1}{\lambda}$$

(i) At t = 0, number of active nuclei = N_0 then number of active nuclei at

$t = T_a$ is $N = N_0e^{-\lambda T_a} = N_0e^{-1} = \frac{N_0}{e} = 0.37N_0 = 37\%$ of N_0

(ii) Number nuclei which have been disintegrated within duration T_a is

$N' = N_0 - N = N_0 - 0.37\,N_0 = 0.63\,N_0 = 63\%$ of N_0

(a) $T_a = \frac{1}{\lambda} = \frac{T_h}{\ell n(2)} = \frac{T_h}{0.693} = 1.44\,T_h$

(b) Within duration $T_h \Rightarrow$ 50% of N_0 decayed and 50% of N_0 remains active

(c) Within duration $T_a \Rightarrow$ 63% of N_0 decayed and 37% of N_0 remains active

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Activity of a sample (or decay rate)

It is the rate of decay of a radioactive sample $R = -\frac{dN}{dt} = N\lambda$ or $R = R_0 e^{-\lambda t}$

(i) Activity of a sample at any instant depends upon number of active nuclei at that instant.

$R \propto N$ (or active mass), $R \propto m$

(ii) R also decreases exponentially w.r.t. time same as the number of active nuclei decreases.

(iii) R is not a constant with N, m and time while λ, T_h and T_a are constant

(iv) At $t = 0$, $R = R_0$ then at $t = T_h \Rightarrow R = \frac{R_0}{2}$ and at $t = T_a \Rightarrow R = \frac{R_0}{e}$ or $0.37\, R_0$

(v) Similarly active mass of radioactive sample decreases exponentially. $m = m_0 e^{-\lambda t}$

(vi) Activity of m gm active sample (molecular weight M_w) is $R = \lambda N = \frac{0.693}{T_h}\left[\frac{N_{AV}}{M_W}\right] m$

here N_{AV} = Avogadro number = 6.023×10^{23}

SI unit of R : 1 becquerel (1 Bq)= 1 decay/sec

Other unit is curie : 1 Ci = 3.70×10^{10} decays/sec

1 Rutherford : (1 Rd) = 10^6 decays/s

Specific activity : Activity of 1 gm sample of radioactive substance. Its unit is Ci/gm

e.g. specific activity of radium (226) is 1 Ci/gm.

Ex. The half–life of cobalt–60 is 5.25 yrs. After how long does its activity reduce to about one eight of its original value?

Sol. The activity is proportional to the number of undecayed atoms: In each half–life, the remaining sample decays to half of its initial value. Since $\left(\frac{1}{2}\right)\times\left(\frac{1}{2}\right)\times\left(\frac{1}{2}\right) = \frac{1}{8}$, therefore, three half–lives or 15.75 years are required for the sample to decay to 1/8th its original strength.

Ex. A count rate meter is used to measure the activity of a given sample. At one instant the meter shows 4750 counts per minute. Five minutes later it shows 2700 counts per minute.

(i) Find the decay constant. **(ii)** Also, find the half–life of the sample.

Sol. Initial activity $A_i = \left|\frac{-dN}{dt}\right|_{t=0} = \lambda N_0 = 4750$ ...(i) Final activity $A_f = \left|\frac{-dN}{dt}\right|_{t=5} = \lambda N = 2700$ ...(ii)

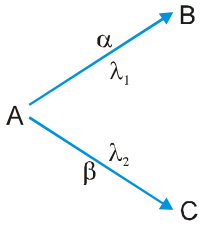
Dividing (i) by (ii), we get $\frac{4750}{2700} = \frac{N_0}{N_t}$

The decay constant is given by $\lambda = \frac{2.303}{t}\log\frac{N_0}{N_t} = \frac{2.303}{5}\log\frac{4750}{2700} = 0.113\ \text{min}^{-1}$

Half–life of the sample is $T = \frac{0.693}{\lambda} = \frac{0.693}{0.113} = 6.14\ \text{min}$

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Parallel radioactive disintegration



Let initial number of nuclei of A is N_0 then at any time number of nuclei of

A, B & C are given by $N_0 = N_A + N_B + N_C \Rightarrow \frac{dN_A}{dt} = \frac{-d}{dt}(N_B + N_C)$

A disintegrates into B and C by emitting α, β particle.

Now, $\frac{dN_B}{dt} = -\lambda_1 N_A$ and $\frac{dN_C}{dt} = -\lambda_2 N_A \Rightarrow \frac{d}{dt}(N_B + N_C) = -(\lambda_1 + \lambda_2)N_A$

$\Rightarrow \frac{dN_A}{dt} = -(\lambda_1 + \lambda_2)N_A \Rightarrow \lambda_{eff} = \lambda_1 + \lambda_2 \Rightarrow t_{eff} = \frac{t_1 t_2}{t_1 + t_2}$

Ex. The mean lives of a radioactive substances are 1620 and 405 years for α–emission and β–emission respectively. Find out the time during which three fourth of a sample will decay if it is decaying both by α–emission and β–emission simultaneously.

Sol. When a substance decays by α and β emission simultaneously, the average rate of disintegration λ_{av} is given by $\lambda_{av} = \lambda_\alpha + \lambda_\beta$ when λ_α = disintegration constant for α–emission only λ_β = disintegration constant for β–emission only

Mean life is given by $T_m = \frac{1}{\lambda}$, $\lambda_{av} = \lambda_\alpha + \lambda_\beta \Rightarrow \frac{1}{T_m} = \frac{1}{T_\alpha} + \frac{1}{T_\beta} = \frac{1}{1620} + \frac{1}{405} = \frac{1}{324}$

$\lambda_{av} \times t = 2.303 \log \frac{N_0}{N_t}$, $\frac{1}{324} t = 2.303 \log \frac{100}{25} \Rightarrow t = 2.303 \times 324 \log 4 = 449$ years.

Ex. A radioactive decay is given by $A \xrightarrow[t_{1/2}=8 \text{ yrs}]{} B$

Only A is present at t=0. Find the time at which if we are able to pick one atom out of the sample, then probability of getting B is 15 times of getting A.

Sol.

		A	⟶	B
at	t = 0	N_0		0
at	t = t	N		$N_0 - N$

Probability of getting A, $P_A = \frac{N}{N_0}$

Probability of getting B, $P_B = \frac{N_0 - N}{N_0} \Rightarrow P_B = 15\, P_A \Rightarrow \frac{N_0 - N}{N_0} = 15\frac{N}{N_0} \Rightarrow N_0 = 16N \Rightarrow N = \frac{N_0}{16}$

Remaining nuclei are $\frac{1}{16}$ th of initial nuclei, hence required time t = 4 half lives =32 years

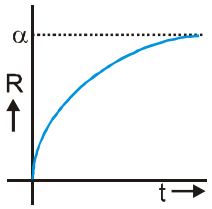
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Radioactive Disintegration with Successive Production

$$\xrightarrow[(\alpha = rate\ of\ production)]{\alpha} A \xrightarrow{\lambda} B$$

$$\frac{dN_A}{dt} = \alpha = \lambda N_A \quad ....(i)$$

when N_A in maximum $\frac{dN_A}{dt} = 0 = \alpha - \lambda N_A = 0$, $N_A \max = \frac{\alpha}{\lambda} = \frac{\text{rate of production}}{\lambda}$



By equation (i) $\int_0^t \frac{dN_A}{\alpha - \lambda N_A} = \int_0^t dt$, Number of nuclei is $N_A = \frac{\alpha}{\lambda}\left(1 - e^{-\lambda t}\right)$

Ex. $\xrightarrow{10^{21}\ \text{per sec}} A \xrightarrow{\lambda=\frac{1}{30}} B$

A shows radioactive disintegration and it is continuously produced at the rate of 10^{21} per sec. Find maximum number of nuclei of A.

Sol. At maximum, $r_{production} = r_{decay} \Rightarrow 10^{21} = \frac{1}{30} N \Rightarrow N = 30 \times 10^{21}$

Soddy and Fajan's Group Displacement Laws :

(i) α–decay : The emission of one α–particle reduces the mass number by 4 units and atomic number by 2 units. If parent and daughter nuclei are represented by symbols X and Y respectively then,

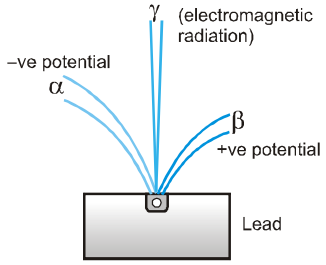
$$_ZX^A \rightarrow {}_{Z-2}Y^{A-4} + {}_2He^4(\alpha)$$

(ii) β–decay : Beta particles are said to be fast moving electrons coming from the nucleus of a radioactive substance. Does it mean that a nucleus contains electrons? No, it is an established fact that nucleus does not contain any electrons. When a nucleus emits a beta particle, one of its neutrons breaks into a proton, an electron (i.e., β–particle) and an antineutrino $n \rightarrow p + e + \bar{\nu}$

where n= neutron p = proton e = β–particle

Thus emission of a beta particle is caused by the decay of a neutron into a proton. The daughter nucleus thus has an atomic number greater than one (due to one new proton in the nucleus) but same mass number as that of parent nucleus. Therefore, representing the parent and daughter nucleus by symbols X and Y respectively, we have $_ZX^A \rightarrow {}_{Z+1}Y^A + \beta + \bar{\nu}$

(iii) γ–decay : When parent atoms emit gamma rays, no charge is involved as these are neutral rays. Thus there is no effect on the atomic number and mass number of the parent nucleus. However the emission of γ–rays represents energy. Hence the emission of these rays changes the nucleus from an excited (high energy) state to a less excited (lower energy) state.



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TIPS& FORMULAS

1. Atomic Models :

(a) Thomson model : (Plum pudding model)

(1) Most of the mass and all the positive charge of an atom is uniformly distributed over the full size of atom (10^{-10} m).

(2) Electrons are studded in this uniform distribution.

(3) Failed to explain the large angle scattering α-particle scattered by thin foils of matter.

(b) Rutherford model : (Nuclear Model)

(1) The most of the mass and all the positive charge is concentrated within a size of 10-14 m inside the atom. This concentrated is called the atomic nucleus.

(2) The electron revolves around the nucleus under electric interaction between them in circular orbits.

(3) An accelerating charge radiates the nucleus spiralling inward and finally fall into the nucleus, which does not happen in an atom. This could not be explained by this model.

(c) Bohr atomic model : Bohr adopted Rutherford model of the atom & added some arbitrary conditions. These conditions are known as his postulates

(1) The electron in a stable orbit does not radiate energy.

(2) A stable orbit is that in which the angular momentum of the electron about nucleus is an integral (n) multiple of $\frac{h}{2\pi}$ i.e., $mvr = n\frac{h}{2\pi}$; $n = 1, 2, 3, ..(n \neq 0)$.

(3) The electron can absorb or radiate energy only if the electron jumps from a lower to a higher orbit or falls from a higher to lower orbit.

(4) The energy emitted or absorbed is a light photon of frequency ν and of energy. $E = h\nu$

For hydrogen atom : (z = atomic number = 1)

L_n = angular momentum in the n^{th} orbit = $n\frac{h}{2\pi}$

r_n = radius of n^{th} circular orbit = $(0.529\ \mathring{A})\, n^2 \Rightarrow r_n \propto n^2$

E_n = Energy of the electron in the n^{th} orbit = $\frac{-13.6\,eV}{n^2} \Rightarrow E_n \propto \frac{1}{n^2}$

Note : Total energy of the electron in an atom is negative, indicating that it is bound.

Binding Energy $(BE)_n = E_n = \frac{13.6\,eV}{n^2}$

(5) $E_{n2} - E_{n1}$ = Energy emitted when an electron jumps from n_2^{th} orbit to n_1^{th} orbit $(n_2 > n_1)$

$$\Delta E = (13.6\,eV)\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$\Delta E = h\nu$; ν = frequency of spectral line emitted.

$\frac{1}{\lambda}$ = wave no, [no. of waves in unit length (1m)] = $R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

where R = Rydberg's constant, for hydrogen = $1.097 \times 10^7\ m^{-1}$

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(6) For hydrogen like atom/species of atomic number Z :

$$r_{nz} = \frac{\text{Bohr radius}}{Z} n^2 = \left(0.529\,\text{Å}\right)\frac{n^2}{Z}; E_{nz} = (-13.6)\frac{Z^2}{n^2}\text{eV}$$

$R_z = RZ^2$; Rydberg's constant for element of atomic no. Z.

Note : If motion of the nucleus is also considered, then μ is replaced by μ. Where μ = reduced mass of electron - nucleus system $= mM/(m+M)$

In this case $E_n = (-13.6\text{ eV})\frac{Z^2}{n^2}\cdot\frac{\mu}{m_e}$

2. Spectral series :

(a) Lyman Series : (Landing orbit n = 1)

Ultraviolet region $\bar{\nu} = R\left[\frac{1}{1^2} - \frac{1}{n_2^2}\right]; n_2 > 1$

(b) Balmer Series : (Landing orbit n = 2)

Visible region $\bar{\nu} = R\left[\frac{1}{2^2} - \frac{1}{n_2^2}\right]; n_2 > 2$

(c) Paschan Series : (Landing orbit n = 3)

In the mid infrared region $\bar{\nu} = R\left[\frac{1}{3^2} - \frac{1}{n_2^2}\right]; n_2 > 3$

(d) Bracket Series : (Landing orbit n = 4)

In the mid infrared region $\bar{\nu} = R\left[\frac{1}{4^2} - \frac{1}{n_2^2}\right]; n_2 > 4$

(e) Pfund Series : (Landing orbit n = 5)

In far infrared region $\bar{\nu} = R\left[\frac{1}{5^2} - \frac{1}{n_2^2}\right]; n_2 > 5$

In all these series $n_2 = n_1 + 1$ is the α line

$= n_1 + 2$ is the β line

$= n_1 + 3$ is the γ line .....etc

where n_1 = Landing orbit

3. Total emission spectral lines

From $n_1 = n$ to $n_2 = 1$ state $= \frac{n(n-1)}{2}$

From $n_1 = n$ to $n_2 = m$ state $= \left(\frac{(n-m)(n-m+1)}{2}\right)$

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4. Excitation Potential of Atom :

Excitation potential for quantum jump from $n_1 \to n_2 = \dfrac{E_{n2} - E_{n1}}{\text{electron charge}}$

5. Ionization energy of hydrogen atom :

The energy required to remove an electron from an atom. The energy required to ionize hydrogen atom is $= 0 - (-13.6) = 13.6$ eV.

6. Ionization Potential :

Potential difference through which a free electron is moved to gain ionization energy $= \dfrac{-E_n}{\text{electron charge}}$

7. X - RAYS

(a) X-rays are produced by bombarding high speed electrons on a target of high atomic weight and high melting point.

(b) Short wavelength (0.1 $\mathring{A}$ to 10 $\mathring{A}$) electromagnetic radiation.

(c) Are produced when a metal anode is bombarded by very high energy electrons

(d) Are not affected by electric and matgnetic field.

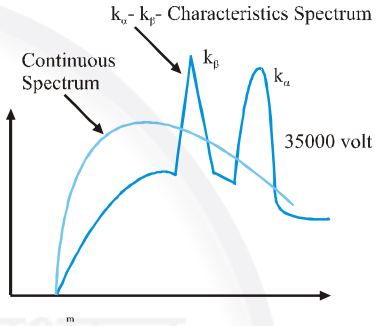
(e) They cause photoelectric emission.

Characteristic equation $eV = h\nu_m$

e = electron charge;

V = accelerating potential

ν_m = maximum frequency of X - radiation



(f) Intensity of X - rays depends on number of electrons hitting the target.

(g) Cut off wavelength or minimum wavelength, where V (in volts) is the p.d. applied to the tube $\lambda_{min} \cong \dfrac{12400}{V}\text{Å}$

(h) Continuous spectrum due to retardation of electrons.

8. Characteristic X - rays

For $K_\alpha, \lambda = \dfrac{hc}{E_K - E_L}$ For $K_\beta, \lambda = \dfrac{hc}{E_L - E_M}$

9. Moseley's law for characteristic spectrum :

Frequency of characteristic line $\sqrt{\nu} = a(Z - b)$

Where a, b are constant, for K_α line b = 1

Z = atomic number of target

ν = frequency of characteristic spectrum

b = screening constant (for K -series b = 1, L series b = 7.4),

a = proportionality constant

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Bohr model		Moseley's correction	
1.	For single electron species	1.	For many electron species
2.	$\Delta E = 13.6 Z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] eV$	2.	$\Delta E = 13.6 (Z-b)^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] eV$
3.	$\nu = RcZ^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$	3.	$\nu = RcZ^2 (Z-b)^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$
4.	$\frac{1}{\lambda} = RZ^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$	4.	$\frac{1}{\lambda} = R (Z-b)^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

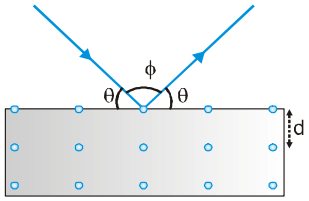
10. Diffraction of X - ray

Diffraction of X- ray take place according to Bragg's law $2d \sin\theta = n\lambda$

d = Spacing of crystal plane or lattice constant or distance between adjacent atomic plane

θ = Bragg's angle or glancing plane

ϕ = Diffracting angle n = 1, 2, 3.....



11. For Maximum Wavelength

$\sin\theta = 1, n = 1 \Rightarrow \lambda_{max} = 2d$

So if $\lambda > 2d$ diffraction is not possible i.e., solution of Bragg's equation is not possible.

12. Binding energy = – [Total Mechanical Energy]

13. Velocity of electron in n^{th} orbit for hydrogen atom $\cong \frac{c}{137n}$; c = speed of light.

14. Series limit means minimum wave length of that series.

15. Binding energy = – [Total Mechanical Energy]

16. Velocity of electron in n^{th} orbit for hydrogen atom $\cong \frac{c}{137n}$; c = speed of light.

17. Series limit means minimum wave length of that series.

18. Photo Electric Effect

The phenomenon of the emission of electrons, when metals are exposed to light (of a certain minimum frequency) is called photo electric effect.

19. Results :

(a) Can be explained only on the basis of the quantum theory (concept of photon)

(b) Electrons are emitted if the incident light has frequency $\nu \geq \nu_0$ (threshold frequency) emission of electrons is independent of intensity. The wave length corresponding to ν_0 is called threshold wave length λ_0

(c) ν_0 is different for different metals

(d) Number of electrons emitted per second depends on the intensity of the incident light.

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20. Einsteins Photo Electric Equation :

Photon energy $= KE_{max}$ of electron + work function

$h\nu = KE_{max} + \phi$

ϕ = Work function = energy needed by the electron in freeing itself from the atoms of the metal $\phi = h\nu_0$

21. Stopping Potential or Cut Off Potential :

The minimum value of the retarding potential to prevent electron emission is

$$eV_{cut\,off} = (KE)_{max}$$

Note : The number of photons incident on a surface per unit time is called photon flux.

22. Wave Nature of Matter :

Beams of electrons and other forms of mattter exhibit wave properties including interference and diffraction with a de Broglie wave length given by $\lambda = \frac{h}{p}$ (wave length of a pratical)

23. De Broglie wavelength associated with moving particles

If a particle of mass m moving with velocity v.

Kinetic energy of the particle $E = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

momentum of particle $p = mv = \sqrt{2mE}$

the wave length associated with the praticles is $\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE}}$

24. De Broglie wavelength associated with the charged particle

(a) For an Electron $\lambda = \frac{12.27\times10^{-10}}{\sqrt{V}}m = \frac{0.286}{\sqrt{V}}\text{Å}$ So $\lambda \propto \frac{1}{\sqrt{V}}$

(b) For Proton $\lambda_p = \frac{0.286\times10^{-10}}{\sqrt{V}}m = \frac{0.286}{\sqrt{V}}\text{Å}$

(c) For Deuteron $\lambda_d = \frac{0.202}{\sqrt{V}}\text{Å}$

(d) For α Particle $\therefore \lambda_\alpha = \frac{0.101}{\sqrt{V}}\text{Å}$

25. NUCLEAR COLLISIONS

We can represent a nuclear collision or reaction by the following notation, which means X (a, b) Y

a + X → Y + b

(bombarding particle) (at rest)

We can apply :

(a) Conservation of momentum **(b)** Conservation of charge **(c)** Conservation of mass- energy

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For any nuclear reaction $\underset{K_1}{a} + \underset{K_2}{X} \rightarrow \underset{K_3}{Y} + \underset{K_4}{b}$

By mass energy conservation

(a) $K_1 + K_2 + (m_\alpha + m_x)c^2 = K_3 + K_4 + (m_Y + m_b)c^2$

(b) Energy released in any nuclear reaction or collision is called Q value of the reaction

(c) $Q = (K_3 + K_4) - (K_1 + K_2) = \sum K_p - \sum K_R = \left(\sum m_R - \sum m_p\right)c^2$

(d) If Q is positive, energy is released and products are more stable in comparison to reactants.

(e) If Q is negative, energy is absorbed and products are less stable in comparison to reactants.

$$Q = \sum (B.E)_{products} - \sum (B.E)_{reactants}$$

26. Nuclear Fission

In 1938 by Hahn and Strassmann. By attack of a particle splitting of a heavy nucleus (A > 230) into two or more lighter nuclei. In this process certain mass disappears which is obtained in the form of energy (enormous amount)

$$A + p \rightarrow \text{excited nucleus} \rightarrow B + C + Q$$

27. Nuclear Fusion

It is the phenomenon of fusing two or more lighter nuclei to form a single heavy nucleus.

$$A + B \rightarrow C + Q \text{ (Energy)}$$

The product (C) is more stable then reactants (A and B) and $m_c < (m_a + m_b)$ and mass defect

$$\Delta m = \left[(m_a + m_b) - m_c\right] \text{ amu}$$

Energy released is $E = \Delta m \ 931$ MeV

The total binding energy and binding energy per nucleon C both are more than of A and B.

$$\Delta E = E_c - (E_a + E_b)$$

28. Radioactivity

Radioactive Decays : Generally, there are three types of radioactive decays

(a) α decay **(b)** β^- and β^+ dacay **(c)** γ decay

(a) α decay : By emitting α particle, the nucleus decreases it's mass number and move towards stability. Nucleus having A > 210 shows a decay.

(b) β decay : In beta decay, either a neutron is converted into proton or proton is converted into neutron.

(c) γ decay : When an α or β decay takes place, the daughter nucleus is usually in higher energy state, such a nucleus comes to ground state by emitting a photon or photons.

Order of energy of γ photon is 100 keV

29. Laws of Radioactive Decay : The rate of disintegration isdirectly proportional to the number of radioactive atoms present at that time i.e., rate of decay $\propto$ number of nuclei.

Rate of decay = λ (number of nuclei) i.e., $\frac{dN}{dt} = -\lambda N$

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where λ is called the decay constant.

This equation may be expressed in the form $\frac{dN}{N} = -\lambda dt$.

$$\int_{N_0}^{N} \frac{dN}{N} = -\lambda \int_0^t dt \Rightarrow \ell n\left(\frac{N}{N_0}\right) = -\lambda t$$

where N_0 is the number of parent nuclei at t = 0. The number that survives at time t is therefore $N = N_0\, e^{-\lambda t}$ and

$t = \frac{2.303}{\lambda} \log_{10}\left(\frac{N_0}{N_t}\right)$

$N = N_0\, e^{-\lambda t}$ where λ = decay constant

(a) Half life $t_{1/2} = \frac{\ell n 2}{\lambda}$

(b) Average life $t_{av} = \frac{1}{\lambda}$

Within duration $t_{1/2} \Rightarrow$ 50 % of N_0 decayed and 50 % of N_0 remains active

Within duration $t_{av} \Rightarrow$ 63 % of N_0 decayed and 37 % of N_0 remains active

(c) Activity $R = \lambda N = R_0\, e^{-\lambda t}$

(d) 1 Bq = 1 decay/s.

(e) 1 curie $= 3.7 \times 10^{10}$ Bq.

(f) 1 rutherford $= 10^6$ Bq

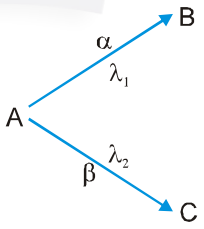
(g) After n half lives Number of nuclei left $= \frac{N_0}{2^n}$

Probability of a nucleous for survival of time $t = \frac{N}{N_0} = \frac{N_0 e^{-\lambda t}}{N_0} = e^{-\lambda t}$

30. Parallel radioactive disintergration

Let initial number of nuclei of A is N_0 then at any time

number of nuclei of A, B & C are given by $N_0 = N_A + N_B + N_C$



$$\Rightarrow \frac{dN_A}{dt} = \frac{-d}{dt}(N_B + N_C)$$

A disintegrates into B and C by emitting α, β particle.

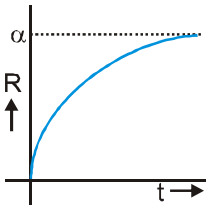
Now, $\frac{dN_B}{dt} = -\lambda_1 N_A$ and $\frac{dN_C}{dt} = -\lambda_2 N_A \Rightarrow \frac{d}{dt}(N_B + N_C) = -(\lambda_1 + \lambda_2) N_A$

$$\Rightarrow \frac{dN_A}{dt} = -(\lambda_1 + \lambda_2) N_A \Rightarrow \lambda_{eff} = \lambda_1 + \lambda_2 \Rightarrow t_{eff} = \frac{t_1 t_2}{t_1 + t_2}$$

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31. Radioactive Disintegration with Successive

Production $\xrightarrow[(\alpha=\text{rate of production})]{\alpha} A \xrightarrow{\lambda} B$



$\frac{dN_A}{dt} = \alpha - \lambda N_A$ .....(i)

When N_A is maximum $\frac{dN_A}{dt} = 0 \Rightarrow \alpha - \lambda N_A = 0$,

$N_{A\,max} = \frac{\alpha}{\lambda} = \frac{\text{rate of production}}{\lambda}$

By equation (i) $\int_0^t \frac{dN_A}{\alpha - \lambda N_A} = \int_0^t dt$, Number of nuclei is $N_A = \frac{\alpha}{\lambda}\left(1 - e^{-\lambda t}\right)$

32. Equivalence of mass and energy $E = mc^2$

Note : - $1u = 1.66 \times 10^{-27}$ kg $= 931$ MeV or $c^2 = 931.5$ MeV/u

33. Binding energy of ${}_ZX^A$

$BE = \Delta mc^2 = [Zm_p + (A-Z)m_n - m_x]c^2 = [Zm_H + (A-Z)m_n - m_x)c^2$

34. Q-value of a nuclear reaction

For $a + X \rightarrow Y + b$ or X (a, b) Y ; $Q = (M_a + M_x - M_Y - M_b)c^2$

35. Radius of the nucleus

$R = R_0 A^{1/3}$ where $R_0 = 1.3\ f_m = 1.3 \times 10^{-15}$ m

From Bohr Model

$n_1 = 1$, $n_2 = 2, 3, 4$.....K series

$n_1 = 2$, $n_2 = 3, 4, 5$.....L series

$n_1 = 3$, $n_2 = 4, 5, 6$.....M series

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SOLVED EXAMPLE

Ex. 1. Find the momentum of a 12.0 MeV photon.

Sol. $p = \frac{E}{c} = 12\ \text{MeV/c}.$

Ex. 2. Monochromatic light of wavelength 3000 Å is incident nornally on a surface of area 4 cm^2. If the intensity of the light is 15×10^{-2} W/m^2, determine the rate at which photons strike the surface.

Sol. Rate at which photons strike the surface

$$= \frac{IA}{hc/\lambda} = \frac{6\times10^{-5}\ J/s}{6.63\times10^{-19}\ J/\text{photon}} = 9.05 \times 10^{13}$$ photon/s.

Ex. 3. The kinetic energies of photoelectrons range from zero to 4.0×10^{-19} J when light of wavelength 3000 Å falls on a surface. What is the stopping potential for this light ?

Sol. $K_{max} = 4.0\times10^{-19}\ J \times \frac{1eV}{1.6\times10^{-19}\ J} = 2.5\ eV.$

Then, from $eV_s = K_{max}$, $V_s = 2.5$ V.

Ex. 4. What is the threshold wavelength for the material in above Ex. ?

Sol. $2.5\ eV = \frac{12.4\times10^3\ eV.Å}{3000\ Å} - \frac{12.4\times10^3\ eV.Å}{\lambda_{th}}$

Solving, $\lambda_{th} = 7590$ Å.

Ex. 5. Find the de Broglie wavelength of a 0.01 kg pellet having a velocity of 10 m/s.

Sol. $\lambda = h/p = \frac{6.63\times10^{-34}\ J.s}{0.01\ kg\times10\ m/s} = 6.63 \times 10^{-23}$ Å.

Ex. 6. Determine the accelerating potential necessary to give an electron a de Broglie wavelength of 1 Å, which is the size of the interatomic spacing of atoms in a crystal.

Sol. $V = \frac{h^2}{2m_0e\lambda^2} = 151$ V.

Ex. 7. Determine the wavelength of the second line of the Paschen series for hydrogen.

Sol. $\frac{1}{\lambda} = (1.097\times10^{-3}\ Å^{-1})\left(\frac{1}{3^2} - \frac{1}{5^2}\right)$ or

$\lambda = 12{,}820$ Å.

Ex. 8. How many different photons can be emitted by hydrogen atoms that undergo transitions to the ground state from the n = 5 state ?

Sol. No of possible transition from n = 5 are $^5C_2 = 10$

Ans. 10 photons.

Ex. 9. An electron rotates in a circle around a nucleus with positive charge Ze. How is the electrons' velocity releated to the radius of its orbit ?

Sol. The force on the electron due to the nuclear provides the required centripetal force

$$\frac{1}{4\pi\varepsilon_0}\ \frac{Ze.e}{r^2} = \frac{mv^2}{r}$$

$\Rightarrow v = \sqrt{\frac{Ze^2}{4\pi\varepsilon_0.rm}}$ **Ans.** $v = \sqrt{\frac{Ze^2}{4\pi\varepsilon_0.rm}}$.

Ex. 10. **(i)** Calculate the first three energy levels for positronium.

(ii) Find the wavelength of the H_a line ($3 \rightarrow 2$ transition) of positronium.

Sol. In positronium electron and positron revolve around their centre of mass

$$\frac{1}{4p\varepsilon_0}\ \frac{e^2}{r^2} = \frac{mv^2}{r/2} \qquad \text{.....(1)}$$

$$\frac{nh}{2\pi} = 2\times mv_{k/2} \qquad \text{.....(2)}$$

From **(1)** & **(2)**

$$V = \frac{1}{2}\cdot\frac{1}{4\pi\varepsilon_0}\cdot\frac{e^2}{nh}\times 2p = \frac{e^2}{4\varepsilon_0 nh}$$

$$TE = -\frac{1}{2}mv^2\times 2 = -m.\frac{e^4}{16\varepsilon_0{}^2n^2h^2}$$

$$= -6.8\ \frac{1}{n^2}\ eV$$

(i) $E_1 = -6.8$ ev

$$E_2 = -6.8\times\frac{1}{2^2}\ eV = -1.70\ eV$$

$$E_3 = -6.8\times\frac{1}{3^2}\ eV = -0.76\ eV$$

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(ii) $\Delta E(3 \to 2) = E_3 - E_2 = -0.76 - (-1.70)\ eV$
$= 0.94\ eV$

The corresponding wave length

$$\lambda = \frac{1.24 \times 10^4}{0.94}\ Å = 1313\ Å$$

Ans. **(i)** –6.8 eV, –1.7 eV , –0.76 eV ;
(ii) 1313 Å .

Ex. 11. A H-atom in ground state is moving with intial kinetic energy K. It collides head on with a He^+ ion in ground state kept at rest but free to move. Find minimum value of K so that both the particles can excite to their first excited state.

Sol. Energy available for excitation $= \frac{4K}{5}$

Total energy required for excitation
$= 10.2\ ev + 40.8\ eV$
$= 51.0\ ev$

$\therefore \quad \frac{4k}{5} = 51 \quad \Rightarrow \quad k = 63.75\ eV$

Ex. 12. A TV tube operates with a 20 kV accelerating potential. What are the maximum–energy X–rays from the TV set ?

Sol. The electrons in the TV tube have an energy of 20 keV, and if these electrons are brought to rest by a collision in which one X–ray photon is emitted, the photon energy is 20 keV.

Ex. 13. In the Moseley relation, $\sqrt{v} = a(Z-b)$ which will have the greater value for the constant a for K_α or K_β transition?

Sol. A is larger for the K_β transitions than for the K_α transitions.

Ex.14 Calculate the electric potential energy due to the electric repulsion between two nuclei of ^{12}C when they 'touch' each other at the surface.

Sol. The radius of a ^{12}C nucleus is

$R = R_0 A^{1/3}$
$= (1.1\ fm)(12)^{1/3} = 2.52\ fm.$

The separation between the centres of the nuclei is $2R = 5.04$ fm. The potential energy of the pair is

$$U = \frac{q_1 q_2}{4\pi\varepsilon_0 r}$$

$= (9 \times 10^9\ N\ m^2\ C^{-2}) \frac{(6 \times 1.6 \times 10^{-19}\ C)^2}{5.04 \times 10^{-15}\ m}$

$= 1.64 \times 10^{-12}\ J = 10.2\ MeV.$

Ex.15 Find the binding energy of $^{56}_{26}Fe$. Atomic mass of ^{56}Fe is 55.9349 u and that of ^1H is 1.00783 u. Mass of neutron = 1.00867 u.

Sol. The number of protons in $^{56}_{26}Fe = 26$ and the number of neutrons = 56 – 26 = 30. The binding energy of $^{56}_{26}Fe$ is

$= [26 \times 1.00783\ u + 30 \times 1.00867\ u - 55.9349\ u]c^2$
$= (0.52878\ u)\ c^2$
$= (0.52878\ u)\ (931\ MeV\ u^{-1}) = 492\ MeV.$

Ex.16 Find the kinetic energy of the α-particle emitted in the decay $^{238}Pu \to {}^{234}U + \alpha$. The atomic masses needed are as follows :

^{238}Pu	^{234}U	^4He
238.04955 u	234.04095 u	4.002603 u

Neglect any recoil of the residual nucleus.

Sol. Using energy conservation,

$m(^{238}Pu)\ c^2 = m(^{234}U)c^2 + m(^4He)c^2 + K$

or, $K = [m(^{238}Pu) - m(^{234}U) - m(^4He)]c^2$
$= [238.04955\ u - 234.04095\ u - 4.002603\ u]\ (931\ MeV\ u^{-1})$
$= 5.58\ MeV.$

Ex.17 Calculate the Q-value in the following decays :

(a) $^{19}O \to {}^{19}F + e + \bar{\nu}$

(b) $^{25}Al \to {}^{25}Mg + e^+ + \nu.$

The atomic masses needed are as follows :

^{19}O	^{19}F	^{25}Al	^{25}Mg
19.003576 u	18.998403 u	24.990432 u	24.985839 u

Sol.

(a) The Q-value of β^--decay is

$Q = [m(^{19}O) - m(^{19}F)]c^2$
$= [19.003576\ u - 18.998403\ u]\ (931\ MeV\ u^{-1})$
$= 4.816\ MeV.$

(b) The Q-value of β^+-decay is

$Q = [m(^{25}Al) - m(^{25}Mg) - 2m_e]c^2$
$= [24.990432\ u - 24.985839\ u - 2 \times 0.511\ MeV\ c^{-2}]\ c^2$
$= (0.004593\ u)\ (931\ MeV\ u^{-1}) - 1.022\ MeV$
$= 4.276\ MeV - 1.022\ MeV = 3.254\ MeV.$

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Ex.18 Find the maximum energy that a beta particle can have in the following decay

$$^{176}Lu \rightarrow {}^{176}Hf + e + \bar{\nu}.$$

Atomic mass of ^{176}Lu is 175.942694 u and that of ^{176}Hf is 175.941420 u.

Sol. The kinetic energy available for the beta particle and the antineutrino is

$$Q = [m(^{176}Lu) - m(^{176}Hf)]c^2$$
$$= (175.942694\,u - 175.941420\,u)(931\ MeVu^{-1})$$
$$= 1.182\ MeV.$$

This energy is shared by the beta particle and the antineutrino. The maximum kinetic energy of a beta particle in this decay is, therefore, 1.182 MeV when the antineutrino practically does not get any share.

Ex.19 Consider the beta decay

$$^{198}Au \rightarrow {}^{198}Hg^* + \beta^- + \bar{\nu}$$

where $^{198}Hg^*$ represents a mercury nucleus in an excited state at energy 1.088 MeV above the ground state. What can be the maximum kinetic energy of the electron emitted ? The atomic mass of ^{198}Au is 197.968233 u and that of ^{198}Hg is 197.966760 u.

Sol. If the product nucleus ^{198}Hg is formed in its ground state, the kinetic energy available to the electron and the antineutrino is

$$Q = [m(^{198}Au) - m(^{198}Hg)]\,c^2.$$

As $^{198}Hg^*$ has energy 1.088 MeV more than ^{198}Hg in ground state, the kinetic energy actually available is

$$Q = [m(^{198}Au) - m(^{198}Hg)]c^2 - 1.088\ MeV$$
$$= (197.968233\,u - 197.966760\,u)(931\ MeV\,u^{-1}) - 1.088\ MeV$$
$$= 1.3686\ MeV - 1.088\ MeV = 0.2806\ MeV$$

This is also the maximum possible kinetic energy of the electron emitted.

Ex.20 The half-life of ^{198}Au is 2.7 days. Calculate (a) the decay constant, (b) the average-life and (c) the activity of 1.00 mg of ^{198}Au. Take atomic weight of ^{198}Au to be 198 g mol^{-1}.

Sol. **(a)** The half-life and the decay constant are related as

$$t_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda} \quad \text{or,} \quad \lambda = \frac{0.693}{t_{1/2}} = \frac{0.693}{2.7\,days}$$
$$= \frac{0.693}{2.7 \times 24 \times 3600\,s} = 2.9 \times 10^{-6}\ s^{-1}.$$

(b) The average-life is $t_{av} = \frac{1}{\lambda} = 3.9$ days.

(c) The activity is $A = \lambda N$. Now, 198 g of ^{198}Au has 6×10^{23} atoms. The number of atoms in 1.00 mg of ^{198}Au is

$$N = 6 \times 10^{23} \times \frac{1.0\,mg}{198\,g} = 3.03 \times 10^{18}.$$

Thus, $A = \lambda N$
$$= (2.9 \times 10^{-6}\ s^{-1})(3.03 \times 10^{18})$$
$$= 8.8 \times 10^{12}\ \text{disintegrations}\ s^{-1}$$
$$= \frac{8.8 \times 10^{12}}{3.7 \times 10^{10}}\,Ci = 240\,Ci.$$

Ex.21 A radioactive sample has 6.0×10^{18} active nuclei at a certain instant. How may of these nuclei will still be in the same active state after two half-lives?

Sol. In one half-life the number of active nuclei reduces to half the original number. Thus, in two half-lives the number is reduced to $\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)$ of the original number. The numbher of remaining active nuclei is, therefore,

$$6.0 \times 10^{18} \times \left(\frac{1}{2}\right) \times \left(\frac{1}{2}\right) = 1.5 \times 10^{18}.$$

Ex.22 The activity of a radioactive sample falls from 600 s^{-1} to 500 s^{-1} in 40 minutes. Calculate its half-life.

Sol. We have,

$$A = A_0 e^{-\lambda t}$$
or, $500\ s^{-1} = (600\ s^{-1})e^{-\lambda t}$
or, $e^{-\lambda t} = \frac{5}{6}$
or, $\lambda t = \ln(6/5)$
or, $\lambda = \frac{\ln(6/5)}{t} = \frac{\ln(6/5)}{40\,min}$

The half-life is $t_{1/2} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{\ln(6/5)} \times 40 = 152$ min.

Ex.23 The number of ^{238}U atoms in an ancient rock equals the number of ^{206}Pb atoms. The half-life of decay of ^{238}U is 4.5×10^9 y. Estimate the age of the rock assuming that all the ^{206}Pb atoms are formed from the decay of ^{238}U.

Sol. Since the number of ^{206}Pb atoms equals the number of ^{238}U atoms, half of the original ^{238}U atoms have decayed. It takes one half-life to decay half of the active nuclei. Thus, the sample is 4.5×10^9 y old.

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Ex.24 Equal masses of two samples of charcoal A and B are burnt separately and the resulting carbon dioxide are collected in two vessels. The radioactivity of ^{14}C is measured for both the gas samples. The gas from the charcoal A gives 2100 counts per week and the gas from the charcoal B gives 1400 counts per week. Find the age difference between the two samples. Half-life of $^{14}C = 5730$ y.

Sol. The activity of sample A is 2100 counts per week. After a certain time t, its activity will be reduced to 1400 counts per week. This is because a fraction of the active ^{14}C nuclei will decay in time t. The sample B must be a time t older than the sample A.

We have,

$$A = A_0 e^{-\lambda t}$$

or, $1400\ s^{-1} = 2100\ s^{-1}\ e^{-\lambda t}$ or $e^{-\lambda t} = \frac{2}{3}$

$$t = \frac{\ln(3/2)}{\lambda} = \frac{0.4055}{0.693} \times 5730\ y = 3352\ y.$$

Ex.25 Suppose, the daughter nucleus in a nucleus in a nuclear decay is itself radioactive. Let λ_p and λ_d be the decay constants of the parent and the daughter nuclei. Also, let N_p and N_d be the number of parent and daughter nuclei at time t. Find the condition for which the number of daughter nuclei becomes constant.

Sol. The number of parent nuclei decaying in a short time interval t to t + dt is $\lambda_p N_p dt$. This is also the number of daughter nuclei produced in this interval. The number of daughter nuclei decaying during the same time interval is $\lambda_d N_d dt$. The number of the daughter nuclei will be constant if

$\lambda_p N_p dt = \lambda_d N_d dt$ or, $\lambda_p N_p = \lambda_d N_d$

Ex.26 A radioactive sample decays with an average-life of 20 ms. A capacitor of capacitance 100 μF is charged to some potential and then the plates are connected through a resistance R. What should be the value of R so that the ratio of the charge on the capacitor to the activity of the radioactive sample remains constant in time?

Sol. The activity of the sample at time t is given by

$$A = A_0 e^{-\lambda t}$$

where λ is the decay constant and A_0 is the activity at time t = 0 when the capacitor plates are connected. The charge on the capacitor at time t is given by

$$Q = Q_0 e^{-t/CR}$$

where Q_0 is the charge at t = 0 and C = 100 μF is the capacitance. Thus,

$$\frac{Q}{A} = \frac{Q_0}{A_0} \frac{e^{-t/CR}}{e^{-\lambda t}}$$

It is independent of t if $\lambda = \frac{1}{CR}$

or,

$$R = \frac{1}{\lambda C} = \frac{t_{av}}{C} = \frac{20 \times 10^{-3}\ s}{100 \times 10^{-6}\ F} = 200\ \Omega$$

Ex.27 A radioactive nucleus can decay by two different process. the half-life for the first process is t_1 and that for the second process t_2. Show that the effective half-life t of the nucleus is given by

$$\frac{1}{t} = \frac{1}{t_1} + \frac{1}{t_2}$$

Sol. The decay constant for the first process is $\lambda_1 = \frac{\ln 2}{t_1}$ and for the second process it is $\lambda_2 = \frac{\ln 2}{t_1}$. The probability that an active nucleus decays by the first process in a time interval dt is $\lambda_1 dt$. Similarly, the probability that it decays by the second process is $\lambda_2 dt$. The probability that it either decays by the first process or by the second process is $\lambda_1 dt + \lambda_2 dt$. If the effective decay constant is λ, this probability is also equal to λdt. Thus,

$$\lambda dt = \lambda_1 dt + \lambda_2 dt$$

or, $\lambda = \lambda_1 + \lambda_2$

or, $\frac{1}{t} = \frac{1}{t_1} + \frac{1}{t_2}$.

Ex.28 Calculate the energy released when three alpha particles combine to form a $_{12}C$ nucleus. The atomic mass of ^4_2He is 4.002603 u.

Sol. The mass of a ^{12}C atom is exactly 12 u. The energy released in the reaction $3\left(^4_2He\right) \rightarrow {}^{12}_6C$ is

$$[3m(^4_2He) - m(^{12}_6C]c^2$$

$$= [3 \times 4.002603\ u - 12\ u]\ (931\ MeV\ u^{-1}) = 7.27\ MeV.$$

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Exercise # 1 SINGLE OBJECTIVE NEET LEVEL

1. If in nature there may not be an element for which the principal quantum number $n > 4$, then the total possible number of elements will be

(A) 60 **(B)** 32

(C) 4 **(D)** 64

2. In the Bohr's hydrogen atom model, the radius of the stationary orbit is directly proportional to (n = principle quantum number)

(A) n^{-1} **(B)** n

(C) n^{-2} **(D)** n^2

3. In the n^{th} orbit, the energy of an electron $E_n = -\frac{13.6}{n^2} eV$ for hydrogen atom. The energy required to take the electron from first orbit to second orbit will be

(A) 10.2 eV **(B)** 12.1 eV

(C) 13.6 eV **(D)** 3.4 eV

4. In the following atoms and moleculates for the transition from $n = 2$ to $n = 1$, the spectral line of minimum wavelength will be produced by

(A) Hydrogen atom **(B)** Deuterium atom

(C) Uni-ionized helium **(D)** di-ionized lithium

5. The Lyman series of hydrogen spectrum lies in the region

(A) Infrared **(B)** Visible

(C) Ultraviolet **(D)** Of x – rays

6. The size of an atom is of the order of

(A) $10^{-8} m$ **(B)** $10^{-10} m$

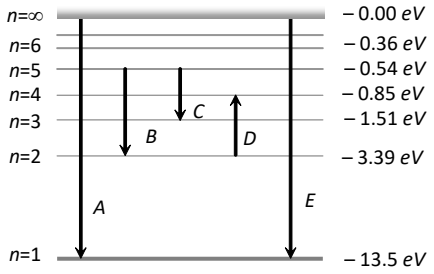
(C) $10^{-12} m$ **(D)** $10^{-14} m$

7. Which one of the series of hydrogen spectrum is in the visible region

(A) Lyman series **(B)** Balmer series

(C) Paschen series **(D)** Bracket series

8. The energy levels of the hydrogen spectrum is shown in figure. There are some transitions A, B, C, D and E. Transition A, B and C respectively represent



(A) First member of Lyman series, third spectral line of Balmer series and the second spectral line of Paschen series

(B) Ionization potential of hydrogen, second spectral line of Balmer series and third spectral line of Paschen series

(C) Series limit of Lyman series, third spectral line of Balmer series and second spectral line of Paschen series

(D) Series limit of Lyman series, second spectral line of Balmer series and third spectral line of Paschen series

9. In the above figure D and E respectively represent

(A) Absorption line of Balmer series and the ionization potential of hydrogen

(B) Absorption line of Balmer series and the wavelength lesser than lowest of the Lyman series

(C) Spectral line of Balmer series and the maximum wavelength of Lyman series

(D) Spectral line of Lyman series and the absorption of greater wavelength of limiting value of Paschen series

10. The Rutherford α-particle experiment shows that most of the α-particles pass through almost unscattered while some are scattered through large angles. What information does it give about the structure of the atom

(A) Atom is hollow

(B) The whole mass of the atom is concentrated in a small centre called nucleus

(C) Nucleus is positively charged

(D) All the above

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11. Which of the following is true

(A) Lyman series is a continuous spectrum

(B) Paschen series is a line spectrum in the infrared

(C) Balmer series is a line spectrum in the ultraviolet

(D) The spectral series formula can be derived from the Rutherford model of the hydrogen atom

12. The energy required to knock out the electron in the third orbit of a hydrogen atom is equal to

(A) 13.6 eV **(B)** $+\frac{13.6}{9}\text{eV}$

(C) $-\frac{13.6}{3}\text{eV}$ **(D)** $-\frac{3}{13.6}\text{eV}$

13. An electron has a mass of $9.1\times10^{-31}\text{kg}$. It revolves round the nucleus in a circular orbit of radius 0.529×10^{-10} metre at a speed of $2.2\times10^{6}\text{m/s}$. The magnitude of its linear momentum in this motion is

(A) $1.1\times10^{-34}\text{kg}-\text{m/s}$ **(B)** $2.0\times10^{-24}\text{kg}-\text{m/s}$

(C) $4.0\times10^{-24}\text{kg}-\text{m/s}$ **(D)** $4.0\times10^{-31}\text{kg}-\text{m/s}$

14. In a beryllium atom, if a_0 be the radius of the first orbit, then the radius of the second orbit will be in general

(A) na_0 **(B)** a_0

(C) n^2a_0 **(D)** $\frac{\text{a}_0}{\text{n}^2}$

15. The ionization potential for second *He* electron is

(A) 13.6 *eV* **(B)** 27.2 *eV*

(C) 54.4 *eV* **(D)** 100 *eV*

16. The energy required to remove an electron in a hydrogen atom from $\text{n}=10$ state is

(A) 13.6 *eV* **(B)** 1.36 *eV*

(C) 0.136 *eV* **(D)** 0.0136 *eV*

17. Every series of hydrogen spectrum has an upper and lower limit in wavelength. The spectral series which has an upper limit of wavelength equal to 18752 Å is

(A) Balmer series **(B)** Lyman series

(C) Paschen series **(D)** Pfund series

(Rydberg constant $\text{R}=1.097\times10^{7}$ *per metre*)

18. The kinetic energy of the electron in an orbit of radius *r* in hydrogen atom is (*e* = electronic charge)

(A) $\frac{\text{e}^2}{\text{r}^2}$ **(B)** $\frac{\text{e}^2}{2\text{r}}$

(C) $\frac{\text{e}^2}{\text{r}}$ **(D)** $\frac{\text{e}^2}{2\text{r}^2}$

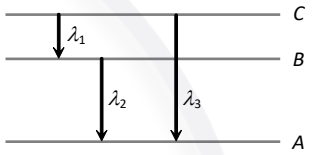
19. Ionization potential of hydrogen atom is 13.6 *V*.

Hydrogen atoms in the ground state are excited by monochromatic radiation of photon energy 12.1 *eV*. The spectral lines emitted by hydrogen atoms according to Bohr's theory will be

(A) One **(B)** Two

(C) Three **(D)** Four

20. Energy levels A, B, C of a certain atom corresponding to increasing values of energy *i.e.* $\text{E}_\text{A}<\text{E}_\text{B}<\text{E}_\text{C}$. If $\lambda_1,\lambda_2,\lambda_3$ are the wavelengths of radiations corresponding to the transitions *C* to *B*, *B* to *A* and *C* to *A* respectively, which of the following statements is correct



(A) $\lambda_3=\lambda_1+\lambda_2$ **(B)** $\lambda_3=\frac{\lambda_1\lambda_2}{\lambda_1+\lambda_2}$

(C) $\lambda_1+\lambda_2+\lambda_3=0$ **(D)** $\lambda_3^2=\lambda_1^2+\lambda_2^2$

21. The angular momentum of electron in n^{th} orbit is given by

(A) *nh* **(B)** $\frac{\text{h}}{2\pi\text{n}}$

(C) $\text{n}\frac{\text{h}}{2\pi}$ **(D)** $\text{n}^2\frac{\text{h}}{2\pi}$

22. The ratio of the energies of the hydrogen atom in its first to second excited state is

(A) 1/4 **(B)** 4/9

(C) 9/4 **(D)** 4

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23. An electron jumps from the 4th orbit to the 2nd orbit of hydrogen atom. Given the Rydberg's constant $R = 10^5 cm^{-1}$. The frequency in *Hz* of the emitted radiation will be

(A) $\frac{3}{16}\times10^5$ **(B)** $\frac{3}{16}\times10^{15}$

(C) $\frac{9}{16}\times10^{15}$ **(D)** $\frac{3}{4}\times10^{15}$

24. The ionisation potential of hydrogen atom is 13.6 *volt*. The energy required to remove an electron in the $n = 2$ state of the hydrogen atom is

(A) 27.2 *eV* **(B)** 13.6 *eV*

(C) 6.8 *eV* **(D)** 3.4 *eV*

25. The ionisation energy of 10 times ionised sodium atom is

(A) 13.6 *eV* **(B)** 13.6×11 eV

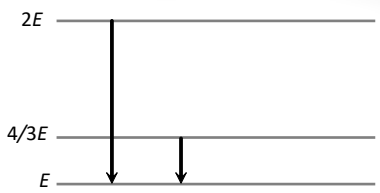
(C) $\frac{13.6}{11}$eV **(D)** $13.6\times(11)^2$eV

26. If the wavelength of the first line of the Balmer series of hydrogen is 6561 Å, the wavelength of the second line of the series should be

(A) 13122 Å **(B)** 3280 Å

(C) 4860 Å **(D)** 2187 Å

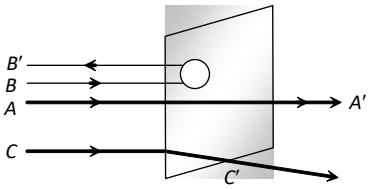
27. The following diagram indicates the energy levels of a certain atom when the system moves from 2*E* level to *E*, a photon of wavelength λ is emitted. The wavelength of photon produced during its transition from $\frac{4E}{3}$ level to *E* is



(A) λ / 3 **(B)** 3λ / 4

(C) 4λ / 3 **(D)** 3λ

28. A beam of fast moving alpha particles were directed towards a thin film of gold. The parts A′, B′ and C′ of the transmitted and reflected beams corresponding to the incident parts *A*, *B* and *C* of the beam, are shown in the adjoining diagram. The number of alpha particles in



(A) B′ will be minimum and in C′ maximum

(B) A′ will be maximum and in B′ minimum

(C) A′ will be minimum and in B′ maximum

(D) C′ will be minimum and in B′ maximum

29. According to Bohr's theory the radius of electron in an orbit described by principal quantum number *n* and atomic number *Z* is proportional to

(A) Z^2n^2 **(B)** $\frac{Z^2}{n^2}$

(C) $\frac{Z^2}{n}$ **(D)** $\frac{n^2}{Z}$

30. The radius of electron's second stationary orbit in Bohr's atom is *R*. The radius of the third orbit will be

(A) 3 *R* **(B)** 2.25 *R*

(C) 9 *R* **(D)** $\frac{R}{3}$

31. In the Millikan's experiment, the distance between two horizontal plates is 2.5 *cm* and the potential difference applied is 250 *V*. The electric field between the plates will be

(A) 900 *V/m* **(B)** 10000 *V/m*

(C) 625 *V/m* **(D)** 6250 *V/m*

32. The cathode rays have particle nature because of the fact that

(A) They can propagate in vacuum

(B) They are deflected by electric and magnetic fields

(C) They produced fluorescence

(D) They cast shadows

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33. In Millikan's experiment for the determination of the charge on the electron, the reason for using the oil is

(A) It is a lubricant

(B) Its density is higher

(C) It vapourises easily

(D) It does not vapourise

34. The mass of a particle is 400 times than that of an electron and the charge is double. The particle is accelerated by 5 V. Initially the particle remained in rest, then its final kinetic energy will be

(A) 5 eV **(B)** 10 eV

(C) 100 eV **(D)** 2000 eV

35. An electron (charge = $1.6 \times 10^{-19}\ C$) is accelerated through a potential of 100,000 V. The energy acquired by the electron is

(A) $1.6 \times 10^{-24}\ J$ **(B)** $1.6 \times 10^{-14}\ erg$

(C) $0.53 \times 10^{-17}\ J$ **(D)** $1.6 \times 10^{-14}\ J$

36. While doing his experiment, Millikan one day observed the following charges on a single drop

(i) $6.563 \times 10^{-19}\ C$ (ii) $8.204 \times 10^{-19}\ C$

(iii) $11.50 \times 10^{-19}\ C$ (iv) $13.13 \times 10^{-19}\ C$

(v) $16.48 \times 10^{-19}\ C$ (vi) $18.09 \times 10^{-19}\ C$

From this data the value of the elementary charge (E) was found to be

(A) $1.641 \times 10^{-19}\ C$ **(B)** $1.630 \times 10^{-19}\ C$

(C) $1.648 \times 10^{-19}\ C$ **(D)** $1.602 \times 10^{-19}\ C$

37. When electron beam passes through an electric field, they gain kinetic energy. If the same beam passes through magnetic field, then

(A) Their energy increases

(B) Their momentum increases

(C) Their potential energy increases

(D) Energy and momentum both remains unchanged

38. Which of the following law is used in the Millikan's method for the determination of charge

(A) Ampere's law **(B)** Stoke's law

(C) Fleming's left hand rule

(D) Fleming's right hand rule

39. The mass of the electron varies with

(A) The size of the cathode ray tube

(B) The variation of 'g'

(C) Velocity

(D) Size of the electron

40. When the speed of electrons increases, then the value of its specific charge

(A) Increases

(B) Decreases

(C) Remains unchanged

(D) Increases upto some velocity and then begins to decrease

41. An electron is accelerated through a potential difference of 1000 *volts*. Its velocity is nearly

(A) $3.8 \times 10^{7}\ m/s$ **(B)** $1.9 \times 10^{6}\ m/s$

(C) $1.9 \times 10^{7}\ m/s$ **(D)** $5.7 \times 10^{7}\ m/s$

42. In an electron gun the control grid is given a negative potential relative to cathode in order to

(A) Decelerate electrons

(B) Repel electrons and thus to control the number of electrons passing through it

(C) To select electrons of same velocity and to converge them along the axis

(D) To decrease the kinetic energy of electrons

43. The ratio of momenta of an electron and an α – particle which are accelerated from rest by a potential difference of 100 V is

(A) 1 **(B)** $\sqrt{\frac{2m_e}{m_\alpha}}$

(C) $\sqrt{\frac{m_e}{m_\alpha}}$ **(D)** $\sqrt{\frac{m_e}{2m_\alpha}}$

44. When subjected to a transverse electric field, cathode rays move

(A) Down the potential gradient

(B) Up the potential gradient

(C) Along a hyperbolic path

(D) Along a circular path

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45. The fact that electric charges are integral multiples of the fundamental electronic charge was proved experimentally by

(A) Planck **(B)** J.J. Thomson

(C) Einstein **(D)** Millikan

46. In Millikan oil drop experiment, a charged drop of mass $1.8\times10^{-14}\,kg$ is stationary between its plates. The distance between its plates is 0.90 *cm* and potential difference is 2.0 *kilo volts*. The number of electrons on the drop is

(A) 500 **(B)** 50

(C) 5 **(D)** 0

47. The charge on electron was discovered by

(A) J.J. Thomson **(B)** Neil Bohr

(C) Millikan **(D)** Chadwick

48. From the following, what charges can be present on oil drops in Millikan's experiment

(A) Zero, equal to the magnitude of charge on particle

(B) $2e, 1.6\times10^{-18}$ C,

(C) 1.6×10^{-19} C, 2.5e

(D) 1.5e, e

(Here *e* is the electronic charge)

49. A narrow electron beam passes undeviated through an electric field $E=3\times10^{4}$ volt / m and an overlapping magnetic field $B=2\times10^{-3}$ Weber / m^2. If electric field and magnetic field are mutually perpendicular. The speed of the electrons is

(A) 60 *m/s* **(B)** 10.3×10^{7} m / s

(C) 1.5×10^{7} m / s **(D)** 0.67×10^{-7} m / s

50. In Thomson's method of determining *e/m* of electrons

(A) Electric and magnetic fields are parallel to electrons beam

(B) Electric and magnetic fields are perpendicular to each other and perpendicular to electrons beam

(C) Magnetic field is parallel to the electrons beam

(D) Electric field is parallel to the electrons beam

51. The idea of matter waves was given by

(A) Davisson and Germer **(B)** de-Broglie

(C) Einstein **(D)** Planck

52. Wave is associated with matter

(A) When it is stationary

(B) When it is in motion with the velocity of light only

(C) When it is in motion with any velocity

(D) None of the above

53. The de-Broglie wavelength associated with the particle of mass *m* moving with velocity *v* is

(A) h/mv **(B)** mv/h

(C) mh/v **(D)** m/hv

54. A photon, an electron and a uranium nucleus all have the same wavelength. The one with the most energy

(A) Is the photon

(B) Is the electron

(C) Is the uranium nucleus

(D) Depends upon the wavelength and the properties of the particle.

55. A particle which has zero rest mass and non-zero energy and momentum must travel with a speed

(A) Equal to *c*, the speed of light in vacuum

(B) Greater than *c*

(C) Less than *c*

(D) Tending to infinity

56. When the kinetic energy of an electron is increased, the wavelength of the associated wave will

(A) Increase

(B) Decrease

(C) Wavelength does not depend on the kinetic energy

(D) None of the above

57. If the de-Broglie wavelengths for a proton and for a α – particle are equal, then the ratio of their velocities will be

(A) 4 : 1 **(B)** 2 : 1

(C) 1 : 2 **(D)** 1 : 4

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58. The de-Broglie wavelength λ associated with an electron having kinetic energy E is given by the expression

(A) $\frac{h}{\sqrt{2mE}}$ **(B)** $\frac{2h}{mE}$

(C) $2mhE$ **(D)** $\frac{2\sqrt{2mE}}{h}$

59. Dual nature of radiation is shown by

(A) Diffraction and reflection

(B) Refraction and diffraction

(C) Photoelectric effect alone

(D) Photoelectric effect and diffraction

60. For the Bohr's first orbit of circumference $2\pi r$, the de-Broglie wavelength of revolving electron will be

(A) $2\pi r$ **(B)** πr

(C) $\frac{1}{2\pi r}$ **(D)** $\frac{1}{4\pi r}$

61. The momentum of a photon is $3.3\times10^{-29}\ kg-m/sec$. Its frequency will be

(A) $3\times10^{3}\ Hz$ **(B)** $6\times10^{3}\ Hz$

(C) $7.5\times10^{12}\ Hz$ **(D)** $1.5\times10^{13}\ Hz$

62. The energy of a photon of wavelength λ is given by

(A) $h\lambda$ **(B)** $ch\lambda$

(C) λ / hc **(D)** hc / λ

63. The momentum of a photon is $2\times10^{-16}\ gm-cm/sec$. Its energy is

(A) $0.61\times10^{-26}\ erg$ **(B)** $2.0\times10^{-26}\ erg$

(C) $6\times10^{-6}\ erg$ **(D)** $6\times10^{-8}\ erg$

64. The rest mass of the photon is

(A) 0

(B) ∞

(C) Between 0 and ∞

(D) Equal to that of an electron

65. The momentum of the photon of wavelength 5000Å will be

(A) 1.3×10^{-27} kg- *m/sec* **(B)** 1.3×10^{-28} kg- *m/sec*

(C) 4×10^{29} kg- *m/sec* **(D)** 4×10^{-18} kg- *m/sec*

66. The momentum of a photon of energy $h\nu$ will be

(A) $h\nu$ **(B)** $h\nu / c$

(C) $h\nu c$ **(D)** h / ν

67. A photon in motion has a mass

(A) $c / h\nu$ **(B)** h / ν

(C) $h\nu$ **(D)** $h\nu / c^2$

68. If the momentum of a photon is p, then its frequency is

(A) $\frac{ph}{c}$ **(B)** $\frac{pc}{h}$

(C) $\frac{mh}{c}$ **(D)** $\frac{mc}{h}$

Where m is the rest mass of the photon

69. An AIR station is broadcasting the waves of wavelength 300 metres. If the radiating power of the transmitter is 10 *kW*, then the number of photons radiated per second is

(A) 1.5×10^{29} **(B)** 1.5×10^{31}

(C) 1.5×10^{33} **(D)** 1.5×10^{35}

70. The energy of a photon is $E = h\nu$ and the momentum of photon $p = \frac{h}{\lambda}$, then the velocity of photon will be

(A) E/p **(B)** Ep

(C) $\left(\frac{E}{p}\right)^2$ **(D)** $3\times10^{8}\ m/s$

71. The approximate wavelength of a photon of energy 2.48 *eV* is

(A) 500Å **(B)** 5000Å

(C) 2000Å **(D)** 1000Å

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72. An important spectral emission line has a wavelength of 21 *cm*. The corresponding photon energy is

(A) 5.9×10^{-4} eV **(B)** 5.9×10^{-6} eV

(C) 5.9×10^{-8} eV **(D)** 11.8×10^{-6} eV

$(h = 6.62\times10^{-34}\,Js;\ c = 3\times10^{8}\,m/s)$

73. The momentum of a photon in an *X*-ray beam of 10^{-10} metre wavelength is

(A) 1.5×10^{-23} kg – *m/sec*

(B) 6.6×10^{-24} kg – m / sec

(C) 6.6×10^{-44} kg – m / sec

(D) 2.2×10^{-52} kg – m / sec

74. The energy of a photon of light with wavelength 5000 Å is approximately 2.5 *eV*. This way the energy of an *X*-ray photon with wavelength 1Å would be

(A) 2.5/5000 *eV* **(B)** $2.5/(5000)^2$ eV

(C) 2.5×5000 eV **(D)** $2.5\times(5000)^2$ eV

75. Energy of a quanta of frequency 10^{15} *Hz* and $h = 6.6\times10^{-34}$ J-sec will be

(A) 6.6×10^{-19} J **(B)** 6.6×10^{-12} J

(C) 6.6×10^{-49} J **(D)** 6.6×10^{-41} J

76. Momentum of a photon of wavelength λ is

(A) $\frac{h}{\lambda}$ **(B)** Zero

(C) $\frac{h\lambda}{c^2}$ **(D)** $\frac{h\lambda}{c}$

77. Wavelength of a 1 *keV* photon is 1.24×10^{-9} m. What is the frequency of 1 *MeV* photon

(A) 1.24×10^{15} Hz **(B)** 2.4×10^{20} Hz

(C) 1.24×10^{18} Hz **(D)** 2.4×10^{23} Hz

78. What is the momentum of a photon having frequency 1.5×10^{13} Hz

(A) 3.3×10^{-29} kg m / s **(B)** 3.3×10^{-34} kg m / s

(C) 6.6×10^{-34} kg m / s **(D)** 6.6×10^{-30} kg m / s

79. The energy of a photon of light of wavelength 450 *nm* is

(A) 4.4×10^{-19} J **(B)** 2.5×10^{-19} J

(C) 1.25×10^{-17} J **(D)** 2.5×10^{-17} J

80. Frequency of photon having energy 66 *eV* is

(A) 8×10^{-15} Hz **(B)** 12×10^{-15} Hz

(C) 16×10^{15} Hz **(D)** None of these

81. Which of the following statement is not correct

(A) Photographic plates are sensitive to infrared rays

(B) Photographic plates are sensitive to ultraviolet rays

(C) Infra-red rays are invisible but can cast shadows like visible light

(D) Infrared photons have more energy than photons of visible light

82. If we express the energy of a photon in *KeV* and the wavelength in angstroms, then energy of a photon can be calculated from the relation

(A) $E = 12.4h\nu$ **(B)** $E = 12.4h/\lambda$

(C) $E = 12.4/\lambda$ **(D)** $E = h\nu$

83. The frequency of a photon, having energy 100 eV is $(h = 6.610^{-34}$ J-sec)

(A) 2.42×10^{26} Hz **(B)** 2.42×10^{16} Hz

(C) 2.42×10^{12} Hz **(D)** 2.42×10^{9} Hz

84. A photon of wavelength 4400 Å is passing through vacuum. The effective mass and momentum of the photon are respectively

(A) 5×10^{-36} kg, 1.5×10^{-27} kg-m / s

(B) 5×10^{-35} kg, 1.5×10^{-26} kg-m / s

(C) Zero, 1.5×10^{-26} kg-m / s

(D) 5×10^{-36} kg, 1.67×10^{-43} kg-m / s

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85. Which of the following is true for photon

(A) $E = \frac{hc}{\lambda}$ **(B)** $E = \frac{1}{2}mu^2$

(C) $p = \frac{E}{2v}$ **(D)** $E = \frac{1}{2}mc^2$

86. Which of the following is incorrect statement regarding photon

(A) Photon exerts no pressure

(B) Photon energy is $h\nu$

(C) Photon rest mass is zero

(D) None of these

87. If a photon has velocity c and frequency ν, then which of following represents its wavelength

(A) $\frac{hc}{E}$ **(B)** $\frac{h\nu}{c}$

(C) $\frac{h\nu}{c^2}$ **(D)** $h\nu$

88. The mass of a photo electron is

(A) 9.1×10^{-27} kg **(B)** 9.1×10^{-29} kg

(C) 9.1×10^{-31} kg **(D)** 9.1×10^{-34} kg

89. Energy of photon whose frequency is 10^{12} MHz, will be

(A) 4.14×10^{3} keV **(B)** 4.14×10^{2} eV

(C) 4.14×10^{3} MeV **(D)** 4.14×10^{3} eV

90. There are n_1 photons of frequency γ_1 in a beam of light. In an equally energetic beam, there are n_2 photons of frequency γ_2. Then the correct relation is

(A) $\frac{n_1}{n_2} = 1$ **(B)** $\frac{n_1}{n_2} = \frac{\gamma_1}{\gamma_2}$

(C) $\frac{n_1}{n_2} = \frac{\gamma_2}{\gamma_1}$ **(D)** $\frac{n_1}{n_2} = \frac{\gamma_1^2}{\gamma_2^2}$

91. An *X*-ray tube is operated at 50 *kV*. The minimum wavelength produced is

(A) 0.5 Å **(B)** 0.75 Å

(C) 0.25 Å **(D)** 1 Å

92. Which of the following wavelength falls in *X*-ray region

(A) 10000 Å **(B)** 1000 Å

(C) 1 Å **(D)** 10^{-2} Å

93. A metal block is exposed to beams of *X*-ray of different wavelength. *X*-rays of which wavelength penetrate most

(A) 2 Å **(B)** 4 Å

(C) 6 Å **(D)** 8 Å

94. *X*-rays and gamma rays are both electromagnetic waves. Which of the following statements is true

(A) In general *X*-rays have larger wavelength than of gamma rays

(B) *X*-rays have smaller wavelength than that of gamma rays

(C) Gamma rays have smaller frequency than that of *X*-rays

(D) Wavelength and frequency of *X*-rays are both larger than that of gamma rays

95. In producing *X*-rays a beam of electrons accelerated by a potential difference *V* is made to strike a metal target. For what value of *V*, *X*-rays will have the lowest wavelength of 0.3094 Å

(A) 10 *kV* **(B)** 20 *kV*

(C) 30 *kV* **(D)** 40 *kV*

96. In radio theraphy, *X*-rays are used to

(A) Detect bone fractures

(B) Treat cancer by controlled exposure

(C) Detect heart diseases

(D) Detect fault in radio receiving circuits

97. Hydrogen atom does not emit X-rays because

(A) Its energy levels are too close to each other

(B) Its energy levels are too apart

(C) It is too small in size

(D) It has a single electron

98. X-rays were discovered by

(A) Becquerel **(B)** Roentgen

(C) Marie Curie **(D)** Von Laue

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99. X-rays are

(A) Stream of electrons

(B) Stream of positively charged particles

(C) Electromagnetic radiations of high frequency

(D) Stream of uncharged particles

100. The voltage applied across an X-rays tube is nearly

(A) 10 V **(B)** 100 V

(C) 10000 V **(D)** 10^6 V

101. The characteristic X-ray radiation is emitted, when

(A) The electrons are accelerated to a fixed energy

(B) The source of electrons emits a monoenergetic beam

(C) The bombarding electrons knock out electrons from the inner shell of the target atoms and one of the outer electrons falls into this vacancy

(D) The valence electrons in the target atoms are removed as a result of the collision

102. Molybdenum is used as a target element for production of X-rays because it is

(A) A heavy element and can easily absorb high velocity electrons

(B) A heavy element with a high melting point

(C) An element having high thermal conductivity

(D) Heavy and can easily deflect electrons

103. Mosley's law relates the frequencies of line X-rays with the following characteristics of the target element

(A) Its density

(B) Its atomic weight

(C) Its atomic number

(D) Interplaner spacing of the atomic planes

104. Compton effect is associated with

(A) α – rays **(B)** β – rays

(C) X-rays **(D)** Positive rays

105. X-rays are in nature similar to

(A) Beta rays **(B)** Gamma rays

(C) de-Broglie waves **(D)** Cathode rays

106. If the cathode–anode potential difference in an X-ray tube be 10^5 V, then the maximum energy of X-ray photon can be

(A) 10^5 J **(B)** 10^5 MeV

(C) 10^{-1} MeV **(D)** 10^5 KeV

107. The shortest wavelength of X-rays emitted from an X-ray tube depends on the

(A) Current in the tube

(B) Voltage applied to the tube

(C) Nature of gas in the tube

(D) Atomic number of target material

108. The wavelength of X-rays is of the order of

(A) *Centimetre* **(B)** *Micron* (10^{-6} m)

(C) *Angstrom* (10^{-10} m) **(D)** *Metre*

109. X – rays and γ – rays of the same energies may be distinguished by

(A) Their velocity

(B) Their ionising power

(C) Their intensity

(D) Method of production

110. When a beam of accelerated electrons hits a target, a continuous X-ray spectrum is emitted from the target. Which of the following wavelength is absent in the X-ray spectrum, if the X-ray tube is operating at 40,000 *volts*

(A) 0.25 Å **(B)** 0.5 Å

(C) 1.5 Å **(D)** 1.0 Å

111. Which of the following particles are constituents of the nucleus

(A) Protons and electrons

(B) Protons and neutrons

(C) Neutrons and electrons

(D) Neutrons and positrons

112. The particles which can be added to the nucleus of an atom without changing its chemical properties are called

(A) Electrons **(B)** Protons

(C) Neutrons **(D)** None of the above

113. The neutron was discovered by

(A) Marie Curie **(B)** Pierre Curie

(C) James Chadwick **(D)** Rutherford

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114. The mass number of a nucleus is

(A) Always less than its atomic number

(B) Always more than its atomic number

(C) Always equal to its atomic number

(D) Sometimes more than and sometimes equal to its atomic number

115. The energy equivalent of 1 *kilogram* of matter is about

(A) $10^{-15}\,J$ **(B)** $1\,J$

(C) $10^{-12}\,J$ **(D)** $10^{17}\,J$

116. Nuclear binding energy is equivalent to

(A) Mass of proton

(B) Mass of neutron

(C) Mass of nucleus

(D) Mass defect of nucleus

117. If the binding energy of the deutrium is 2.23 *MeV*. The mass defect given in *a.m.u.* is

(A) -0.0024 **(B)** -0.0012

(C) 0.0012 **(D)** 0.0024

118. Which of the following has the mass closest in value to that of the positron

(A) Proton **(B)** Electron

(C) Photon **(D)** Neutrino

$(1\ a.m.u = 931\ MeV)$

119. Size of nucleus is of the order of

(A) $10^{-10}\,m$ **(B)** $10^{-15}\,m$

(C) $10^{-12}\,m$ **(D)** 10^{-19} m

120. For effective nuclear forces, the distance should be

(A) $10^{-10}\,m$ **(B)** $10^{-13}\,m$

(C) $10^{-15}\,m$ **(D)** $10^{-20}\,m$

121. The masses of neutron and proton are 1.0087 *a.m.u.* and 1.0073 *a.m.u.* respectively. If the neutrons and protons combine to form a helium nucleus (alpha particles) of mass 4.0015 *a.m.u.* The binding energy of the helium nucleus will be (1 *a.m.u.*= 931 *MeV*)

(A) 28.4 *MeV* **(B)** 20.8 *MeV*

(C) 27.3 *MeV* **(D)** 14.2 *MeV*

122. The mass defect for the nucleus of helium is 0.0303 *a.m.u.* What is the binding energy per nucleon for helium in *MeV*

(A) 28 **(B)** 7

(C) 4 **(D)** 1

123. Atomic power station at Tarapore has a generating capacity of 200 *MW*. The energy generated in a day by this station is

(A) 200 *MW* **(B)** $200\,J$

(C) $4800 \times 10^{6}\,J$ **(D)** $1728 \times 10^{10}\,J$

124. One microgram of matter converted into energy will give

(A) $90\,J$ **(B)** $9 \times 10^{3}\,J$

(C) $9 \times 10^{10}\,J$ **(D)** $9 \times 10^{5}\,J$

125. The average binding energy per nucleon in the nucleus of an atom is approximately

(A) 8 *eV* **(B)** 8 *KeV*

(C) 8 *MeV* **(D)** 8 *J*

126. The binding energy of deuteron ${}_1^2H$ is 1.112 *MeV* per nucleon and an α – particle ${}_2^4He$ has a binding energy of 7.047 *MeV* per nucleon. Then in the fusion reaction ${}_1^2H + {}_1^2H \rightarrow {}_2^4He + Q$, the energy Q released is

(A) 1 *MeV* **(B)** 11.9 *MeV*

(C) 23.8 *MeV* **(D)** 931 *MeV*

127. Binding energy of a nucleus is

(A) Energy given to its nucleus during its formation

(B) Total mass of nucleus converted to energy units

(C) Loss of energy from the nucleus during its formation

(D) Total K.E. and P.E. of the nucleons in the nucleus

128. One requires energy E_n to remove a nucleon from a nucleus and an energy 'E_e' to remove an electron from the orbit of an atom. Then

(A) $E_n = E_e$ **(B)** $E_n < E_e$

(C) $E_n > E_e$ **(D)** $E_n \geq E_e$

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129. Which of the following pairs is an isobar

(A) ${}_1H^1$ and ${}_1H^2$ **(B)** ${}_1H^2$ and ${}_1H^3$

(C) ${}_6C^{12}$ and ${}_6C^{13}$ **(D)** ${}_{15}P^{30}$ and ${}_{14}Si^{30}$

130. Equivalent energy of mass equal to 1 *a.m.u.* is

(A) 931 *KeV* **(B)** 931 *eV*

(C) 931 *MeV* **(D)** 9.31 *MeV*

131. The binding energies per nucleon for a deuteron and an α– particle are x_1 and x_2 respectively. What will be the energy Q released in the reaction ${}_1H^2 + {}_1H^2 \rightarrow {}_2He^4 + Q$

(A) $4(x_1 + x_2)$ **(B)** $4(x_2 - x_1)$

(C) $2(x_1 + x_2)$ **(D)** $2(x_2 - x_1)$

132. The mass number of a nucleus is equal to the number of

(A) Electrons it contains

(B) Protons it contains

(C) Neutrons it contains

(D) Nucleons it contains

133. The rest energy of an electron is

(A) 510 *KeV* **(B)** 931 *KeV*

(C) 510 *MeV* **(D)** 931 *MeV*

134. In ${}_{88}Ra^{226}$ nucleus, there are

(A) 138 protons and 88 neutrons

(B) 138 neutrons and 88 protons

(C) 226 protons and 88 electrons

(D) 226 neutrons and 138 electrons

135. Outside a nucleus

(A) Neutron is stable

(B) Proton and neutron both are stable

(C) Neutron is unstable

(D) Neither neutron nor proton is stable

136. Order of magnitude of density of uranium nucleus is $(m_p = 1.67 \times 10^{-27} kg)$

(A) $10^{20} kg/m^3$ **(B)** $10^{17} kg/m^3$

(C) $10^{14} kg/m^3$ **(D)** $10^{11} kg/m^3$

137. Radius of ${}_2^4He$ nucleus is 3 *Fermi*. The radius of ${}_{82}^{206}Pb$ nucleus will be

(A) 5 *Fermi* **(B)** 6 *Fermi*

(C) 11.16 *Fermi* **(D)** 8 *Fermi*

138. Nucleus of an atom whose atomic mass is 24 consists of

(A) 11 electrons, 11 protons and 13 neutrons

(B) 11 electrons, 13 protons and 11 neutrons

(C) 11 protons and 13 neutrons

(D) 11 protons and 13 electrons

139. Atomic weight of boron is 10.81 and it has two isotopes ${}_5B^{10}$ and ${}_5B^{11}$. Then ratio of ${}_5B^{10}$:${}_5B^{11}$ in nature would be

(A) 19 : 81 **(B)** 10 : 11

(C) 15 : 16 **(D)** 81 : 19

140. The mass of a neutron is the same as that of

(A) A proton **(B)** A meson

(C) An epsilon **(D)** An electron

141. Radioactive substance do not emit

(A) Electron **(B)** Helium nucleus

(C) Positron **(D)** Proton

142. In a radioactive substance at $t = 0$, the number of atoms is 8×10^4. Its half life period is 3 *years*. The number of atoms 1×10^4 will remain after interval

(A) 9 *yearss* **(B)** 8 *years*

(C) 6 *years* **(D)** 24 *years*

143. The half life period of radium is 1600 *years*. The fraction of a sample of radium that would remain after 6400 *years* is

(A) $\frac{1}{4}$ **(B)** $\frac{1}{2}$

(C) $\frac{1}{8}$ **(D)** $\frac{1}{16}$

144. During a negative beta decay

(A) An atomic electron is ejected

(B) An electron which is already present within the nucleus is ejected

(C) A neutron in the nucleus decays emitting an electron

(D) A part of the binding energy is converted into electron

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145. Some radioactive nucleus may emit

(A) Only one α, β or γ at a time

(B) All the three α, β and γ one after another

(C) All the three α, β and γ simultaneously

(D) Only α and β simultaneously

146. Which can pass through 20 *cm* thickness of the steel

(A) α– particles **(B)** β–particles

(C) γ–rays **(D)** Ultraviolet rays

147. The half-life period of radium is 1600 *years*. Its average life time will be

(A) 3200 *years* **(B)** 4800 *years*

(C) 2319 *years* **(D)** 4217 *years*

148. What percentage of original radioactive atoms is left after five half lives

(A) 0.3% **(B)** 1%

(C) 31% **(D)** 3.125%

149. Beta rays emitted by a radioactive material are

(A) Electromagnetic radiation

(B) The electrons orbiting around the nucleus

(C) Charged particles emitted by nucleus

(D) Neutral particles

150. Alpha rays emitted from a radioactive substance are

(A) Negatively charged particles

(B) Ionised hydrogen nuclei

(C) Doubly ionised helium atom

(D) Uncharged particles having the mass equal to proton

151. In the given reaction

$${}_zX^A \rightarrow {}_{z+1}Y^A \rightarrow {}_{z-1}K^{A-4} \rightarrow {}_{z-1}K^{A-4}$$

Radioactive radiations are emitted in the sequence

(A) α, β, γ **(B)** β, α, γ

(C) γ, α, β **(D)** β, γ, α

152. Half life of Bi^{210} is 5 *days*. If we start with 50,000 atoms of this isotope, the number of atoms left over after 10 *days* is

(A) 5,000 **(B)** 25,000

(C) 12,500 **(D)** 20,000

153. A nucleus of atomic mass A and atomic number Z emits β – particles. The atomic mass and atomic number of the resulting nucleus are

(A) A, Z **(B)** $A+1, Z$

(C) $A, Z+1$ **(D)** $A-4, Z-2$

154. The radioactivity of a certain radioactive element drops to 1/64 of its initial value in 30 *seconds*. Its half life is

(A) 2 *seconds* **(B)** 4 *seconds*

(C) 5 *seconds* **(D)** 6 *seconds*

155. Radioactivity was discovered by

(A) Becquerel **(B)** Pierre Curie

(C) Roentgen **(D)** Rutherford

156. The decay constant λ of the radioactive sample is the probability of decay of an atom in unit time, then

(A) λ decreases as atoms become older

(B) λ increases as the age of atoms increases

(C) λ is independent of the age

(D) Behaviour of λ with time depends on the nature of the activity

157. The average life T and the decay constant λ of a radioactive nucleus are related as

(A) $T\lambda = 1$ **(B)** $T = \frac{0.693}{\lambda}$

(C) $\frac{T}{\lambda} = 1$ **(D)** $T = \frac{c}{\lambda}$

158. If T is the half life of a radioactive material, then the fraction that would remain after a time $\frac{T}{2}$ is

(A) $\frac{1}{2}$ **(B)** $\frac{3}{4}$

(C) $\frac{1}{\sqrt{2}}$ **(D)** $\frac{\sqrt{2}-1}{\sqrt{2}}$

159. If the decay or disintegration constant of a radioactive substance is λ, then its half life and mean life are respectively

(A) $\frac{1}{\lambda}$ and $\frac{\log_e 2}{\lambda}$ **(B)** $\frac{\log_e 2}{\lambda}$ and $\frac{1}{\lambda}$

(C) $\lambda \log_e 2$ and $\frac{1}{\lambda}$ **(D)** $\frac{\lambda}{\log_e 2}$ and $\frac{1}{\lambda}$

($\log_e 2$ can be written as *l*n 2)

160. Which of the following is in the increasing order for penetrating power

(A) α, β, γ **(B)** β, α, γ

(C) γ, α, β **(D)** γ, β, α

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Exercise # 2 SINGLE OBJECTIVE AIIMS LEVEL

1. If the frequency of light in a photoelectric experiment is doubled then maximum kinetic energy of photoelectron

(A) be doubled

(B) be halved

(C) become more than double

(D) become less than double

2. In a photoelectric experiment, if stopping potential is applied, then photocurrent becomes zero. This means that :

(A) the emission of photoelectrons is stopped

(B) the photoelectrons are emitted but are reabsorbed by the emitter metal

(C) the photoelectrons are accumulated near the collector plate

(D) the photoelectrons are dispersed from the sides of the apparatus.

3. Two separate monochromatic light beams A and B of the same intensity (energy per unit area per unit time) are falling normally on a unit area of a metallic surface. Their wavelength are λ_A and λ_B respectively. Assuming that all the incident light is used in ejecting the photoelectrons, the ratio of the number of photoelectrons from beam A to that from B is

(A) $\left(\frac{\lambda_A}{\lambda_B}\right)$ **(B)** $\left(\frac{\lambda_B}{\lambda_A}\right)$

(C) $\left(\frac{\lambda_A}{\lambda_B}\right)^2$ **(D)** $\left(\frac{\lambda_B}{\lambda_A}\right)^2$

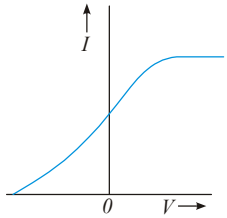
4. When a centimetre thick surface is illuminated with light of wavelength λ, the stopping potential is V. When the same surface is illuminated by light of wavelength 2λ, the stopping potential is $V/3$. The threshold wavelength for the surface is :

(A) $\frac{4\lambda}{3}$ **(B)** 4λ

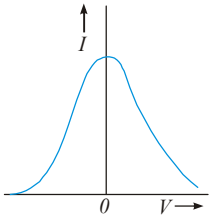
(C) 6λ **(D)** $\frac{8\lambda}{3}$

5. Which one of the following graphs in figure shows the variation of photoelectric current (I) with voltage (V) between the electrodes in a photoelectric cell ?

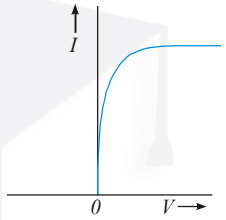
(A)



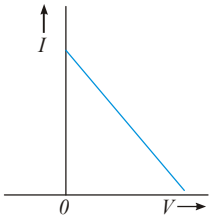
(B)



(C)



(D)



6. A photon of light enters a block of glass after travelling through vacuum. The energy of the photon on entering the glass block

(A) increases because its associated wavelength decreases

(B) Decreases because the speed of the radiation decreases

(C) Stays the same because the speed of the radiation and the associated wavelength do not change

(D) Stays the same because the frequency of the radiation does not change

7. The maximum kinetic energy of photoelectrons emitted from a surface when photons of energy 6 eV fall on it is 4 eV. The stopping potential is :

(A) 2V **(B)** 4V

(C) 6V **(D)** 10V

8. The anode plate in an experiment on photoelectric effect is kept vertically above the cathode plate. Light source is put on and a saturation photocurrent is recorded. An electric field is switched on which has vertically downward direction

(A) The photocurrent will increase

(B) The kinetic energy of the electrons will increase

(C) The stopping potential will decrease

(D) The threshold wavelength will increase

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9. The energy of a photon of frequency ν is $E = h\nu$ and the momentum of a photon of wavelength λ is $p = h/\lambda$. From this statement one may conclude that the wave velocity of light is equal to :

(A) $3 \times 10^8\ ms^{-1}$ **(B)** $\frac{E}{p}$

(C) E p **(D)** $\left(\frac{E}{p}\right)^2$

10. Let p and E denote the linear momentum and the energy of a photon. For another photon of smaller wavelength (in same medium)

(A) both p and E increase

(B) p increases and E decreases

(C) p decreases and E increases

(D) both p and E decreases

11. The de Broglie wavelength of an electron moving with a velocity $1.5 \times 10^8\ ms^{-1}$ is equal to that of a photon. The ratio of the kinetic energy of the electron to that of the energy of photon is :

(A) 2 **(B)** 4

(C) $\frac{1}{2}$ **(D)** $\frac{1}{4}$

12. A particle of mass *M* at rest decays into two particles of masses m_1 and m_2, having non zero velocities. The ratio of the de Broglie wavelengths of the particles, λ_1/λ_2 is :

(A) $\frac{m_1}{m_2}$ **(B)** $\frac{m_2}{m_1}$

(C) 1 : 1 **(D)** $\sqrt{\frac{m_2}{m_1}}$

13. The wavelength λ of de Broglie waves associated with an electron (mass *m*, charge *e*) accelerated through a potential difference of *V* is given by (*h* is Planck's constant) :

(A) $\lambda = h/mV$ **(B)** $\lambda = h/2\ meV$

(C) $\lambda = h/\sqrt{meV}$ **(D)** $\lambda = h/\sqrt{2meV}$

14. The de Broglie wavelength of a neutron correspoding to root mean square speed at 927°C is λ. What will be the de Broglie wavelength of the neutron correspoding to root mean square speed at 27°C?

(A) $\frac{\lambda}{2}$ **(B)** λ

(C) 2λ **(D)** 4λ

15. Consider 2 hydrogen like ions A and B. Ionization energy of A is greater than that of B. Let r, u, E and L represent the radius of the orbit, speed of the electron, energy of the atom and orbital angular momentum of the electron respectively. In ground state:

(A) $r_A > r_B$ **(B)** $u_A > u_B$

(C) $E_A > E_B$ **(D)** $L_A > L_B$

16. If a_0 is the Bohr radius, the radius of the n = 2 electronic orbit in triply ionized beryllium is -

(A) $4a_0$ **(B)** a_0

(C) $a_0/4$ **(D)** $a_0/16$

17. Which energy state of doubly ionized lithium (Li^{++}) has the same energy as that of the ground state of hydrogen ? Given *Z* for lithium = 3 :

(A) $n = 1$ **(B)** $n = 2$

(C) $n = 3$ **(D)** $n = 4$

18. If an orbital electron of the hydrogen atom jumps from the ground state to a higher energy state, its orbital speed reduces to half its initial value. If the radius of the electron orbit in the ground state is *r*, then the radius of the new orbit would be :

(A) 2*r* **(B)** 4*r*

(C) 8*r* **(D)** 16*r*

19. In Bohr's model of hydrogen atom, the centripetal force is provided by the Coulomb attraction between the proton and the electron. If a_0 is the radius of the ground state orbit, *m* is the mass and *e* the charge of an electron and ε_0 is the vacuum permittivity, the speed of the electron is :

(A) zero **(B)** $\frac{e}{\sqrt{\varepsilon_0 a_0 m}}$

(C) $\frac{e}{\sqrt{4\pi\varepsilon_0 a_0 m}}$ **(D)** $\frac{\sqrt{4\pi\varepsilon_0 a_0 m}}{e}$

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20. Three photons coming from emission spectra of hydrogen sample are picked up. Their energies are 12.1eV, 10.2eV and 1.9eV. These photons must come from

(A) a single atom **(B)** two atoms
(C) three atom
(D) either two atoms or three atoms

21. In the Bohr model of the hydrogen atom, the ratio of the kinetic energy to the total energy of the electron in a quantum state n is :

(A) -1 **(B)** $+1$
(C) $\frac{1}{n}$ **(D)** $\frac{1}{n^2}$

22. The ionization energy of hydrogen atom is 13.6 eV. Hydrogen atoms in the ground state are excited by electromagnetic radiation of energy 12.1 eV. How many spectral lines will be emitted by the hydrogen atoms?

(A) one **(B)** two
(C) three **(D)** four

23. In a hypothetical atom, if transition from n = 4 to n = 3 produces visible light then the possible transition to obtain infrared radiation is :

(A) n = 5 to n = 3 **(B)** n = 4 to n = 2
(C) n = 3 to n = 1 **(D)** none of these

24. The wavelength of the first line in balmer series in the hydrogen spectrum is λ. What is the wavelength of the second line :

(A) $\frac{20\lambda}{27}$ **(B)** $\frac{3\lambda}{16}$
(C) $\frac{5\lambda}{36}$ **(D)** $\frac{3\lambda}{4}$

25. Energy levels A, B and C of a certain atom correspond to increasing values of energy, i.e. $E_A < E_B < E_C$. If λ_1, λ_2 and λ_3 are the wavelengths of radiations corresponding to transitions C to B, B to A and C to A respectively, which of the following relations is correct ?

(A) $\lambda_3 = \lambda_1 + \lambda_2$ **(B)** $\lambda_3 = \frac{\lambda_1\lambda_2}{\lambda_1 + \lambda_2}$
(C) $\lambda_1 + \lambda_2 + \lambda_3 = 0$ **(D)** $\lambda_3^2 = \lambda_1^2 + \lambda_2^2$

26. The frequency of the first line in Lyman series in the hydrogen spectrum is ν. What is the frequency of the corresponding line in the spectrum of doubly ionized Lithium ?

(A) ν **(B)** 3 ν
(C) 9 ν **(D)** 27 ν

27. Consider a photon of continuous X-ray coming from a Coolidge tube. Energy of photon comes from

(A) the kinetic energy of the stricking electron
(B) the kinetic energy of the free electrons of the target
(C) the kinetic energy of the ions of the target
(D) an atomic transition in the target

28. An electron with kinetic energy 10 eV is incident on a hydrogen atom in its ground state. The collision

(A) must be elastic
(B) may be partially elastic
(C) must be completely inelastic
(D) may be completely inelastic

29. The characteristic X-ray spectrum is emitted due to transition of

(A) valence electrons of the atom
(B) inner electrons of the atom
(C) nucleus of the atom
(D) both, the inner electrons and the nucleus of the atom

30. If the voltage across the filament is increased, the cutoff wavelength

(i) will increase **(ii)** will decrease
(iii) will remain unchanged **(iv)** will change

(A) increasing the potential difference between the anode and filament
(B) increasing the filament current
(C) decreasing the filament current
(D) decreasing the potential difference between the anode and filament

31. In the Davisson and Germer experiment, the velocity of electrons emitted from the electron gun can be increased by :

(A) increasing the potential difference between the anode and filament
(B) increasing the filament current
(C) decreasing the filament current
(D) decreasing the potential difference between the anode and filament

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32. When ultraviolet light is incident on a photocell, its stopping potential is V_0 and the maximum kinetic energy of the photoelectrons is K_{max}. When X-rays are incident on the same cell, then :

(A) V_0 and K_{max} both increase

(B) V_0 and K_{max} both decrease

(C) V_0 increases but K_{max} remains the same

(D) K_{max} increases but V_0 remains the same

33. In Davisson-Germer experiment, the filament emits

(A) Photons **(B)** Protons

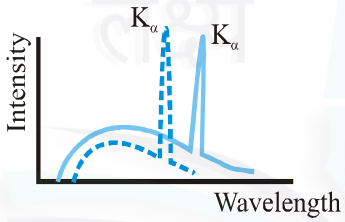
(C) X-rays **(D)** Electrons

34. The relation between λ_1: wavelength of series limit of Lyman series, λ_2: the wavelength of the series limit of Balmer series & λ_3: the wavelength of first line of Lyman series is :

(A) $\lambda_1 = \lambda_2 + \lambda_3$ **(B)** $\lambda_3 = \lambda_1 + \lambda_2$

(C) $\lambda_2 = \lambda_3 - \lambda_1$ **(D)** none of these

35. Given curve shows the intensity-wavelength relations of X-rays coming from two different Coolidge tubes A and B. The dark curve represents the relation for the tube A in which the potential difference between the target and the filament is V_A and the atomic number of the target material is Z_A. Similarly dotted curve is for tube B. These quantities are V_B and Z_B for the tube B. Then,



(A) $V_A > V_B, Z_A > Z_B$ **(B)** $V_A > V_B, Z_A < Z_B$

(C) $V_A < V_B, Z_A > Z_B$ **(D)** $V_A < V_B, Z_A < Z_B$

36. According to Moseley's law the ratio of the slopes of graph between $\sqrt{\nu}$ and Z for K_β and K_α is :

(A) $\sqrt{\frac{32}{27}}$ **(B)** $\sqrt{\frac{27}{32}}$

(C) $\sqrt{\frac{33}{22}}$ **(D)** $\sqrt{\frac{22}{33}}$

37. If λ_{min} is minimum wavelength produced in X-ray tube and $\lambda_{k\alpha}$ is the wavelength of k_α line. As the operating tube voltage is increased.

(A) $(\lambda_k - \lambda_{min})$ increases **(B)** $(\lambda_k - \lambda_{min})$ decreases

(C) $\lambda_{k\alpha}$ increases **(D)** $\lambda_{k\alpha}$ decreases

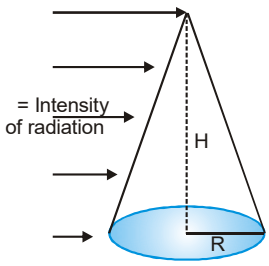
38. The radiation force experienced by body exposed to radiation of intensity I, assuming surface of body to be perfectly absorbing is :

(A) $\frac{\pi R^2 I}{c}$

(B) $\frac{\pi RHI}{c}$

(C) $\frac{IRH}{2c}$

(D) $\frac{IRH}{c}$



39. If the frequency of K_α X-ray emitted from element with atomic number 31 is f, then the frequency of K_α X-ray emitted from the element with atomic number 51 would be (assume that screening constant for K_α is 1):

(A) $\frac{5}{3}$ f **(B)** $\frac{51}{31}$ f

(C) $\frac{9}{25}$ f **(D)** $\frac{25}{9}$ f

40. Radiation pressure on any surface (for a given intensity):

(A) is dependent on wavelength of the light used

(B) is dependent on nature of surface and intensity of light used

(C) is dependent on frequency and nature of surface

(D) depends on the nature of source from which light is coming and on nature of surface on which it is falling.

41. In a discharge tube when 200 volt potential difference is applied 6.25×10^{18} electrons move from cathode to anode and 3.125×10^{18} singly charged positive ions move from anode to cathode in one second. Then the power of tube is:

(A) 100 watt **(B)** 200 watt

(C) 300 watt **(D)** 400 watt

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42. An atom consists of three energy levels given by a ground state with energy $E_0 = 0$, the first excited state with energy $E_1 = K$ and the second excited state with energy $E_2 = 2K$ where $K > 0$. The atom is initially in the ground state. Light from a laser which emits photons with energy 1.5K is shined on the atom. Which of the following is/are correct ?

(A) The photons are absorbed, putting one atom in a state E_1 and one atom in a state E_2.

(B) A photon will always be absorbed, but half the time the atom will go into the state with energy K and the other half into the state with energy 2K. In this way, energy will be conserved on the average.

(C) The atom absorbs a photon, goes into the first excited state with energy K and emits a photon with energy 0.5 K to conserve energy.

(D) The atom does not absorb any photon and stays in the ground state.

43. The wavelengths of K_α x-rays of two metals 'A' and 'B' are $\frac{4}{1875\ R}$ and $\frac{1}{675\ R}$ respectively, where 'R' is rydberg constant. The number of elements lying between 'A' and 'B' according to their atomic numbers is

(A) 3 **(B)** 6
(C) 5 **(D)** 4

44. An image of the sun is formed by a lens of focal length 30 cm on the metal surface of a photo-electric cell and it produces a current I. The lens forming the image is then replaced by another lens of the same diameter but of focal length 15 cm. The photoelectric current in this case will be : (In both cases the plate is kept at focal plane and normal to the axis lens). (Assume saturation current only).

(A) I/2 **(B)** 2 I
(C) I **(D)** 4 I

45. The work function of a certain metal is $\frac{hC}{\lambda_0}$. When a monochromatic light of wavelength $\lambda < \lambda_0$ is incident such that the plate gains a total power P. If the efficiency of photoelectric emission is $\eta\%$ and all the emitted photoelectrons are captured by a hollow conducting sphere of radius R already charged to potential V, then neglecting any interaction between plate and the sphere, expression of potential of the sphere at time t is :

(A) $V + \frac{100\eta\lambda Pet}{4\pi\varepsilon_0 RhC}$ **(B)** $V - \frac{\eta\lambda Pet}{400\pi\varepsilon_0 RhC}$

(C) V **(D)** $\frac{\lambda Pet}{4\pi\varepsilon_0 RhC}$

46. Which one of the following statements is NOT true for de Broglie waves ?

(A) All atomic particles in motion have waves of a definite wavelength associated with them

(B) The higher the momentum, the longer is the wavelength

(C) The faster the particle, the shorter is the wavelength

(D) For the same velocity, a heavier particle has a shorter wavelength

47. When a monochromatic source of light is at a distance of 0.2 m from a photoelectric cell, the cut-off voltage and the saturation current are respectively 0.6 V and 18 mA. If the same source is placed 0.6 m away from the cell, then :

(A) the stopping potential will be 0.2 V

(B) the stopping potential will be 1.8 V

(C) the saturation current will be 6.0 mA

(D) the saturation current will be 2.0 mA

48. In a photoelectric experiment, the frequency and intensity of a light source are both doubled. Then consider the following statements.

(i) The saturation photocurrent remains almost the same.

(ii) The maximum kinetic energy of the photoelectrons is doubled.

(A) Both (i) and (ii) are true

(B) (i) is true but (ii) is false

(C) (i) is false but (ii) is true

(D) both (i) and (ii) are false

49. An X-ray photon of wavelength λ and frequency ν collides with an intially stationary electron (but free to move) and bounces off. If λ' and ν' are respectively the wavelength and frequency of the scattered photon, then :

(A) $\lambda' = \lambda; \nu' = \nu$ **(B)** $\lambda' < \lambda; \nu' > \nu$
(C) $\lambda' > \lambda; \nu' > \nu$ **(D)** $\lambda' > \lambda; \nu' < \nu$

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50. An X-ray tube is operated at 66 kV. Then, in the continuous spectrum of the emitted X-rays :

(A) wavelengths 0.01 nm and 0.02 nm will both be present

(B) wavelengths 0.01 nm and 0.02 nm will both be absent

(C) wavelengths 0.01 nm will be present but wavelength 0.02 nm will be absent

(D) wavelength 0.01 nm will be absent but wavelength 0.02 nm will be present

51. A cesium photo cell, with a steady potential difference of 60 volt across it, is illuminated by a small bright light placed 50 cm away. When the same light is placed one meter away, the photoelectrons emerging from the photo cell : (assume that potential difference applied is sufficient to produce saturation current)

(A) each carry one quarter of their previous energy

(B) each carry one quarter of their previous momentum

(C) are half as numerous

(D) are one quarter as numerous

52. The work function for aluminium surface is 4.2 eV and that for sodium surface is 2.0 ev. The two metals were illuminated with appropriate radiations so as to cause photo emission. Then :

(A) Both aluminium and sodium will have the same threshold frequency

(B) The threshold frequency of aluminium will be more than that of sodium

(C) The threshold frequency of aluminium will be less than that of sodium

(D) The threshold wavelength of aluminium will be more than that of sodium

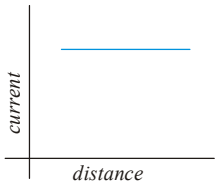
53. Let ν_1 be the frequency of the series limited of the Lyman series, ν_2 be the frequency of the first line of the Lyman series, and ν_3 be the frequency of the series limited of the Balmer series.

(A) $\nu_1 - \nu_2 = \nu_3$ **(B)** $\nu_2 - \nu_1 = \nu_3$

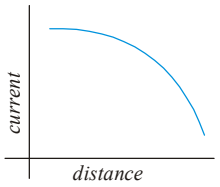
(C) $\nu_3 = \frac{1}{2}(\nu_1 + \nu_3)$ **(D)** $\nu_1 + \nu_2 = \nu_3$

54. A point source causes photoelectric effect from a small metal plate. Which of the following curves may represent the saturation photocurrent as a function of the distance between the source and the metal?

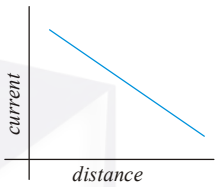
(A)



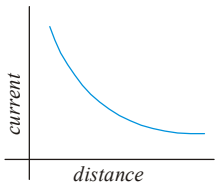
(B)



(C)



(D)



55. A point source of light is used in a photoelectric effect. If the source is moved toward the emitting metal, the stopping potential

(A) will increase

(B) will decrease

(C) will remain constant

(D) will either increase or decrease

56. The energy difference between the first two levels of hydrogen atom is 10.2 eV. What is the corresponding energy difference for a singly ionized helium atom ?

(A) 10.2 eV **(B)** 20.4 eV

(C) 40.8 eV **(D)** 81.6 eV

57. The innermost orbit of the hydrogen atom has a diameter of 1.06 Å. What is the diameter of the tenth orbit?

(A) 5.3 Å **(B)** 10.6 Å

(C) 53 Å **(D)** 106 Å

58. For the structural analysis of crystals, X-rays are used because :

(A) X-rays have wavelength of the order of the inter-atomic spacing

(B) X-rays are highly penetrating radiations

(C) Wavelength of X-rays is of the order of nuclear size

(D) X-rays are coherent radiations

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59. In a photoelectric experiment, with light of wavelength λ, the fastest electron has speed v. If the exciting wavelength is changed to $\frac{3\lambda}{4}$, the speed of the fastest emitted electron will become

(A) $v\sqrt{\frac{3}{4}}$ **(B)** $v\sqrt{\frac{4}{3}}$

(C) less than $v\sqrt{\frac{3}{4}}$ **(D)** greater than $v\sqrt{\frac{4}{3}}$

60. An α particle with a kinetic energy of 2.1 eV makes a head on collision with a hydrogen in ground state atom moving towards it with a kinetic energy of 8.4 eV. The collision.

(A) must be perfectly elastic

(B) may be perfectly inelastic

(C) may be inelastic

(D) must be perfectly inelastic

61. The photoelectrons emitted from a metal surface :

(A) Are all at rest

(B) Have the same kinetic energy

(C) Have the same momentum

(D) Have speeds varying from zero up to a certain maximum value

62. An energy of 24.6 eV is required to remove one of the electrons from a neutral helium atom. The energy (In eV) required to remove both the electrons from a neutral helium atom is :

(A) 38.2 **(B)** 49.2

(C) 51.8 **(D)** 79.0

63. The stable nucleus that has a radius 1/3 that of Os^{189} is -

(A) $_3Li^7$ **(B)** $_2He^4$

(C) $_5B^{10}$ **(D)** $_6C^{12}$

64. The mass number of a nucleus is

(A) always less than its atomic number

(B) always more than its atomic number

(C) equal to its atomic number

(D) sometimes more than and sometimes equal to its atomic number

65. As the mass number A increases, the binding energy per nucleon in a nucleus

(A) increases

(B) decreases

(C) remains the same

(D) varies in a way that depends on the actual value of A.

66. The energy of the reaction $Li^7 + p \longrightarrow 2\ He^4$ is (the binding energy per nucleon in Li^7 and He^4 nuclei are 5.60 and 7.06 MeV respectively.)

(A) 17.3 MeV

(B) 1.73 MeV

(C) 1.46 MeV

(D) depends on binding energy of proton

67. Which of the following is a wrong description of binding energy of a nucleus ?

(A) It is the energy required to break a nucleus into its constituent nucleons.

(B) It is the energy released when free nucleons combine to from a nucleus

(C) It is the sum of the rest mass energies of its nucleons minus the rest mass energy of the nucleus

(D) It is the sum of the kinetic energy of all the nucleons in the nucleus

68. A free neutron decays into a proton, an electron and :

(A) A neutrino **(B)** An antineutrino

(C) An α-particle **(D)** A β-particle

69. An α-particle is bombarded on ^{14}N. As a result, a ^{17}O nucleus is formed and a particle is emitted. This particle is a

(A) neutron **(B)** proton

(C) electron **(D)** positron

70. The atomic weight of boron is 10.81 g/mole and it has two isotopes $^{10}_5B$ and $^{11}_5B$. The ratio (by number) of $^{10}_5B$: $^{11}_5B$ in nature would be :

(A) 19 : 81 **(B)** 10 : 11

(C) 15 : 16 **(D)** 81 : 19

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71. Nuclei X decay into nuclei Y by emitting α particles. Energies of α particle are found to be only 1 MeV & 1.4 MeV. Disregarding the recoil of nuclei Y. The energy of γ photon emitted will be

(A) 0.8 MeV **(B)** 1.4 MeV

(C) 1 MeV **(D)** 0.4 MeV

72. Two isotopes P and Q of atomic weight 10 and 20, respectively are mixed in equal amount by weight. After 20 days their weight ratio is found to be 1 : 4. Isotope P has a half-life of 10 days. The half-life of isotope Q is

(A) zero **(B)** 5 days

(C) 20 days **(D)** inifinite

73. In one average-life

(A) half the active nuclei decay

(B) less than half the active nuclei decay

(C) more than half the active nuclei decay

(D) all the nuclei decay

74. A freshly prepared radioactive source of half-life 2 h emits radiation of intensity which is 64 times the permissible safe level. The minimum time after which it would be possible to work safely with this source is -

(A) 6 h **(B)** 12 h

(C) 24 h **(D)** 128 h

75. $A \xrightarrow{\lambda} B \xrightarrow{2\lambda} C$

t = 0	N_0	0	0
t	N_1	N_2	N_3

The ratio of N_1 to N_2 when N_2 is maximum is :

(A) at no time this is possible

(B) 2

(C) 1/2

(D) $\frac{\ell n\, 2}{2}$

76. 10 grams of ^{57}Co kept in an open container beta-decays with a half-life of 270 days. The weight of the material inside the container after 540 days will be very nearly -

(A) 10 g **(B)** 7.5 g

(C) 5 g **(D)** 2.5 g

77. $_{92}U^{235}$ nucleus absorbs a slow neutron and undergoes fission into $_{54}X^{139}$ and $_{38}Sr^{94}$ nuclei. The other particles produced in this fission process are

(A) 1 β and 1 α

(B) 2 β and 1 neutron

(C) 2 neturons

(D) 3 neutrons

78. The half-life of ^{131}I is 8 days. Given a sample of ^{131}I at time t = 0, we can assert that

(A) No nucleus will decay before t = 4 days

(B) No nucleus will decay before t = 8 days

(C) All nuclei will decay before t = 16 days

(D) A given nucleus may decay at any time after t = 0.

79. Two lithium ^{6}Li nuclei in a lithium vapour at room temperature do not combine to form a carbon ^{12}C nucleus because

(A) a lithium nucleus is more tightly bound than a carbon nucleus

(B) carbon nucleus is an unstable particle

(C) it is not energetically favourable

(D) Coulomb repulsion does not allow the nuclei to come very close

80. Choose the statement which is true.

(A) The energy released per unit mass is more in fission than in fusion

(B) The energy released per atom is more in fusion than in fission.

(C) The energy released per unit mass is more in fusion and that per atom is more in fission.

(D) Both fission and fusion produce same amount of energy per atom as well as per unit mass.

81. In a uranium reactor whose thermal power is P = 100 MW, if the average number of neutrons liberated in each nuclear splitting is 2.5. Each splitting is assumed to release an energy E = 200 MeV. The number of neutrons generated per unit time is -

(A) $4 \times 10^{18}\ s^{-1}$ **(B)** $8 \times 10^{23}\ s^{-1}$

(C) $8 \times 10^{19}\ s^{-1}$ **(D)** $\frac{125}{16} \times 10^{18}\ s^{-1}$

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82. In a fission reaction

$$^{236}_{92}U \longrightarrow {}^{117}X + {}^{117}Y + n + n$$

the average binding energy per nucleon of X and Y is 8.5 MeV whereas that of ^{236}U is 7.6 MeV. The total energy liberated will be about :

$$^{236}_{92}U \longrightarrow {}^{117}X + {}^{117}Y + n + n$$

(A) 200 keV **(B)** 2 MeV

(C) 200 MeV **(D)** 2000 MeV

83. Fusion reaction is possible at high temperature because -

(A) atoms are ionised at high temperature

(B) molecules break-up at high temperature

(C) nuclei break-up at high temperature

(D) kinetic energy is high enough to overcome repulsion between nuclei.

84. Assuming that about 20 MeV of energy is released per fusion reaction, $_1H^2 + {}_1H^3 \rightarrow {}_0n^1 + {}_2He^4$, the mass of $_1H^2$ consumed per day in a future fusion reactor of power 1 MW would be approximately

(A) 0.1 gm **(B)** 0.01 gm

(C) 1 gm **(D)** 10 gm

85. A heavy nucleus having mass number 200 gets disintegrated into two small fragments of mass number 80 and 120. If binding energy per nucleon for parent atom is 6.5 M eV and for daughter nuclei is 7 M eV and 8 M eV respectively, then the energy released in each decay will be :

(A) 200 M eV **(B)** – 220 M eV

(C) 220 M eV **(D)** 180 M eV

86. Let F_{pp}, F_{pn} and F_{nn} denote the magnitudes of the nuclear force by a proton on a proton, by a proton on a neutron and by a neutron on a neutron respectively. When the separation is 1 fm,

(A) $F_{pp} > F_{pn} = F_{nn}$ **(B)** $F_{pp} = F_{pn} = F_{nn}$

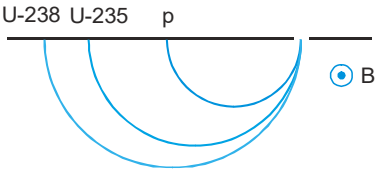
(C) $F_{pp} > F_{pn} > F_{nn}$ **(D)** $F_{pp} < F_{pn} = F_{nn}$

87. The graph of $\ell n(R/R_0)$ versus $\ell n A$ (R = radius of a nucleus and A = its mass number) is

(A) a straight line **(B)** a parabola

(C) an ellipse **(D)** none of them

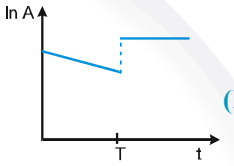
88. Protons and singly ionized atoms of U^{235} & U^{238} are passed in turn (which means one after the other and not at the same time) through a velocity selector and then enter a uniform magnetic field. The protons describe semicircles of radius 10 mm. The separation between the ions of U^{235} and U^{238} after describing semicircle is given by

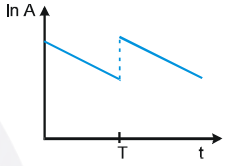


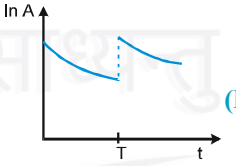
(A) 60 mm **(B)** 30 mm

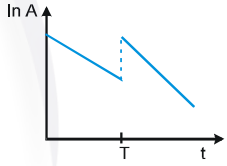
(C) 2350 mm **(D)** 2380 mm

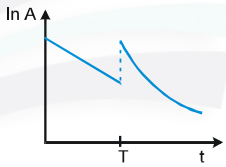
89. At time t = 0, some radioactive gas is injected into a sealed vessel. At time T, some more of the same gas is injected into the same vessel. Which one of the following graphs best represents the variation of the logarithm of the activity A of the gas with time t?

(A)


(B)


(C)


(D)


(E)


90. When a β^--particle is emitted from a nucleus, the neutron-proton ratio :

(A) is decreased

(B) is increased

(C) remains the same

(D) first (A) then (B)

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91. A sample of radioactive material has mass m, decay constant λ, and molecular weight M. Avogadro constant = N_A. The initial acitvity of the sample is :

(A) λm **(B)** $\frac{\lambda m}{M}$

(C) $\frac{\lambda m N_A}{M}$ **(D)** $mN_A e^{\lambda}$

92. Match the following :

Column I	Column II
(A) Photoelectric effect	I. Photon
(B) Wave	II. Frequency
(C) X rays	III. K capture
(D) Nucleus	IV. γ rays

(A) a – I, b – II, c – III, d – IV

(B) a – II, b – I, c – IV, d – III

(C) a – II, b – I, c – III, d – IV

(D) None of these

93. Consider a sample of a pure beta-active material

(A) All the beta particles emitted have the same energy

(B) The beta particles originally exist inside the nucleus and are ejected at the time of beta decay

(C) The antineutrino emitted in a beta decay has zero rest mass and hence zero momentum.

(D) The active nucleus changes to one of its isobars after the beta decay

94. Two radioactive sources A and B initially contain equal number of radioactive atoms. Source A has a half-life of 1 hour and source B has a half-life of 2 hours. At the end of 2 hours, the ratio of the rate of disintegration of A to that of B is:

(A) 1 : 2 **(B)** 2 : 1

(C) 1 : 1 **(D)** 1 : 4

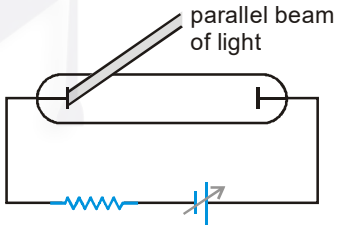
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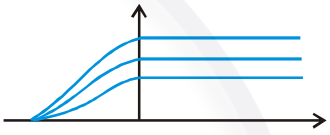
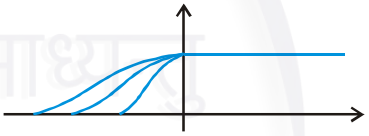
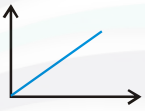
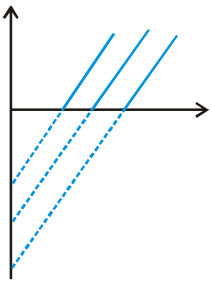
Exercise # 3 PART - 1 MATRIX MATCH COLUMN

1. The energy, the magnitude of linear momentum, magnitude of angular momentum and orbital radius of an electron in a hydrogen atom corresponding to the quantum number n are E, p, L and r respectively. Then according to Bohr's theory of hydrogen atom, match the expressions in column-I with statement in column-II.

Column-I	Column-II
(A) Epr	**(P)** is independent of n.
(B) $\frac{p}{E}$	**(Q)** is directly proportional to n
(C) Er	**(R)** is inversely proportional to n.
(D) pr	**(S)** is directly proportional to L.

2. In the shown experimental setup to study photoelectric effect, two conducting electrodes are enclosed in an evacuated glass-tube as shown. A parallel beam of monochromatic radiation, falls on photosensitive electrode. Assume that for each photons incident, a photoelectron is ejected if its energy is greater than work function of electrode. Match the statements in column I with corresponding graphs in column II.



Column-I	Column-II
(A) Saturation photocurrent (for same metal) versus intensity of radiation is represented by	**(P)** 
(B) Maximum kinetic energy of ejected photoelectrons versus frequency for electrodes of different work function is represented by	**(Q)** 
(C) Photo current versus applied voltage for different intensity of radiation (for same metal) is represented by	**(R)** 
(D) Photo current versus applied voltage at constant intensity of radiation for electrodes of different work function.	**(S)** 

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3. In each situation of column I a physical quantity related to orbiting electron in a hydrogen like atom is given.The terms 'Z' and 'n' given in column-II have usual meaning in Bohr's theory. Match the quantities in column-I with the terms those depend on quantity given in column-II.

Column I	Column II
(A) Frequency of orbiting electron	**(P)** is directly proportional to Z^2
(B) Angular momentum of orbiting electron	**(Q)** is directly proportional to n.
(C) Magnetic moment of orbiting electron	**(R)** is inversely proportional to n^3
(D) The average current due to orbiting of electron	**(S)** is independent of Z

4. In column-I, consider each process just before and just after it occurs. Initial system is isolated from all other bodies. Consider all product particles (even those having rest mass zero) in the system. Match the system in column-I with the result they produce in column-II.

Column-I	Column-II
(A) Spontaneous radioactive decay of an uranium nucleus initially at rest as given by reaction $^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He + ...$	**(P)** Number of protons is increased
(B) Fusion reaction of two hydrogen nuclei as given by reaction $^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + ...$	**(Q)** Momentum is conserved
(C) Fission of U^{235} nucleus initiated by a thermal neutron as given by reaction $^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + 3{}^{1}_{0}n + ...$	**(R)** Mass is converted to energy or vice versa
(D) β^- decay (negative beta decay)	**(S)** Charge is conserved

5. Match the column-I of properties with column-II of reactions

Column-I	Column-II
(A) Mass of product formed is less than the original mass of the system in	**(P)** α-decay
(B) Binding energy per nucleon increase in	**(Q)** β-decay
(C) Mass number is conserved in	**(R)** Nuclear fission
(D) Charge number is conserved in	**(S)** Nuclear fusion

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Exercise # 3 PART - 2 ASSERTION & REASONING

These questions contains, Statement I (assertion) and Statement II (reason).

(A) If both assertion and reason are true and the reason is the correct explanation of the assertion.

(B) If both assertion and reason are true but reason is not the correct explanation of the assertion.

(C) If assertion is true but reason is false.

(D) If assertion is false but reason is true.

(E) If the assertion and reason both are false.

1. **Assertion :** When a beam of highly energetic neutrons is incident on a tungsten target, no X-rays will be produced.

Reason : Neutrons do not exert any electrostatic force on electrons or nucleus of an atom.

2. **Assertion :** Work function of aluminium is 4.2 eV. Emission of electrons will not be possible if two photons each of energy 2.5 eV collide with free electrons of aluminium.

Reason : For photoelectric emission the energy of each photon should be greater than or equal to the work function of aluminium.

3. **Assertion :** Though light of a single frequency (monochromatic light) is incident on a metal, the kinetic energies of all the emitted photoelectrons are different.

Reason : The energy of electrons just after they absorb photons incident on metal surface may be lost in collision with other atoms in the metal before the electron is ejected out of the metal.

4. **Assertion :** In the duration electron jumps from first excited state to ground state in a stationary isolated hydrogen atom, angular momentum of the electron about the nucleus is conserved.

Reason : As the electron jumps from first excited state to ground state, in a hydrogen atom, the electrostatic force on electron is always directed towards the nucleus.

5. **Assertion :** Q- value of a reaction : $A + B \rightarrow C + Q$ is – 30 MeV. B is at rest. The minimum kinetic energy of bombarding nucleus A to initiate the nuclear reaction is 30 MeV.

Reason : Momentum will conserve in the endoergic reaction also.

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Exercise # 4 PART - 1 PREVIOUS YEAR (NEET/AIPMT)

ELECTRONS AND PHOTONS

1. Einsteins' work on photoelectric effect gives support to

(A) $E = mc^2$ (B) $E = hv$

(C) $hv = \frac{1}{2}mv^2$ (D) $E = \frac{h}{\lambda}$

2. The energy of a photon of light is 3 eV. Then the wavelength of photon must be

(A) 4125 nm (B) 412.5 nm

(C) 41250 nm (D) 4 nm

3. A light source is at a distance d from a photoelectric cell, then the number of photoelectrons emitted from the cell is n. If the distance of light source and cell is reduced to half, then the number of photoelectrons emitted will become

(A) $\frac{n}{2}$ (B) 2 n

(C) 4 n (D) n

4. The following particels are moving with the same velocity, then maximum de-Broglie wavelength will be for

(A) proton (B) α-particle

(C) neutron (D) β-particle

5. Which of the following rays are incident on metal plate, the photoelectric effect does not occur. It occurs by incidence of

(A) It produces heating effect

(B) It does not deflect in electric field

(C) Its casts shadow

(D) It produces fluorescence

6. When ultraviolet rays are incident on metal plate, the photoelectric effect does not occur. It occurs by incidence of

(A) infrared rays (B) X-rays

(C) radiowaves (D) light waves

7. A photoelectric cell is illuminated by a point source of light 1 m away. When the source is shifted to 2 m, then

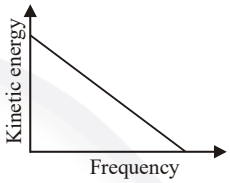
(A) each emitted electron carries half the initial energy

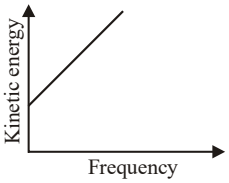
(B) number of electrons emitted is a quarter of the initial number

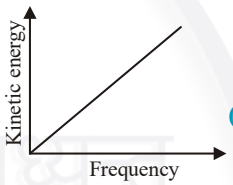
(C) each emitted electron carries one quarter of the initial energy

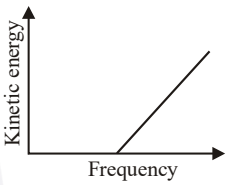
(D) number of electrons emitted is half the initial number

8. According to Einsteins' photoelectric equation, the graph between the kinetic energy of photoelectrons ejected and the frequency of incident radiation is

(A) 

(B) 

(C) 

(D) 

9. The work functions for metals A, B and C are respectively.1.92 eV, 2.0 eV and 5 eV. According to Einsteins' equation, the metals which will emit photoelectrons for a radiation of wavelength 4100 Å is/are

(A) None of these (B) A only

(C) A and B only (D) All the three metals

10. A photosensitive metallic surface has work function, $h v_0$. If photons of energy 2 hv_0 fall on this surface, the electrons come out with a maximum velocity of 4 × 10^6 m/s. When the photon energy is increased to 5 hv_0, then maximum velocity of photoelectrons will be

(A) 2 × 10^6 m/s (B) 2 × 10^7 m/s

(C) 8 × 10^5 m/s (D) 8 × 10^6 m/s

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11. A photocell employs photoelectric effect to convert

(A) change in the frequency of light into a change in electric voltage

(B) change in the intensity of illumination into a change in photoelectric current

(C) change in the intensity of illumination into a change in the work function of the photocathode

(D) change in the frequency of light into a change in the electric current

12. In a discharge tube ionisation of enclosed gas is produced due to collisions between

(A) positive ions and neutral atoms/molecules

(B) negative electrons and neutral atoms/molecules

(C) photons and neutral atmos/molecules

(D) neutral gas atoms/molecules

13. The momentum of a photon of energy 1 MeV in kg m/s, will be

(A) 0.33×10^{6} **(B)** 7×10^{-24}

(C) 10^{-22} **(D)** 5×10^{-22}

14. A 5 W source emits monochromatic light of wavelength 5000 Å. When placed 0.5 m away, it liberated photoelectrons from a photosensitive metallic surface. When the source is moved toa distance ot 1.0 m, the number of photoelectrons liberated will be reduced by a factor of

(A) 4 **(B)** 8

(C) 16 **(D)** 2

15. Monochromatic light of frequency 6.0×10^{14} Hz is produced by a laser. The power emitted is 2×10^{-3} W. The number of photons emitted, on the average, by the source per second is

(A) 5×10^{15} **(B)** 5×10^{16}

(C) 5×10^{17} **(D)** 5×10^{14}

16. The work function of a surface of a photosensitive material is 6.2 eV. The wavelength of the incident radiation for which the stopping potential is 5 V lies in the

(A) ultraviolet region **(B)** visible region

(C) infrared region **(D)** X-ray region

17. In the phenomenon of electric discharge through gases at low pressure, the coloured glow in the tube appears as a result of

(A) excitation of electrons in the atoms

(B) collision between the atoms of the gas

(C) collisions between the charged and the atoms of the gas

(D) collision between different electrons of the atoms of the gas

18. A particle of mass 1 mg has the same wavelength as an electron moving with a velocity of 3×10^{6} ms^{-1}. The velocity of the particle is (mass of electron = 9.1×10^{-31} kg)

(A) 2.7×10^{-18} ms^{-1} **(B)** 9×10^{-2} ms^{-1}

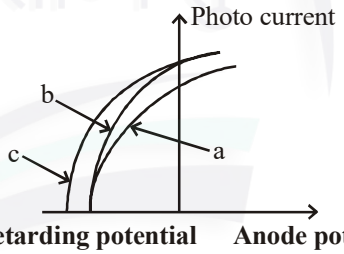
(C) 3×10^{-31} ms^{-1} **(D)** 2.7×10^{-21} ms^{-1}

19. Monochromatic light of wavelength 667 nm is produced by a helium neon laser. The power emitted is 9 mW. The number of photons arriving per second on the average at a target irradiated by this beam is

(A) 9×10^{17} **(B)** 3×10^{16}

(C) 9×10^{15} **(D)** 3×10^{19}

20. The figure shows a plot of photocurrent versus anode potential for a photo sensitive surface for three different radiations. Which one of the following is a correct statement?



(A) Curves a and b represent incident radiations of different frequencies and different intensities

(B) Curves a and b represent incident radiations of same frequency but of different intensities

(C) Curves b and c represent incident radiations of different frequencies and different intensities

(D) Curves b and c represent incident radiations of same frequency having same intensity

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21. The number of photoelectrons emitted for light of a frequency v (higher than the threshold frequency v_0) is proportional to

(A) $v - v_0$

(B) threshold frequency (v_0)

(C) intensity of ligth

(D) frequency of light (v)

22. A source S_1 is producing, 10^{15} photons/s of wavelength 5000 Å. Another source S_2 is producing 1.02×10^{15} photons per second of wavelength 5100 Å. Then, (power of S_2)/(power of S_1) is equal to

(A) 1.00 **(B)** 1.02

(C) 1.04 **(D)** 0.98

23. In photoelectric emission process from a metal of work function 1.8 eV, the kinetic energy of most energetic electrons is 0.5 eV. The corresponding stopping potential is

(A) 1.3 V **(B)** 0.5 V

(C) 2.3 V **(D)** 1.8 V

24. Photoelectric emission occurs only when the incident light has more than a certain minimum

(A) wavelength **(B)** intensity

(C) frequency **(D)** power

25. Light of two different frequencies whose photons have energies 1 eV and 2.5 eV respectively illuminate a metallic surface whose work function is 0.5 eV successively. Ratio of maximum speeds of emitted electrons will be

(A) 1 : 2 **(B)** 1 : 1

(C) 1 : 5 **(D)** 1 : 4

26. A 200 W sodium street lamp emits yellow light of wavelength 0.6 μm. Assuming it to be 25% efficient in converting electrical energy to light, the number of photons of yellow light it emits per second is

(A) 1.5×10^{20} **(B)** 6×10^{18}

(C) 62×10^{20} **(D)** 3×10^{19}

27. Monochromatic radiation emitted when electron state on hydrogen atom jumps from first excited state to the ground state irradiates a photosensitive material. The stopping potential is measured to be 3.57 V. The threshold frequency of the material is

(A) 4×10^{15} Hz **(B)** 5×10^{15} Hz

(C) 1.6×10^{15} Hz **(D)** 2.5×10^{15} Hz

28. The wavelength λ_e of an electron and λ_p of a photon of same energy E are related by

(A) $\lambda_p \propto \lambda_e^2$ **(B)** $\lambda_p \propto \lambda_e$

(C) $\lambda_p \propto \sqrt{\lambda_e}$ **(D)** $\lambda_p \propto \frac{1}{\sqrt{\lambda_e}}$

29. For photoelectric emission from certain metal, the cut-off frequency is v. If radiation of frequency 2 v impinges on the metal plate, the maximum possible velocity of the emitted electron will be (m is the electron mass)

(A) $\sqrt{\frac{hv}{(2m)}}$ **(B)** $\sqrt{\frac{hv}{m}}$

(C) $\sqrt{\frac{2hv}{m}}$ **(D)** $2\sqrt{\frac{hv}{m}}$

30. If the kinetic energy of the particle is increased to 16 times its previous value, the percentage change in the de-Broglie wavelength of the particle is

(A) 25 **(B)** 75

(C) 60 **(D)** 50

31. When the energy of the incident radiation is increased by 20%, the kinetic energy of the photoelectrons emitted from a metal surface increased from 0.5 eV to 0.8 eV. The work function of the metal is

(A) 0.65 eV **(B)** 1.0 eV

(C) 1.3 eV **(D)** 1.5 eV

32. Light of wavelength 500 nm is incident on a metal with work function 2.28 eV. The de-Broglie wavelength of the emitted electron is

(A) $< 2.8 \times 10^{-10}$ m **(B)** $< 2.8 \times 10^{-9}$ m

(C) $\geq 2.8 \times 10^{-9}$ m **(D)** $\leq 2.8 \times 10^{-12}$ m

33. A photoelectric surface is illuminated successively by monochromatic light of wavelength λ and $\frac{\lambda}{2}$. If the maximum kinetic energy of the emitted photoelectrons in the second case is 3 times that in the first case, the work function of the surface of the material is

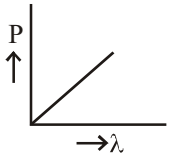
(h = Planck's constant, c = speed of light)

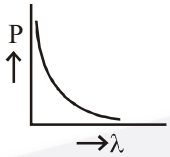
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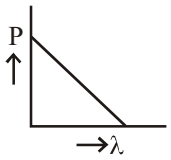
(A) $\frac{hc}{2\lambda}$ (B) $\frac{hc}{\lambda}$

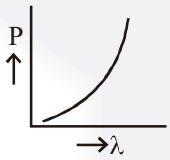
(C) $\frac{2hc}{\lambda}$ (D) $\frac{hc}{3\lambda}$

34. Which of the following figures represent the variation of particle momentum and the associated de-Broglie wavelength?

(A) 

(B) 

(C) 

(D) 

35. A certain metallic surface is illuminated with monochromatic light of wavelength λ. The stopping potential for photoelectric current for this light is $3V_0$. If the same surface is illuminated with light of wavelength 2λ, the stopping potential is V_0. The threshold wavelength for this surface for photoelectric effect is

(A) 6λ (B) 4λ

(C) $\frac{\lambda}{4}$ (D) $\frac{\lambda}{6}$

36. A radiation of energy 'E' falls normally on a perfectly reflecting surface. The momentum transferred to the surface is (c = velocity of light)

(A) $\frac{E}{c}$ (B) $\frac{2E}{c}$

(C) $\frac{2E}{c^2}$ (D) $\frac{E}{c^2}$

37. Photons with energy 5 eV are incident on a cathode C in a photoelectric cell. The maximum energy of emitted photoelectrons is 2 eV. When photons of energy 6 eV are incident on C, no photoelectrons will reach the anode A, if the stopping potential of A relative to C is

(A) +3 V (B) +4 V

(C) –1 V (D) –3 V

38. Electrons of mass m with de-Broglie wavelength λ fall on the target in an X-ray tube. The cut-off wavelength (λ_0) of the emitted X-ray is

(A) $\lambda_0 = \frac{2mc\lambda^2}{h}$ (B) $\lambda_0 = \frac{2h}{mc}$

(C) $\lambda_0 = \frac{2m^2c^2\lambda^3}{h^2}$ (D) $\lambda_0 = \lambda$

39. When a metallic surface is illuminated with radiation of wavelength λ, the stopping potential is V. If the same surface is illumianted with radiatio of wavelength 2λ, the stopping potential is $\frac{V}{4}$. The threshold wavelength for the metallic surface is

(A) 5λ (B) $\frac{5}{2}\lambda$

(C) 3λ (D) 4λ

40. An electron of mass m and a photon have same energy E. The ratio of de-Broglie wavelengths associated with them is

(A) $\left(\frac{E}{2m}\right)^{\frac{1}{2}}$ (B) $c(2mE)^{\frac{1}{2}}$

(C) $\frac{1}{c}\left(\frac{2m}{E}\right)^{\frac{1}{2}}$ (D) $\frac{1}{c}\left(\frac{E}{2m}\right)^{\frac{1}{2}}$

41. The de-Broglie wavelength of a neutron in thermal equilibrium with heavy water at a temperature T (Kelvin) and mass m, is

(A) $\frac{h}{\sqrt{mkT}}$ (B) $\frac{h}{\sqrt{3mkT}}$

(C) $\frac{2h}{\sqrt{3mkT}}$ (D) $\frac{2h}{\sqrt{mkT}}$

42. The photoelectric threshold wavelength of silver is 3250×10^{-10} m. The velocity of the electron ejected from a silver surface by ultraviolet light of wavelength 2563×10^{-10} m is (Given, h = 4.14×10^{-15} eVs and c = 3×10^8 ms^{-1})

(A) $\approx 6 \times 10^5$ ms^{-1} (B) $\approx 0.6 \times 10^6$ ms^{-1}

(C) $\approx 61 \times 10^3$ ms^{-1} (D) $\approx 0.3 \times 10^6$ ms^{-1}

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ATOMIC PHYSICS

43. When electron jumps from n = 4 to n = 2 orbit, we get

(A) second line of Lyman series

(B) second line of Balmer series

(C) second line of paschen series

(D) an sbsorption line of Balmer series

44. Which of the following transitions gives photon of maximum energy ?

(A) n = 1 to n = 2 **(B)** n = 2 to n = 1

(C) n = 2 to n = 6 **(D)** n = 6 to n = 2

45. The Bolr model of atoms

(A) assumes that the angular momentum of electrons is quantised

(B) uses Einstein's photoelectric equation

(C) predicts continuous emission spectra atoms

(D) predicts the same emission spectra for all types of atoms

46. Energy E of a hydrogen atom with principal quantum number n is given by $E = \frac{-13.6}{n^2}$ eV. The energy of a photon ejected when the electron jumps from n = 3 state to n = 2 state of hydrogen, is approximately.

(A) 1.5 eV **(B)** 0.5 eV

(C) 3.4 eV **(D)** 1.9 eV

47. The total energy of an electron in the first excited state of hydrogen is about – 3.4 eV. its kinetic energy in this state is

(A) – 3.4 eV **(B)** – 6.8 eV

(C) 6.8 eV **(D)** 3.4 eV

48. Ionisation potential of hydrogen atom is 13.6eV. Hydrogen atoms in the ground state are excited by monochromatic radiation of photon energy 12.1 eV. According to Bohr's theory the spectral lines emitted by hydrogen will be

(A) two **(B)** three

(C) four **(D)** one

49. The total energy of electron in the ground state of hydrogen atom is – 13.6eV. The kinetic energy of an electron in the first excited state is

(A) 3.4 eV **(B)** 6.8 eV

(C) 13.6 eV **(D)** 1.7 eV

50. The ground state energy of hydrogen atom is – 13.6 eV. When its electron is in the first excited state, its excitation energy is

(A) 3.4 eV **(B)** 6.8 eV

(C) 10.2 eV **(D)** zero

51. In a Rutherford scattering experiment when a projectile of charge Z_1 and mass M_1 approaches a target nucleus of charge Z_2 and mass M_2, the distance of closest approach is r_0. The energy of the projectile is

(A) directly proportional to $M_1 \times M_2$

(B) directly proportional to Z_1Z_2

(C) inversely proportional to Z_1

(D) directly proportional to mass M_1

52. The ionisation energy of the electron in the hydrogen atom in its ground state is 13.6 eV. The atoms are excited to higher energy levels to emit radiations of 6 wavelengths. Maximum wavelength of emitted radiation corresponds to the transition between

(A) n = 3 to n = 2 states **(B)** n = 3 to n = 1 states

(C) n = 2 to n = states **(D)** n = 4 to n = 3 states

53. The energy of a hydrogen atom in the ground state is – 13.6eV. The energy of a He^+ ion in the first excited state will be

(A) – 13.6eV **(B)** – 27.2 eV

(C) – 54.4 eV **(D)** – 6.8eV

54. The wavelength of the first line of Lyman series for hydrogen atom is equal to that of the second line of Balmer series for a hydrogen like ion. The atomic number Z of hydrogen like ion is

(A) 4 **(B)** 1

(C) 2 **(D)** 3

55. An electron of a stationary hydrogen atom passes from the fifth energy level to the ground level. The velocity 3that the atom acquired as a result of photon emission will be

(A) $\frac{24hR}{25m}$ **(B)** $\frac{25hR}{24m}$

(C) $\frac{25m}{24hR}$ **(D)** $\frac{24m}{25hR}$

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56. Electron in hydrogen atom first jumps from third excited state to second excited state and then from second excited to the first excited state. Thev ratio of the wavelengths l1 : l2 emitted in the two cases is

(A) 7/5 (B) 27/20
(C) 27/5 (D) 20/7

57. Ratio of longest wavelengths corresponding to Lyman and Balmer series in hydrogen spectrum is -

(A) 5/27 (B) 3/23
(C) 7/29 (D) 9/31

58. Hydrogen atom in ground state is excited by a monochromatic radiation of l= 975 Å. Number of spectral lines in the resulting spectrum emitted will be

(A) 3 (B) 2
(C) 6 (D) 10

59. Consider 3rd orbit of He+ (Helium), using non-relativistic approach, the speed of electron in this orbit will be (given K = 9 × 109 constant, Z = 2 and h (Planck's constant) = 6.6×10^{-34} J-s)

(A) 2.92×10^6 m/s (B) 1.46×10^6 m/s
(C) 0.73×10^6 m/s (D) 3.0×10^8 m/s

60. In the spectrum of hydrogen, the ratio of the longest wavelength in the Lyman series to the longest wavelength in the Balmer series is

(A) 4/9 (B) 9/4
(C) 27/5 (D) 5/27

61. A proton and an alpha particle both enter a region of uniform magnetic field B, moving at right angles to the field B. If the radius of circular orbits for both the particles is equal and the kinetic energy acquired by proton is 1 MeV, the energy acquired by the alpha particle will be

(A) 4 MeV (B) 0.5 MeV
(C) 1.5 MeV (D) 1 MeV

62. If an electron in a hydrogen atom jumps from the 3rd orbit to the 2nd orbit, it emits a photon of wavelength λ. When it jumps from the 4th orbit to the 3rd orgbit, the corresponding wavelength of the photon will be

(A) $\frac{16}{25}\lambda$ (B) $\frac{9}{16}\lambda$
(C) $\frac{20}{7}\lambda$ (D) $\frac{20}{13}\lambda$

63. The ratio of wavelengths of the last line of Balmer series and the last of Lyman series is

(A) 2 (B) 1
(C) 4 (D) 0.5

64. Radioactive material A has decay constant 8λ and material B has decay constant λ. Initially, they have same number of nuclei. After what time, the ratio of number of nuclei of material B to that A will be 1/e ?

(A) 1/λ (B) 1/7λ
(C) 1/8λ (D) 1/9λ

NUCLEAR PHYSICS

65. Nuclear fission can be explained by

(A) proton-proton cycle
(B) liquid drop model of nucleus
(C) independent of nuclear particle model
(D) nuclear shell model

66. The relationship between disintegration constant (λ) and half-life (T) will be

(A) $\lambda = \frac{\log_{10} 2}{T}$ (B) $\lambda = \frac{\log_e 2}{T}$
(C) $\lambda = \frac{T}{\log_e 2}$ (D) $\lambda = \frac{\log_2 e}{T}$

67. The half-life of a radioactive material is 3h. If the initial amount is 300g, then after 18h, it will remain

(A) 4.68 g (B) 46.8 g
(C) 9.375 g (D) 93.75 g

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68. A nuclear fecay is expressed as

$$_6C^{11} \rightarrow {}_5B^{11} + \beta^+ + X$$

Then the unknown particle X is

(A) neutron **(B)** antineutrino
(C) proton **(D)** neutrino

69. Which of the following is positively charged ?

(A) α-particle **(B)** β-particle
(C) γ-rays **(D)** X-rays

70. m_p and m_n are masses of proton and neutron respectively . AN element, then

(A) $m > Zm_p + Nm_n$
(B) $m = Zm_p + Nm_n$
(C) $m < Zm_p + Nm_n$
(D) m may be greater than, less than or equal to $Zm_p + Nm_n$, depending on nature of element

71. In nuclear fission process, energy is

(A) mass of products is more than mass of nucleus
(B) total binding energy of products formed due to nuclear fission is more than the parent fissionable material
(C) total binding energy of products formed due to nuclear fission is less than parent fissionable material
(D) mass of some particles is converted into energy

72. Half-life period of a radioactive substance is 6h. After 24h activity is 0.01μC, what was the initial activity ?

(A) 0.04 μC **(B)** 0.08 μC
(C) 0.24 μC **(D)** 0.16 μC

73. Half-life of a radioactive substance is 12.5 h and its mass is 256 g. After what time, the amount of remaining substance is 1 g ?

(A) 75 h **(B)** 100 h
(C) 125 h **(D)** 150 h

74. In compound $X(n, \alpha) \rightarrow {}_3Li^7$, the element X is-

(A) $_2He^4$ **(B)** $_5B^{10}$
(C) $_5B^9$ **(D)** $_4Be^{11}$

75. A sample of radioactive elements contains 4×10^{10} active nuclei. If half-life of element is 10 day, then the number of decayed nuclei after 30 days is

(A) 0.5×10^{10} **(B)** 2×10^{10}
(C) 3.5×10^{10} **(D)** 1×10^{10}

76. Which of the following are suitable for the fusion process ?

(A) Light nuclei
(B) heavy nuclei
(C) Elements lying in the middle of periodic table
(D) Elements lying in the middle of binding energy curve

77. When a deuterium is bombarded on $_8O^{16}$ nucleus, an a-particle is emitted, then the product nucleus is

(A) $_7N^{13}$ **(B)** $_5B^{10}$
(C) $_4Be^9$ **(D)** $_7N^{14}$

78. The volume occupied by an atom is greater than the volume of the nucleus by factor of about

(A) 10^{10} **(B)** 10^{15}
(C) 10^1 **(D)** 10^5

79. The mass number of a nucleus is

(A) Sometimes equal to its atomic number
(B) sometimes less than and sometimes more than its atomic number
(C) always less than its atomic number
(D) always more than its atomic number

80. The mass of proton is 1.0087 u (u = atomic mass unit) The binding energy of $_2He^4$ is (mass of helium nucleus = 4.0015 u)

(A) 28.4 meV **(B)** 0.061 u
(C) 0.0305 J **(D)** 0.0305 erg

81. Solar energy is mainly caused due to

(A) fusion of protons during synthesis of heavier elements
(B) gravitational contraction
(C) burning of hydrogen in the oxygen
(D) fission of uranium present in the sun

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82. A nuclear reaction given by

$_ZX^A \rightarrow Z+_1Y^A+ _{-1}e^0 + \bar{\nu}$ represents

(A) fusion **(B)** fission
(C) β-decay **(D)** γ-decay

83. A sample of radioactive element has a mass of 10 g at an instant t = 0. The approximate mass of this element in the sample after two mean lives is

(A) 3.70 g **(B)** 6.30 g
(C) 1.35 g **(D)** 2.50 g

84. If in a nuclear fusion process, the masses of the fusing nuclei be m_1 and m_2 and the mass of the resultant nucleus be m_3, then

(A) $m_3 = m_1 + m_2$ **(B)** $m_3 = |m_1 - m_2|$
(C) $m_3 < (m_1 + m_2)$ **(D)** $m_3 > (m_1 + m_2)$

85. The half-life of radium is about 1600 yr. Of 100 g of radium existing now, 25g will remain unchanged after

(A) 4800 yr **(B)** 6400 yr
(C) 2400 yr **(D)** 3200 yr

86. mp denotes the mass of a proton and m_n that of a neutron. A given nucleus of binding energy BE, contains Z protons and N neutrons. The mass m (N, Z) of the nucleus is given by

(A) $m(N,Z) = Nm_n + ZM_p - BEc^2$
(B) $m(N,Z) = Nm_n + Zm_p + BEc^2$
(C) $m(N,Z) = Nm_n + Zm_p - BE/c^2$
(D) $m(N,Z) = Nm_n + ZM_p + BE/c^2$

87. In the reaction $_1^2H + _1^3H \rightarrow _2^4He + _0^1n$ if the binding energies of $_1^2H, _1^3H$ and $_2^4He$ respectively a, b, and c (in MeV), then the energy (in MeV) released in this reaction is

(A) c + a – b **(B)** c – a – b
(C) a + b + c **(D)** a b – c

88. The nuclei of which one of the following pairs of nuclei are isotones

(A) $_{34}Se^{74}, _{31}Ga^{71}$ **(B)** $_{42}Mo^{92}, _{40}Zr^{92}$
(C) $_{38}Sr^{84}, _{38}Sr^{86}$ **(D)** $_{20}Ca^{40}, _{16}S^{32}$

89. Fission of nuclei is possible because the binding energy per nucleon in them

(A) increases with mass number at high mass
(B) decreases with mass number at high mass numbers
(C) increases with mass number at low mass numbers
(D) decreases with mass number at low mass

90. In any fission process the ratio $\frac{\text{mass of fission products}}{\text{mass of parent nucleus}}$ is

(A) less than 1
(B) greater than 1
(C) equal to 1
(D) depends on the mass of parent nucleus

91. The binding energy of deuteron is 2.2 MeV and that of $_2^4He$ is 28 MeV. If two deuterons are fused to form one $_2^4He$ then the energy released is

(A) 25.8 MeV **(B)** 23.6 MeV
(C) 19.2 MeV **(D)** 30.2 MeV

92. In a radioactive materials the activity at time t_1 is R_1 and at a later time t_2. it is R_2. If the decay constant of the material is λ , then

(A) $R_1 = R_2 e^{-\lambda(t_1 - t_2)}$ **(B)** $R_1 = R_2 e^{\lambda(t_1 - t_2)}$
(C) $R_1 = R_2\left(\frac{t_2}{t_1}\right)$ **(D)** $R_1 = R_2$

93. The radius of germanium (Ge) nuclide is measured to be twice the radius of $_4^9Be$. The number of nucleons in Ge are

(A) 73 **(B)** 74
(C) 75 **(D)** 72

94. In radioactive decay process, the negatively charged emitted β-particle are

(A) the electrons present inside the nucleus
(B) the electrons produced as a result of the decay of neutrons inside the nucleus
(C) the electrons produced as a result of collisions between atoms
(D) the electrons orbiting around the nucleus

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95. A nucleus ${}^{A}_{Z}X$ has mass represented by m(A,Z). if m_p and m_n denote the mass of proton and neutron respectively and BE the binding energy (in MeV), then

(A) $BE = [m(A,Z) - Zm_p - (A-Z)m_n]c^2$

(B) $BE = [Zm_p + (A-Z)m_n\ (A,Z)]c^2$

(C) $BE = [Zm_p + Am_n - m(A,Z)]c^2$

(D) $BE = m(A,Z) - Zm_p - (A-Z)m_n$

96. If the nucleus ${}^{27}_{13}Al$ has a nuclear radius of about 3.6 fm, then ${}^{125}_{520}Te$ would have tis radius approximately as

(A) 6.0 fm **(B)** 9.6 fm

(C) 12.0 fm **(D)** 4.8 fm

97. Two radioactive substances A and B have decay constants 5λ and λ respectively. At t = 0 they have the same number of nuclei. The ratio of number of nuclei of A to those of B will be $\left(\frac{1}{e}\right)^2$ after a time interval

(A) $\frac{1}{4\lambda}$ **(B)** 4λ

(C) 2λ **(D)** $\frac{1}{2\lambda}$

98. Two radioactive materials X_1 and X_2 have decay constants 5λ and λ respectively.If initially they have the same number of nuclei, then the ratio of the number of nuclei of X_1 to the of X_2 will be 1/e after a time

(A) λ **(B)** $\frac{1}{2}\lambda$

(C) $\frac{1}{4\lambda}$ **(D)** $\frac{e}{\lambda}$

99. In the nuclear decay given below

${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y \rightarrow {}^{A-4}_{Z-1}B^* \rightarrow {}^{A-4}_{Z-1}B$

the particles emitted in the sequence are

(A) β, α, γ **(B)** γ,β,α

(C) β, γ, α **(D)** α, β, γ

100. The number of beta particles emitted by a radioactive substance is twice the number of alpha particles emitted by it. The resulting daughter is an

(A) isobar of parent **(B)** isomer of parent

(C) isotone of parent **(D)** isotope of parent

101. The activity of a radioactive sample is measured as N_0 counts per minute at t= 0 and N_0/e counts per minute at t = 5 min. The time (in minute) at which the activity reduces to half its value is

(A) $\log_e 2/5$ **(B)** $\frac{5}{\log_e 2}$

(C) $5\log_{10}2$ **(D)** $5\log_e 2$

102. The mass of a ${}^{7}_{3}Li$ nucleus is 0.042u less than the sum of the masses of all its nucleons. The binding energy per nucleon of ${}^{7}_{3}Li$ nucleus is nearly

(A) 46 MeV **(B)** 5.6 MeV

(C) 3.9 MeV **(D)** 23 MeV

103. A nucleus ${}^{m}_{n}X$ emits one α-particle and two β^- particles. The resulting nucleus is

(A) ${}^{m-6}_{n}Z$ **(B)** ${}^{m-4}_{n}Z$

(C) ${}^{m-4}_{n-2}Z$ **(D)** ${}^{m-6}_{n-2}Z$

104. Fusion reactionn takes place at high temperature because

(A) atoms get ionised at high temperature

(B) kinetic energy is high enough to overcome the coulomb repulsion between nuclei

(C) molecules break up at high temperature

(D) nuclei break up at high temperature

105. The half-life of a radioactive isotope X is 50yr. It decays to another element Y which is stable. The elements X and Y were found to be in the ratio of 1 : 15 in a sample of a given rock. The age of the rock was estimated to be

(A) 200 yr **(B)** 250 yr

(C) 100 yr **(D)** 150 yr

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106. A radioactive nucleus of mass M emits a photon of frequency v and the nucleus recoils. The recoil energy will be

(A) $h^2v^2/2Mc^2$ **(B)** zero

(C) hv **(D)** $Mc^2 - hv$

107. A mixture consists of two radioactive materials A_1 and A_2 with half lives of 20s and 10s respectively. Initially the mixture has 40 g of A_1 and 160g of A_2. The amount of the two in the mixture will become equal after

(A) 60s **(B)** 80s

(C) 20s **(D)** 40s

108. A certain mass of hydrogen is changed to helium by the process of fusion. The mass defect in fusion reaction is 0.02866 u. The energy 1 u = 931 MeV

(A) 2.67 MeV **(B)** 126.7 MeV

(C) 6.675 MeV **(D)** 13.35 MeV

109. The half - life of a radioactive isotope X is 20yr. It decays to another element Y which is stable. The two elements X and Y were found to be in the ratio 1 :7 in a sample of a gigven rock. The age of the rock is estimated to be

(A) 40 yr **(B)** 60 yr

(C) 80 yr **(D)** 100 yr

110. A radio isotope X with a half life 1.4×10^9 yr decays of Y which is stable. A sample of the rock from a cave was found to contain X and Y in the ratio 1 : 7. The age of the rock is

(A) 1.96×10^9yr **(B)** 3.92×10^9yr

(C) 4.20×10^9yr **(D)** 8.40×10^9yr

111. The binding energy per nucleon of ^7_3Li and ^4_2He nuclei are 5.60 MeV and 7.06 MeV, respectively . In the nuclear reaction $^7_3Li + ^1_1H \rightarrow ^4_2He + ^4_2H + Q$ the value of energy Q released is

(A) 19.6 MeV **(B)** –2.4 MeV

(C) 8.4 MeV **(D)** 17.3 MeV

112. A nucleus of uranium decays at rest into nuclei of thorium and helium. Then

(A) the helium nucleus has more kinetic energy than the thorium nucleus

(B) the helium nucleus has less momentum than the thorium nucleus

(C) the helium nucleus has more momentum than the thorium nucleus

(D) the helium nucleus has less kinetic energy than the thorium nucleus

113. If radius of the $^{125}_{53}Al$ nucleus is taken to be R_{Al}, then the radius of $^{125}_{53}Te$ nucleus is nearly

(A) s **(B)** s

(C) s **(D)** a

114. The half- life of a radioactive substance is 30 minutes. The time (in minutes) taken between 40% decay and 85% decay of the same radioactive substance

(A) 15 **(B)** 30

(C) 45 **(D)** 60

115. When ar a-particle of mass m moving with velocity v bonbards on a heavy nucleus of charge Ze, its distance of closest approach from the nucleus depends on m as

(A) $\frac{1}{\sqrt{m}}$ **(B)** $\frac{1}{m^2}$

(C) m **(D)** $\frac{1}{m}$

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Exercise # 4 PART - 2 PREVIOUS YEAR (AIIMS)

DUAL NATURE OF RADIATION AND MATTER

1. In a Neon discharge tube 2.9×10^{18} Ne^+ ions move to the right each second, while 1.2×10^{18} electrons move to the left per second, electron charge is 1.6×10^{-19} C. The current in the discharge tube is

(A) 1 A towards right **(B)** 0.66 A towards right

(C) 0.66 A towards left **(D)** 1 eV

2. Mass of the proton is 1840 times that of electron. It is accelerated through a potential difference of 1 V. Find its kinetic energy.

(A) 6 eV **(B)** 2 eV

(C) 10 eV **(D)** 1 eV

3. The work function of a metal is 3.4 eV. If the frequency of incident radiation is increased to twice, then the work function of the metal becomes

(A) 3.4 eV **(B)** 7.2 eV

(C) 6.8 eV **(D)** 1.7 eV

4. The speed of an electron having a wavelength of 10^{-10} m is

(A) 7.25×10^6 m/s **(B)** 5.25×10^6 m/s

(C) 6.26×10^6 m/s **(D)** 4.24×10^6 m/s

5. A proton is about 1840 times heavier than an electron. When it is accelerated by a potential difference of 1 kV, its kinetic energy will be

(A) 1840 keV **(B)** (1/1840) keV

(C) 1 keV **(D)** 920 keV

6. If an electron and a photon propagate in the form of waves having the same wavelength, it implies that they have the same

(A) energy **(B)** momentum

(C) velocity **(D)** angular momentum.

7. In a material medium, when a positron meets an electron both the particles annihilate leading to the emission of two gamma ray photons. This process forms the basis of an important diagnostic procedure called

(A) MRI **(B)** PET

(C) CAT **(D)** SPECT

8. A photon of energy 4 eV is incident on a metal surface whose work function is 2eV. The minimum reverse potential to be applied for stopping the emission of electrons is

(A) 2 V **(B)** 4 V

(C) 6 V **(D)** 8 V

9. We wish to see inside an atom. Assuming the atoms to have a diameter of 100 pm, this means that one must be able to resolve a width of say 10 pm. If an electron microscope is used, the minimum electron energy required is about

(A) 1.5 keV **(B)** 15 keV

(C) 150 keV **(D)** 1.5 MeV

10. In photoelectric effect, the electrons are ejected from metals if the incident light has a certain minimum

(A) wavelength **(B)** frequency

(C) amplitude **(D)** angle of incidence.

11. If alpha, beta and gamma rays carry same momentum, which has the longest wavelength

(A) alpha rays

(B) beta rays

(C) gamma rays

(D) none, all have same wavelength.

12. What is the energy of photon whose wavelength is 6840 Å?

(A) 1.81 eV **(B)** 3.6 eV

(C) –13.6 eV **(D)** 12.1 eV

13. Which of the following is matched wrongly ?

(A) oil drop experiment → Millikan [

(B) dual nature of light → de Brogile

(C) uncertainty principle → Heisenberg

(D) none of these

14. de Broglie wavelength λ associated with neutrons is related with absolute temperature T as

(A) $\lambda \propto T$ **(B)** $\lambda \propto \frac{1}{T}$

(C) $\lambda \propto \frac{1}{\sqrt{T}}$ **(D)** $\lambda \propto T^2$

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15. If the kinetic energy of a particle is increased by 16 times, the percentage change in the de Broglie wavelength of the particle is

(A) 25 % (B) 75%

(C) 60% (D) 50%

16. Whenever a stream of electrons collides with a stream of photons, in this collision, which of the following is not conserved ?

(A) Linear momentum (B) Total energy

(C) No. of photons (D) No. of electrons

17. If K_1 and K_2 are maximum kinetic energies of photoelectrons emitted when lights of wavelengths λ_1 and λ_2 respectively incident on a metallic surface. If $\lambda_1 = 3\lambda_2$, then

(A) $K_1 > (K_2/3)$ (B) $K_1 < (K_2/3)$

(C) $K_1 = 2K_2$ (D) $K_2 = 2K_1$

18. If we assume kinetic energy of a proton is equal to energy of the photon, the ratio of de Broglie wavelength of proton to photon is proportional to

(A) E (B) $E^{-1/2}$

(C) $E^{1/2}$ (D) $E^{3/2}$

19. A photon is incident having frequency 1×10^{14} sec^{-1}. Threshold frequency of metal is 5×10^{13} sec^{-1}. Find the kinetic energy of the ejected electron.

(A) 3.3×10^{-21} J (B) 6.6×10^{-21} J

(C) 3.3×10^{-20} J (D) 6.6×10^{-20} J

20. Calculate the kinetic energy of the electron having wavelength 1 nm.

(A) 2.1 eV (B) 3.1 eV

(C) 1.5 eV (D) 4.2 eV

21. If velocity of a particle is three times of that of electron and ratio of de Broglie wavelength of particle to that of electrons is 1.814×10^{-4}. The particle will be

(A) Neutron (B) Deutron

(C) Alpha (D) Tritium

22. The light of wavelength 4000 Å falls on a photosensitive substance whose work function is 2 eV. Its stopping potential is

(A) 1.1 V (B) 1.8 V

(C) 1.26 V (D) 0.8 V

23. de-Broglie wavelength associated with a ball of mass 1 kg having kinetic energy 0.5 J is

(A) 6.63×10^{-30} m (B) 6.63×10^{-34} m

(C) 1.32×10^{-33} m (D) 1.32×10^{-34} m

24. Photoelectric effect supports quantum nature of light because

(A) there is minimum frequency of light below which no photoelectrons are emitted

(B) the maximum energy of photoelectron depends only on the frequency of light and not on its intensity

(C) photoelectric effect is an instantaneous process

(D) all the above choices are correct

25. Which of the following has the longest de Broglie wavelength if they are moving with the same velocity ?

(A) Neutron (B) Proton

(C) α particle (D) β-particle

ASSERTION AND REASON

26. **Assertion :** On increasing the frequency of light, larger number of photoelectrons are emitted.

Reason : The number of electrons emitted is inversely Proportional to the intensity of incident light.

27. **Assertion :** Photoelectric effect demonstrates the wave nature of light.

Reason : The number of photoelectrons is proportional to the frequency of light.

28. **Assertion :** The energy (e) and momentum (p) of a photon are related by p = E/c.

Reason : The photon behaves like a particle.

29. **Assertion :** The photoelectrons produced by a monochromatic light beam incident on a metal surface, have a spread in their kinetic energies.

Reason : The work function of the metal varies as a function of depth from the surface.

30. **Assertion :** Stopping potential depends upon the frequency of incident light but is independent of the intensity of the light.

Reason : The maximum kinetic energy of the photoelectrons is proportional to stopping potential.

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31. **Assertion :** A photon has no rest mass, yet it carries definite momentum.
Reason : Momentum of photon is due to its energy and hence its equivalent mass.

32. **Assertion :** The de Broglie equation has significance for any microscopic or sub-microscopic particles.
Reason : The de Broglie wavelength is inversely proportional to the mass of the object if velocity is constant.

33. **Assertion :** There is a physical significance of matter waves.
Reason : Both interference and diffraction occurs in it.

34. **Assertion :** An electron microscope is based on de Broglie hypothesis.
Reason : A beam of electrons behaves as a wave which can be converged by electric and magnetic lenses.

35. **Assertion :** When a certain wavelength of light fall on a metal surface it ejects electron.
Reason : Light has wave nature.

ATOMS

36. For an electron in the second orbit of hydrogen, what is the moment of momentum as per the Bohr's model ?
(A) $2\pi h$ **(B)** πh
(C) $\frac{h}{\pi}$ **(D)** $\frac{2h}{\pi}$

37. Characteristic X-rays are produced due to
(A) transfer of momentum in collision of electrons with target atoms
(B) transition of electron from higher to lower electrons orbits in an atom
(C) heating of the target
(D) transfer of energy in collision of electrons with atoms in the target.

38. The ground state energy of hydrogen atom is –13.6 eV. What is the potential energy of the electron in this state?
(A) eV **(B)** –27.2 eV
(C) 1 eV **(D)** 2 eV.

39. Solid targets of different elements are bombarded by highly energetic electron beams. The frequency (f) of the characteristic X-rays emitted from different targets varies with atomic number Z as
(A) $f \propto \sqrt{Z}$ **(B)** $f \propto Z^2$
(C) $f \propto Z$ **(D)** $f \propto Z^{3/2}$

40. The magnetic moment (μ) of a revolving electron around the nucleus varies with principal quantum number n as
(A) $\mu \propto n$ **(B)** $\mu \propto 1/n$
(C) $\mu \propto n^2$ **(D)** $\mu \propto 1/n^2$

41. Hard X-rays for the study of fractures in bones should have a minimum wavelength of 10^{-11} m. The accelerating voltage for electrons in X-ray machine should be
(A) < 124.2 kV
(B) > 124.2 kV
(C) between 60 kV and 70 kV
(D) = 100 kV.

42. What is the energy of He^+ electron in first orbit ?
(A) 40.8 eV **(B)** –27.2 eV
(C) –54.4 eV **(D)** –13.6 eV

43. Co_2 laser uses
(A) microwaves **(B)** infra red
(C) ultra violet **(D)** visible light

44. A laser beam is used for carrying out surgery because, it
(A) is highly monochromatic
(B) is highly coherent
(C) is highly directional
(D) can be sharply focussed with high power.

45. What is ratio of Bohr magneton to the nuclear magneton?
(A) m_p/m_e **(B)** m_p^2 / m_e^2
(C) 1 **(C)** $\frac{m_e}{m_p}$

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46. The wavelengths of Ka X-rays for lead isotopes Pb208, Pb206 and Pb204 are λ_1, λ_2 and λ_3 respectively. Then

(A) $\lambda_2 = \sqrt{\lambda_1\lambda_3}$ **(B)** $\lambda_2 = \lambda_1 + \lambda_3$

(C) $\lambda_2 = \lambda_1\lambda_3$ **(D)** $\lambda_2 = \frac{\lambda_1}{\lambda_3}$

47. What would be maximum wavelength for Brackett series of hydrogen-spectrum ?

(A) 74583 Å **(B)** 22790 Å

(C) 40519 Å **(D)** 18753 Å

48. What would be the radius of second orbit of He^+ ion ?

(A) 1.058 Å **(B)** 3.023 Å

(C) 2.068 Å **(D)** 4.458 Å

49. The wavelength of Lyman series for first number is

(A) $\frac{4\times1.097\times10^7}{3}$m **(B)** $\frac{3}{4\times1.097\times10^7}$m

(C) $\frac{4}{3\times1.097\times10^7}$m **(D)** $\frac{3}{4}\times1.097\times10^7$m

50. The series corresponding to minimum wavelength transition in H-atom

(A) Balmer series **(B)** Lyman series

(C) Paschen series **(D)** Brackett series

51. The minimum magnetic dipole moment of electron in hydrogen atom is

(A) $\frac{eh}{2\pi m}$ **(B)** $\frac{eh}{4\pi m}$

(C) $\frac{eh}{\pi m}$ **(D)** 0

52. Total energy of the electron in hydrogen atom above 0 eV leads to

(A) continuation of energy states.

(B) large number of discrete ionised states.

(C) balmar series.

(D) paschen series.

53. Ratio of longest wavelengths corresponding to Lyman and Balmer series in hydrogen spectrum is

(A) $\frac{7}{29}$ **(B)** $\frac{9}{31}$

(C) $\frac{5}{27}$ **(D)** $\frac{3}{23}$

54. If the wavelength of 1st line of Balmer series of hydrogen is 6561 Å, the wavelength of the 24nd line of series will be

(A) 9780 Å **(B)** 4860 Å

(C) 8857 Å **(D)** 4429 Å

55. A triply ionized beryllium (Be^{3+}) is the same orbital radius as the ground state of hydrogen.

Then the quantum state n of Be^{3+} is

(A) n = 1 **(B)** n = 2

(C) n = 3 **(D)** n = 4

56. Total energy of an electron in hydrogen atoms above 0 eV leads to

(A) ionisation of the atom

(B) accelerate the atom

(C) send the atom in higher excited state

(D) none of these

57. Ionisation potential of hydrogen atom is 13.6 V. Hydrogen atoms in the ground state are excited by monochromatic radiation of photon energy 12.1 eV. The spectral lines emitted by hydrogen atoms according to Bohr's theory will be

(A) one **(B)** two

(C) four **(D)** three

ASSERTION AND REASON

58. **Assertion :** LASER is used to measure distant object as moon.

Reason : They are highly coherent source of light.

59. **Assertion :** A tube light emits white light.

Reason : emission of light in a tube takes place at a very high temperature.

60. **Assertion :** Bohr had to postulate that the electrons in stationary orbits around the nucleus do not radiate.

Reason : According to classical physics all moving electrons radiate.

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61. **Assertion :** In He-Ne laser, population inversion takes place between energy levels of neon atoms.

Reason : Helium atoms have a meta-stable energy level.

62. **Assertion :** Crystalline solids can cause X-rays to diffract.

Reason : Interatomic distance in crystalline solids is of the other of 0.1 nm.

63. **Assertion :** It is not possible to use ^{35}Cl as the fuel for fusion energy.

Reason : The binding energy of ^{35}Cl is too small

64. **Assertion :** In a metal all the free electrons have same energy.

Reason : Electron do not obey Pauli's exclusion principle.

65. **Assertion :** It is essential that all the lines available in the emission spectrum will also be available in the emission spectrum will also be available in the absorption spectrum.

Reason : The spectrum of hydrogen atom is only absorption spectrum.

66. **Assertion :** X-ray astronomy is possible only from satellites orbiting the earth.

Reason : Efficiency of X-rays telescope is large as compared to any other telescope.

67. **Assertion :** Bohr's atomic model cannot be used to explain multiple electron species.

Reason : It does not take inter-electronic interactions in account.

68. **Assertion :** Total energy of electron in an hydrogen atom is negative.

Reason : It is bounded to the nucleus.

69. **Assertion :** Electrons in the atom are held due to coulomb forces.

Reason : The atom is stable only because the centripetal force due to Coulomb's law is balanced by the centrifugal force.

NUCLEI

70. Half life of a substance is 20 minutes. What is the time between 33% decay and 67% decay?

(A) 40 minutes **(B)** 20 minutes

(C) 30 minutes **(D)** 25 minutes

71. A certain radioactive element has a half-life of 20 years. If we have a block with 10 g of the element in it, after how many year will there be just 2.5 g of the element in the block ?

(A) 80 years **(B)** 40 years

(C) 100 years **(D)** 60 years

72. A radioactive substance decays to $1/16^{th}$ of its initial activity in 40 days. The-life of the radioactive substance expressed in day is

(A) 2.5 **(B)** 5

(C) 10 **(D)** 20

73. Nuclear fusion is possible

(A) only between light nuclei

(B) only between heavy nuclei

(C) between both light and heavy nuclei

(D) only between nuclei which are stable against β-decay.

74. Radioactive nuclei that are injected into a patient collect at certain sites within its body, undergoing radioactive decay and emitting electromagnetic radiation. These radiation can then be recorded by a detector. This procedure provides an important diagnostic tool called

(A) gamma camera

(B) CAT scan

(C) radiotracer technique

(D) gamma ray spectroscopy.

75. A nucleus of mass number A, originally at rest, emits an α-particle with speed v. The daughter nucleus recoils with a speed

(A) $\frac{2v}{A+4}$ **(B)** $\frac{4v}{A+4}$

(C) $\frac{4v}{A-4}$ **(D)** $\frac{2v}{A-4}$

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76. When an electron-positron pair annihilates, the energy released is about

(A) 0.8×10^{-13} J **(B)** 1.6×10^{-13} J

(C) 3.2×10^{-13} J **(D)** 4.8×10^{-13} J

77. The Magnetic Resonance Imaging (MRI) is based on the phenomenon of

(A) nuclear magnetic resonance

(B) electron spin resonance

(C) electron paramagnetic resonance

(D) diamagnetism of human tissues

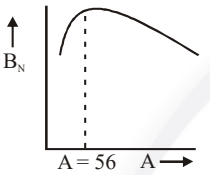
78. Carbon dating is best suited for determining the age of fossils if their age in year is of the order of

(A) 10^3 **(B)** 10^4

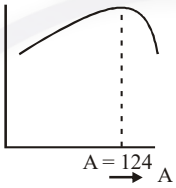
(C) 10 **(D)** 10^6

79. The dependence of binding energy per nucleon, B_N, on the mass number A, is represented by

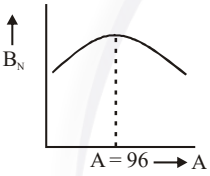
(A)



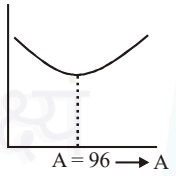
(B)



(C)



(D)



80. A radioactive material has a half-life of 10 days. What fraction of the material would remain after 30 days ?

(A) 0.5 **(B)** 0.25

(C) 0.125 **(D)** 0.33

81. The operation of a nuclear reactor is said to be critical, if the multiplication factor (K) has a value

(A) 1 **(B)** 1.5

(C) 2.1 **(D)** 2.5

82. $^{238}_{92}U$ has 92 protons and 238 nucleons. It decays by emitting an alpha particle and becomes

(A) $^{234}_{92}U$ **(B)** $^{234}_{90}Th$

(C) $^{235}_{92}U$ **(D)** $^{237}_{93}Np$

83. The fossil bone has a $^{14}C : ^{12}C$ ratio, which is [1/16] of that in a living animal bone. If the half-life time of ^{14}C is 5730 years, then the age of the fossil bone is

(A) 11460 years **(B)** 17190 years

(C) 22920 years **(D)** 45840 years.

84. Which one of the following is a possible nuclear reaction ?

(A) $^{10}_{5}B + ^{4}_{2}He \rightarrow ^{13}_{7}N + ^{1}_{1}H$

(B) $^{23}_{11}Na + ^{1}_{1}H \rightarrow ^{20}_{10}Ne + ^{4}_{2}He$

(C) $^{239}_{93}Np \rightarrow ^{239}_{94}Pu + \beta^- + \bar{\nu}$

(D) $^{11}_{7}N + ^{1}_{1}H \rightarrow ^{12}_{6}C + \beta^- + \bar{\nu}$

85. What is the amount of energy released by deuterium and tritum fusion ?

(A) 60.6 eV **(B)** 12.6 eV

(D) 17.6 eV **(D)** 28.3 eV

86. Calculate power output of $^{235}_{92}U$ reactor, if it takes 30 days to use up 2 kg of fuel, and if each fission gives 185 MeV of useable energy. Avogadro's number = 6×10^{23}/mol ?

(A) 56.3 MW **(B)** 60.3 MW

(C) 58.3 MW **(D)** 54.3 MW

87. N_1 atoms of a radioactive element emit N_2 beta particles per second. The decay constant of the element is (in s^{-1})

(C) $N_1(1n\,2)$ **(D)** $N_2(1n\,2)$

88. A nucleus of mass number 220 decays by α decay. The energy released in the reaction is 5 MeV. The kinetic energy of an a- particle is

(A) $\frac{1}{54}$MeV **(B)** $\frac{27}{11}$MeV

(C) $\frac{54}{11}$MeV **(D)** $\frac{55}{54}$MeV

89. If the half lives of a radioactive element for α and β decay are 4 years and 12 years respectively, the ratio of its inital activity and that after 12 year will be

(A) 6.25% **(B)** 12.5%

(C) 25% **(D)** 50%

90. A radioactive nucleus is being produced at a constant

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rate α per second. Its decay constant is λ If N_0 are the number of nuclei at time t = 0, then the maximum number of nuclei possible are

(A) $N_0 + \frac{\alpha}{\lambda}$ (B) N_0

(C) $\frac{\lambda}{\alpha} + N_0$ (D) $\frac{\alpha}{\lambda}$

91. Two radioactive substances A and B have decay constants 5λ and λ respectively. At t = 0, they have the same number of nuclei. The ratio of number of nuclei of A to those of B will be (i/e^2) after a time

(A) 4λ (B) 2λ

(C) $\frac{1}{2\lambda}$ (D) $\frac{1}{4\lambda}$

92. The intensity of gamma radiation from a given source is I. On passing through 36 mm of lead, it is reduced to I/8. the thickness of lead which will reduce the intensity to I/2 will be

(A) 18 mm (B) 12 mm

(C) 6 mm (D) 9 mm

93. The ratio of the masses of the elements having their nuclear radii 2 fermi and 1 fermi is

(A) 8 (B) 2

(C) 3 (D) 4

94. For a nuclear reactor to run in critical condition the reproduction factor k should be

(A) = 1 (B) > 1

(C) < 1 (D) >>>1

95. Half life of a radioactive material is 5 years, then the percentage of it remained after 25 year will be

(A) 3.125 % (B) 6.25 %

(C) 1.25 % (D) 25%

96. Among the following which is used to control the rate of reaction in nuclear fission reactions ?

(A) Water (B) Heavy water

(C) Cadmium (D) Graphite

97. S^{32} absorbs energy and decays into which element after two α-emission ?

(A) Carbon (B) Aluminium

(C) Oxygen (D) Magnesium

98. Half life of a radio-active element is 8 years, how much amount will be present after 32 years ?

(A) $\frac{1}{4}$ (B) $\frac{1}{8}$]

(C) $\frac{1}{16}$ (D) $\frac{1}{32}$

99. Gamma decay takes place

(A) prior to alpha decay.

(B) prior to beta decay.

(C) prior to positron decay.

(D) due to de-excitment of nuclear levels.

100. The nucleus ${}^{m}_{n}X$ emits one α particle and 2β-particles. The resulting nucleus is

(A) ${}^{m-4}_{n-2}Y$ (B) ${}^{m-6}_{n-4}Z$

(C) ${}^{m-6}_{n}Z$ (D) ${}^{m-4}_{n}X$

101. In nuclear fission, which of the following quantity is conserved ?

(A) Energy

(B) Mass

(C) Momentum

(D) Both energy and mass.

102. When a slow neutron is captured by a ${}^{235}_{92}U$ nucleus, a fission energy releasing 200 MeV. If power of nuclear reactor is 100 W then rate of nuclear fission is

(A) $3.6 \times 10^6\ s^{-1}$ (B) $3.1 \times 10^{12}\ s^{-1}$

(C) $1.8 \times 10^4\ s^{-1}$ (D) $4.1 \times 10^6\ s^{-1}$

103. Which of the following statement is incorrect ?

(A) Neutron is less stable than proton

(B) Neutron can cause fission is nuclear reactors but proton can not.

(C) A free proton can emit beta particle.

(D) A bound proton can emit beta particle.

104. In beta plus decay

(A) antineutrino is produced with electron

(B) neutrino is produced with positron

(C) neutron is produced with electron

(D) none of these

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105. n-alpha particles per second are emitted from N atoms of a radioactive element. The half-life of the radioactive element is

(A) $\frac{n}{N}s$ (B) $\frac{N}{n}s$

(C) $\frac{0.693N}{n}s$ (D) $\frac{0.693n}{N}s$

106. The half-life of radium is 1600 years. What is the fraction of sample undecayed after 6400 years ?

(A) $\frac{1}{16}$ (B) $\frac{1}{4}$

(C) $\frac{1}{8}$ (D) $\frac{1}{24}$

107. An atom of mass number 15 and atomic number 7 captures an α-particle and then emits a proton. The mass number and atomic number of the resulting atom will be respectively

(A) 14 and 2 (B) 15 and 3

(C) 16 and 4 (D) 18 and 8

ASSERTION AND REASON

108. **Assertion :** Radioactive nuclei emit β-particles.

Reason : Electrons exist inside the nucleus.

109. **Assertion :** A beam of charged particles is employed in the treatment of cancer.

Reason : Charged particles on passing through a material medium lose their energy by causing ionization of the atoms along their path.

110. **Assertion :** Neutrons penetrate matter more readily as compared to protons.

Reason : Neutrons are slightly more massive than proton.

111. **Assertion :** Heavy water preferred over ordinary water as a moderator in reactors.

Reason : Heavy water, used for slowing down the neutrons, has lesser absorption probability of neutrons than ordinary water.

112. **Assertion :** the binding energy per nucleon, for nuclei with atomic mass number A > 100 decreases with A.

Reason : The nuclear forces are weak for heavier nuclei.

113. **Assertion :** Magnetic Resonance Imaging (MRI) is a useful diagnostic tool for producing images of various parts of human body.

Reason : Protons of various tissues of human body play a role in MRI.

114. **Assertion :** Cobalt-60 is useful in cancer therapy.

Reason : Cobalt-60 is a source of γ-radiations capable of killing cancerous cells.

115. **Assertion :** ^{90}Sr from the radioactive fall out from a nuclear bomb ends up in the bones of human beings through the milk consumed by them. It causes impairment of the production of red blood cells.

Reason : The energetic β-particles emitted in the decay of ^{90}Sr damage the bone marrow.

116. **Assertion :** Heavy water is a better moderator than normal water.

Reason : Heavy water absorbs neutrons more efficiently than normal water.

117. **Assertion :** X-rays can penetrate through the flesh but not through the bones.

Reason : The penetrating power of X-rays depends on voltage.

118. **Assertion :** Nuclei having mass number about 60 are most stable.

Reason : When two or more light nuclei are combined into a heavier nucleus, then the binding energy per nucleon will increase.

119. **Assertion :** For nuclear reactor, it is desirable to have K = 1.

Reason : Sustained chain reaction occur at this critical condition.

120. **Assertion :** Mass defect in nuclear reactions is less than 1%.

Reason : In nuclear reaction, change in BE/N is generally less than 1%.

121. **Assertion :** It is very easy to detect neutrino in nature.

Reason : It has high affinity to interact with matter.

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122. **Assertion :** It is desirable to slow down fast moving neutrons to sustain controlled chain reactions.

Reason : Slow moving neutrons efficiently collides with U^{235}.

123. **Assertion :** At rest, radium is decayed into Radon and an α-particle. They both moves back to back of each other.

Reason : Splitting of radioactive particle is based on conservation of liner momentum.

124. **Assertion :** More energy is released in fusion than fission.

Reason : More number of nucleons take part in fission.

125. **Assertion :** γ-radiation emission occurs after α and β decay.

Reason : Energy level occur in nucleus.

126. **Assertion :** $^{60}_{27}Co$ is a source of gamma radiation.

Reason : Gamma emission is due to nuclear decay.

127. **Assertion :** The ratio for time taken for light emission from an atom to that for release of nuclear energy in fission is 1 : 100.

Reason : Time taken for the light emission from an atom is of the order of 10^{-8} s.

128. **Assertion :** g-radiation emission occurs after a and b-decay.

Reason : Energy levels occur in nucleus. **[2014]**

129. **Assertion :** if a heavy nucleus is split into tow medium sized parts, each of the nuclei will have more binding energy per nucleon than the original nucleus.

Reason : Joining two light nuclei together to give a single nucleus of medium size means more binding energy per nucleon than the two nucleus. **[2015]**

130. **Assertion :** Generally heavy nuclei are unstable.

Reason : it has more neutrons and protons. **[2016]**

131. **Assertion :** Heavy water is used as moderator in nuclear reactor.

Reason : Water cools down the fast neutron. **[2016]**

132. **Assertion :** Unlike electric forces and gravitational forces, nuclear force has limited range.

Reason : Nuclear force do not obey inverse square law. **[2016]**

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MOCK TEST

STRAIGHT OBJECTIVE TYPE

1. In an α-decay the Kinetic energy of α particle is 48 MeV and Q-value of the reaction is 50 MeV. The mass number of the mother nucleus is:- (Assume that daughter nucleus is in ground state)

(A) 96 **(B)** 100 **(C)** 104 **(D)** none of these

2. The angular momentum of an electron in first orbit of Li^{++} ion is :

(A) $\frac{3h}{2\pi}$ **(B)** $\frac{9h}{2\pi}$ **(C)** $\frac{h}{2\pi}$ **(D)** $\frac{h}{6\pi}$

3. If first excitation potential of a hydrogen like atom is V electron volt, then the ionization energy of this atom will be:

(A) V electron volt **(B)** $\frac{3V}{4}$ electron volt

(C) $\frac{4V}{3}$ electron volt **(D)** cannot be calculated by given information.

4. All electrons ejected from a surface by incident light of wavelength 200 nm can be stopped before travelling 1 m in the direction of uniform electric field of 4 N/C. The work function of the surface is:

(A) 4 eV **(B)** 6.2 eV **(C)** 2 eV **(D)** 2.2 eV

5. An electron of mass 'm', when accelerated through a potential V has de–Broglie wavelength λ. The de–Broglie wavelength associated with a proton of mass M accelerated through the same potential difference will be:

(A) $\lambda\sqrt{\frac{M}{m}}$ **(B)** $\lambda\sqrt{\frac{m}{M}}$ **(C)** $\lambda\left(\frac{M}{m}\right)$ **(D)** $\lambda\left(\frac{m}{M}\right)$

6. Two hydrogen atoms are in excited state with electrons residing in n = 2. First one is moving towards left and emits a photon of energy E_1 towards right. Second one is moving towards right with same speed and emits a photon of energy E_2 towards right. Taking recoil of nucleus into account during emission process

(A) $E_1 > E_2$ **(B)** $E_1 < E_2$ **(C)** $E_1 = E_2$ **(D)** information insufficient

7. In a hydrogen atom following the Bohr's postulates the product of linear momentum and angular momentum is proportional to $(n)^x$ where 'n' is the orbit number. Then 'x' is :

(A) 0 **(B)** 2 **(C)** –2 **(D)** 1

8. The voltage applied to an X-ray tube is 18 kV. The maximum mass of photon emitted by the X-ray tube will be:

(A) 2×10^{-13} kg **(B)** 3.2×10^{-36} kg **(C)** 3.2×10^{-32} kg **(D)** 9.1×10^{-31} kg

9. The wavelengths of K_α x-rays of two metals 'A' and 'B' are $\frac{4}{1875\ R}$ and $\frac{1}{675\ R}$ respectively, where 'R' is Rydberg's constant. The number of elements lying between 'A' and 'B' according to their atomic numbers is

(A) 3 **(B)** 6 **(C)** 5 **(D)** 4

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10. One of the lines in the emission spectrum of Li^{2+} has the same wavelength as that of the 2nd line of Balmer series in hydrogen spectrum. The electronic transition corresponding to this line is :

(A) $n = 4 \rightarrow n = 2$ **(B)** $n = 8 \rightarrow n = 2$ **(C)** $n = 8 \rightarrow n = 4$ **(D)** $n = 12 \rightarrow n = 6$

11. If the short wavelength limit of the continuous spectrum coming out of a coolidge tube is 10 Å, then the debroglie wavelength of the electrons reaching the target metal in the coolidge tube is approximately :

(A) 0.3 Å **(B)** 3 Å **(C)** 30 Å **(D)** 10 Å

12. The photon radiated from hydrogen corresponding to 2nd line of Lyman series is absorbed by a hydrogen like atom 'X' in 2nd excited state. As a result the hydrogen like atom 'X' makes a transition to nth orbit. Then,

(A) $X = He^{+}, n = 4$ **(B)** $X = Li^{++}, n = 6$ **(C)** $X = He^{+}, n = 6$ **(D)** $X = Li^{++}, n = 9$

13. In a photoelectric experiment, with light of wavelength λ, the fastest electron has speed v. If the exciting wavelength is changed to $\frac{3\lambda}{4}$, the speed of the fastest emitted electron will become

(A) $v\sqrt{\frac{3}{4}}$ **(B)** $v\sqrt{\frac{4}{3}}$ **(C)** less than $v\sqrt{\frac{3}{4}}$ **(D)** greater than $v\sqrt{\frac{4}{3}}$

14. 1.5 MW of 400 nm light is directed at a photoelectric cell. If 0.10% of the incident photons produce photoelectrons, the current in the cell is

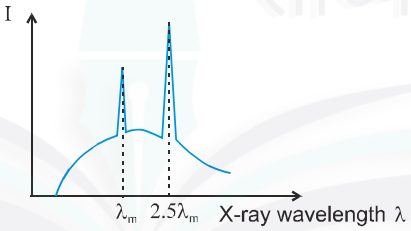
(A) 0.36 μA **(B)** 0.48 μA **(C)** 0.42 mA **(D)** 0.32 mA

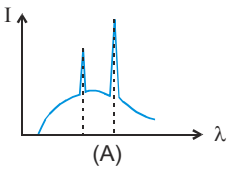
15. The element which has a k_α x-rays line of wavelength 1.8 Å is

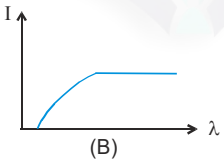
$(R = 1.1 \times 10^7\ m^{-1}, b = 1$ and $\sqrt{5/33} = 0.39)$

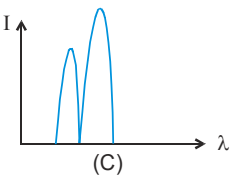
(A) Co, Z = 27 **(B)** Iron, Z = 26 **(C)** Mn, z = 25 **(D)** Ni, z = 28

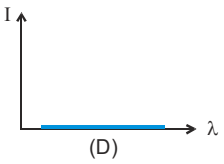
16. When an electron accelerated by potential difference U is bombarded on a specific metal, the emitted X-ray spectrum obtained is shown in adjoining graph. If the potential difference is reduced to U/3, the correct spectrum is



(A)


(B)


(C)


(D)


17. In the hydrogen atom, an electron makes a transition from n = 2 to n = 1. The magnetic field produced by the circulating electron at the nucleus

(A) decreases 16 times **(B)** increases 4 times **(C)** decreases 4 times **(D)** increases 32 times

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18. An electron in a hydrogen atom makes a transition from first excited state to ground state. The equivalent current due to circulating electron

(A) increases 2 times **(B)** increases 4 times **(C)** increases 8 times **(D)** remains the same

19. A free neutron decays to a proton but a free proton does not decay to a neutron. This is because

(A) neutron is a composite particle made of a proton and an electron whereas proton is fundamental particle

(B) neutron is an uncharged particle whereas proton is a charged particle

(C) neutron has larger rest mass than the proton

(D) weak forces can operate in a neutron but not in a proton.

20.

$$A \xrightarrow{\lambda_1} B \xrightarrow{\lambda_2} C$$

$t = 0$	N_0	0	0
t	N_1	N_2	N_3

In the above radioactive decay C is stable nucleus. Then:

(A) rate of decay of A will first increase and then decrease

(B) number of nuclei of B will first increase and then decrease

(C) if $\lambda_2 > \lambda_1$, then activity of B will always be higher than activity of A

(D) if $\lambda_1 >> \lambda_2$, then number of nucleus of C will always be less than number of nucleus of B.

21. Two identical samples (same material and same amount initially) P and Q of a radioactive substance having mean life T are observed to have activities A_P & A_Q respectively at the time of observation. If P is older than Q, then the difference in their ages is:

(A) $T\,\ell n\left(\frac{A_P}{A_Q}\right)$ **(B)** $T\,\ell n\left(\frac{A_Q}{A_P}\right)$ **(C)** $\frac{1}{T}\,\ell n\left(\frac{A_P}{A_Q}\right)$ **(D)** $T\left(\frac{A_P}{A_Q}\right)$

22. Radio isotope $^{234}Ra_{88}$ decays by a series emission of three β-particles and two α-particles. The end product X is

(A) $^{220}X_{88}$ **(B)** $^{226}X_{87}$ **(C)** $^{234}X_{90}$ **(D)** $^{216}X_{88}$

23. N atoms of a radioactive element emit n alpha particles per second at an instant. Then the half - life of the element is:

(A) $\frac{n}{N}$ sec. **(B)** $1.44\,\frac{n}{N}$ sec. **(C)** $0.69\,\frac{n}{N}$ sec. **(D)** $0.69\,\frac{N}{n}$ sec.

24. Masses of two isobars $^{64}_{29}Cu$ and $^{64}_{30}Zn$ are 63.9298 u and 63.9292 u respectively. It can be concluded from these data that :

(A) Both the isobars are stable

(B) ^{64}Zn is radioactive, decaying to ^{64}Cu through β-decay

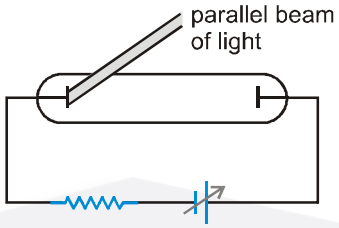
(C) ^{64}Cu is radioactive, decaying to ^{64}Zn through γ-decay

(D) ^{64}Cu is radioactive, decaying to ^{64}Zn through β-decay

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MATRIX - MATCH TYPE

25. In the shown experimental setup to study photoelectric effect, two conducting electrodes arc enclosed in an evacuated glass-tube as shown. A parallel beam of monochromatic light, falls on photosensitive electrodes. The emf of battery shown is high enough such that all photoelectrons ejected from left electrode will reach the right electrode. Under initial conditions photoelectrons are emitted. As changes are made in each situation of column I; Match the statements in column I with results in column II.



Column I	Column II
(A) If frequency of incident light is increased keeping number of photons per second constant	**(P)** magnitude of stopping potential will increase
(B) If frequency of incident light is increased and number of photons per second is decreased.	**(Q)** current through circuit may stop
(C) If work function of photo sensitive electrode is increased	**(R)** maximum kinetic energy of ejected photoelectrons will increase
(D) If number of photons per second of incident light is increased keeping its frequency constant	**(S)** saturation current will increase **(T)** saturation current will decrease

26. Four physical quantities are listed in column I. Their values are listed in Column II in a random order.

Column I	Column II
(A) Thermal energy of air molecules at room temperature	**(E)** 0.04 eV
(B) Binding energy of heavy nuclei per nucleon	**(F)** 2 eV
(C) X–ray photon energy	**(G)** 1 KeV
(D) Photon energy of visible light	**(H)** 7 MeV

The correct matching of columns I & II is given by :

(A) A – E, B – H, C – G, D – F

(B) A – E, B – G, C – F, D – H

(C) A – F, B – E, C – G, D – H

(D) A – F, B – H, C – E, D – G

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ASSERTION AND REASON TYPE

These questions contains, Statement 1 (assertion) and Statement II (reason).

(A) Statement-1 is True, Statement-2 is True; Statement-2 **is** a correct explanation for Statement-1

(B) Statement-1 is True, Statement-2 is True; Statement-2 **is NOT** a correct explanation for Statement-1

(C) Statement-1 is True, Statement-2 is False

(D) Statement-1 is False, Statement-2 is True.

27. **Assertion :** Though light of a single frequency (monochromatic light) is incident on a metal, the energies of emitted photoelectrons are different.

Reason : The energy of electrons just after they absorb photons incident on metal surface may be lost in collision with other atoms in the metal before the electron is ejected out of the metal.

28. **Assertion :** The de-Broglie wavelength of a molecule (in a sample of ideal gas) varies inversely as the square root of absolute temperature.

Reason : The rms velocity of a molecule (in a sample of ideal gas) depends on temperature.

29. **Assertion :** ${}_{Z}X^{A}$ undergoes 2 α decays, 2β decays (negative β) and 2 γ decays. As a result the daughter product is ${}_{Z-2}Y^{A-8}$.

Reason : In α decay the mass number decreases by 4 unit and atomic number decreases by 2 unit. In β decay (negative β) the mass number remains unchanged and atomic number increases by 1 unit. In γ decay, mass number and atomic number remains unchanged.

30. **Assertion :** In spontaneous fission, the energy is always released.

Reason : Spontaneous fission occurs to lower the binding energy of reactant nuclei.

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ANSWER KEY

EXERCISE - 1

1. A	2. D	3. A	4. D	5. C	6. B	7. B	8. C	9. A	10. D	11. B	12. B	13. B		
14. C	15. C	16. C	17. C	18. B	19. C	20. B	21. C	22. C	23. C	24. D	25. D	26. C		
27. D	28. B	29. D	30. B	31. B	32. B	33. D	34. B	35. D	36. A	37. D	38. B	39. C		
40. B	41. C	42. B	43. D	44. B	45. D	46. C	47. C	48. B	49. C	50. B	51. B	52. C		
53. A	54. A	55. A	56. B	57. A	58. A	59. D	60. A	61. D	62. D	63. C	64. A	65. A		
66. B	67. D	68. B	69. B	70. A	71. B	72. B	73. B	74. C	75. A	76. A	77. B	78. A		
79. A	80. C	81. D	82. C	83. B	84. A	85. A	86. A	87. A	88. C	89. D	90. C	91. C		
92. C	93. A	94. A	95. D	96. B	97. A	98. B	99. C	100.C	101. C	102.B	103.C	104.C		
105.B	106.C	107.B	108.C	109.D	110.A	111.B	112.C	113.C	114.D	115.D	116.D	117.D		
118.B	119.B	120.C	121.A	122.B	123.D	124.C	125.C	126.C	127.C	128.C	129.D	130.C		
131.B	132.D	133.A	134.B	135.C	136.B	137.C	138.C	139.A	140.A	141.A	142.A	143.D		
144.C	145.A	146.C	147.C	148.D	149.C	150.C	151.B	152.C	153.C	154.C	155.A	156.C		
157.A	158.C	159.B	160.A											

EXERCISE - 2

1. C	2. B	3. A	4. B	5. A	6. D	7. B	8. B	9. B	10. A	11. D	12. C	13. D
14. C	15. B	16. B	17. C	18. B	19. C	20. D	21. A	22. C	23. D	24. A	25. B	26. C
27. A	28. A	29. B	30. C	31. A	32. A	33. D	34. D	35. B	36. A	37. A	38. D	39. D
40. B	41. C	42. D	43. D	44. C	45. B	46. B	47. D	48. B	49. D	50. D	51. D	52. B
53. A	54. D	55. C	56. C	57. D	58. A	59. D	60. C	61. D	62. D	63. A	64. D	65. D
66. A	67. D	68. B	69. B	70. A	71. D	72. D	73. C	74. B	75. B	76. A	77. D	78. D
79. D	80. C	81. D	82. C	83. D	84. A	85. C	86. B	87. A	88. A	89. B	90. A	91. C
92. A	93. D	94. C										

EXERCISE - 3 : PART # 1

1. $A \rightarrow R$; $B \rightarrow Q,S$; $C \rightarrow P$; $D \rightarrow Q,S$
2. $A \rightarrow R$; $B \rightarrow S$; $C \rightarrow P$; $D \rightarrow Q$
3. $A \rightarrow P,R$; $B \rightarrow Q,S$; $C \rightarrow Q,S$ $D \rightarrow P,R$
4. $A \rightarrow Q,R,S$; $B \rightarrow Q,R,S$; $C \rightarrow Q,R,S$; $D \rightarrow P,Q,R,S$
5. $A \rightarrow P,Q,R,S$; $B \rightarrow P,Q,R,S$; $C \rightarrow P,Q,R,S$; $D \rightarrow P,Q,R,S$

PART # 2

1. D	2. A	3. D	4. D	5. D

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EXERCISE - 4 : PART # 1

1. B **2.** B **3.** C **4.** D **5.** B **6.** B **7.** B **8.** D **9.** C **10.** D **11.** B **12.** B **13.** D
14. A **15.** A **16.** D **17.** C **18.** A **19.** B **20.** B **21.** C **22.** A **23.** B **24.** C **25.** A **26.** A
27. C **28.** A **29.** C **30.** B **31.** B **32.** C **33.** A **34.** B **35.** B **36.** B **37.** D **38.** A **39.** C
40. D **41.** B **42.** A **43.** B **44.** B **45.** A **46.** D **47.** D **48.** B **49.** A **50.** C **51.** B **52.** D
53. A **54.** C **55.** A **56.** D **57.** A **58.** C **59.** B **60.** D **61.** D **62.** C **63.** C **64.** B **65.** B
66. B **67.** A **68.** D **69.** A **70.** C **71.** B **72.** D **73.** B **74.** B **75.** C **76.** A **77.** D **78.** B
79. A **80.** A **81.** A **82.** C **83.** C **84.** C **85.** D **86.** C **87.** B **88.** A **89.** B **90.** A **91.** B
92. A **93.** D **94.** B **95.** B **96.** A **97.** D **98.** C **99.** A **100.** D **101.** D **102.** B **103.** B **104.** B
105. A **106.** A **107.** D **108.** C **109.** B **110.** C **111.** D **112.** A **113.** B **114.** D **115.** D

PART # 2

1. B **2.** D **3.** A **4.** A **5.** C **6.** B **7.** B **8.** A **9.** B **10.** B **11.** D **12.** A **13.** D
14. C **15.** B **16.** C **17.** B **18.** C **19.** C **20.** C **21.** A **22.** A **23.** B **24.** D **25.** D **26.** D
27. D **28.** A **29.** C **30.** B **31.** A **32.** A **33.** A **34.** A **35.** B **36.** C **37.** B **38.** B **39.** B
40. A **41.** B **42.** C **43.** C **44.** D **45.** A **46.** A **47.** C **48.** A **49.** A **50.** B **51.** B **52.** A
53. C **54.** B **55.** B **56.** A **57.** D **58.** A **59.** D **60.** B **61.** A **62.** A **63.** C **64.** C **65.** D
66. C **67.** B **68.** A **69.** C **70.** B **71.** B **72.** C **73.** A **74.** C **75.** C **76.** B **77.** A **78.** B
79. A **80.** C **81.** A **82.** B **83.** C **84.** C **85.** C **86.** C **87.** B **88.** C **89.** A **90.** D **91.** C
92. B **93.** A **94.** A **95.** A **96.** C **97.** D **98.** C **99.** D **100.** D **101.** D **102.** B **103.** C **104.** B
105. C **106.** A **107.** D **108.** C **109.** B **110.** B **111.** A **112.** B **113.** A **114.** A **115.** A **116.** C **117.** B
118. B **119.** A **120.** A **121.** D **122.** C **123.** A **124.** B **125.** A **126.** C **127.** A **128.** A **129.** B **130.** B
131. C **132.** B

MOCK TEST

1 B **2.** C **3.** C **4.** D **5.** B **6.** B **7.** A **8.** C **9.** D **10.** D **11.** A **12.** D **13.** D
14. B **15.** A **16.** B **17.** D **18.** C **19.** C **20.** B **21.** B **22.** B **23.** D **24.** D
25. A $\rightarrow$ p,r ; B $\rightarrow$ p,r,t ; C $\rightarrow$ q ; D $\rightarrow$ s **26.** A **27.** A **28.** B **29.** A **30.** C

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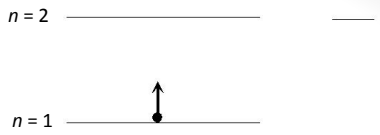
HINTS & SOLUTIONS

EXERCISE - 1
NEET LEVEL

1. (A) For $n=1$, maximum number of states $= 2n^2 = 2$ and for $n=2, 3, 4$, maximum number of states would be 8, 18, 32 respectively, Hence number of possible elements $= 2+8+18+32 = 60$.

2. (D) Bohr radius $r = \frac{\varepsilon_0 n^2 h^2}{\pi Z m e^2}$; $\therefore r \propto n^2$

3. (A)



$E_{1\to 2} = -3.4 - (13.6) = +10.2\, eV$

4. (D) $\frac{1}{\lambda} = RZ^2\left(\frac{1}{1^2} - \frac{1}{2^2}\right)$

For di-ionised lithium the value of Z is maximum.

5. (C) Lyman series lies in the UV region.

6. (B) The size of the atom is of the order of $1\text{Å} = 10^{-10} m$.

7. (B) Balmer series lies in the visible region.

8. (C) Transition A ($n=\infty$ to 1) : Series limit of Lyman series
Transition B ($n=5$ to $n=2$) : Third spectral line of Balmer series
Transition C ($n = 5$ to $n = 3$) : Second spectral line of Paschen series

9. (A) D is excitation of electron from 2^{nd} orbit corresponding to absorption line in Balmer series and E is the energy released to bring the electron from ∞ to ground state *i.e.* ionisation potential.

10. (D)

11. (B) Paschen series lies in the infrared region.

12. (B) Energy required to knock out the electron in the n^{th} orbit $= +\frac{13.6}{n^2} eV \Rightarrow E_3 = +\frac{13.6}{9} eV$.

13. (B) Linear momentum $= mv = 9.1\times10^{-31}\times 2.2\times10^{6}$
$= 2.0\times10^{-24}\, kg-m/s$

14. (C) $r \propto n^2 \Rightarrow r_n = n^2 a_0$ $(\because r_1 = a_0)$

15. (C) For the ionization of second *He* electron. He^+ will act as hydrogen like atom.
Hence ionization potential
$= Z^2 \times 13.6\, volt = (2)^2 \times 13.6 = 54.4\, V$

16. (C) Energy required $= \frac{13.6}{n^2} = \frac{13.6}{10^2} = 0.136\, eV$

17. (C) $\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] \Rightarrow \frac{1}{n_1^2} - \frac{1}{n_2^2} = \frac{1}{R\lambda}$

$= \frac{1}{1.097\times10^7 \times 18752\times10^{-10}} = 0.0486 = \frac{7}{144}$. But

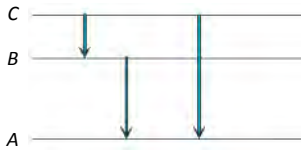
$\frac{1}{3^2} - \frac{1}{4^2} = \frac{7}{144} \Rightarrow n_1 = 3$ and $n_2 = 4$ (Paschen series)

18. (B) Potential energy of electron in n^{th} orbit of radius r in H-atom $U = -\frac{e^2}{r}$ (in CGS)

$\because$ K.E. $= \frac{1}{2}|P.E.| \Rightarrow K = \frac{e^2}{2r}$

19. (C) Final energy of electron $= -13.6 + 12.1 = -1.51\, eV$. which is corresponds to third level *i.e.* $n=3$. Hence number of spectral lines emitted
$= \frac{n(n-1)}{2} = \frac{3(3-1)}{2} = 3$

20. (B) Let the energy in A, B and C state be E_A, E_B and E_C, then from the figure



$(E_C - E_B) + (E_B - E_A) = (E_C - E_A)$ or $\frac{hc}{\lambda_1} + \frac{hc}{\lambda_2} = \frac{hc}{\lambda_3}$

$\Rightarrow \lambda_3 = \frac{\lambda_1\lambda_2}{\lambda_1 + \lambda_2}$

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21. (C) According to Bohr's second postulate.

22. (C) First excited state *i.e.* second orbit ($n = 2$)

Second excited state *i.e.* third orbit ($n = 3$)

$$\because E = -\frac{13.6}{n^2} \Rightarrow \frac{E_2}{E_3} = \left(\frac{3}{2}\right)^2 = \frac{9}{4}$$

23. (C) $\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{4^2}\right) = \frac{3R}{16} \Rightarrow \lambda = \frac{16}{3R} = \frac{16}{3} \times 10^{-5} cm$

Frequency $n = \frac{c}{\lambda} = \frac{3 \times 10^{10}}{\frac{16}{3} \times 10^{-5}} = \frac{9}{16} \times 10^{15} Hz$

24. (D) Energy required to remove electron in the $n = 2$ state $= +\frac{13.6}{(2)^2} = +3.4\ eV$

25. (D) $(E_{ion})_{Na} = Z^2 (E_{ion})_H = (11)^2 13.6\ eV$

26. (C) The wavelength of spectral line in Balmer series is given by $\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n^2}\right]$

For first line of Balmer series, $n = 3$

$$\Rightarrow \frac{1}{\lambda_1} = R\left[\frac{1}{2^2} - \frac{1}{3^2}\right] = \frac{5R}{36}; \quad \text{For second line } n = 4.$$

$$\Rightarrow \frac{1}{\lambda_2} = R\left[\frac{1}{2^2} - \frac{1}{4^2}\right] = \frac{3R}{16}$$

$$\therefore \frac{\lambda_2}{\lambda_1} = \frac{20}{27} \Rightarrow \lambda_1 = \frac{20}{27} \times 6561 = 4860\ \text{Å}$$

27. (D) $2E - E = \frac{hc}{\lambda} \Rightarrow E = \frac{hc}{\lambda}$

$$\frac{4E}{3} - E = \frac{hc}{\lambda'} \Rightarrow \frac{E}{3} = \frac{hc}{\lambda'} \quad \therefore \frac{\lambda'}{\lambda} = 3 \Rightarrow \lambda' = 3\lambda$$

28. (B) Because atom is hollow and whole mass of atom is concentrated in a small centre called nucleus.

29. (D) $r = \frac{\varepsilon_0 n^2 h^2}{\pi Z m e^2}; \ \therefore r \propto \frac{n^2}{Z}$

30. (B) $r \propto n^2 \Rightarrow \frac{r_{(n=2)}}{r_{(n=3)}} = \frac{4}{9} \Rightarrow r_{(n=3)} = \frac{9}{4} R = 2.25 R$

31. (B) Electric field $= \frac{V}{d} = \frac{250}{2.5 \times 10^{-2}} = 10000\ V/m$.

32. (B)

33. (D) In Millikan's experiment, drops of non-volatile liquid (cloak oil) are used to prevent evaporation.

34. (B) $E = eV = 2e \times 5 = 10\ eV$

35. (D) $E = eV = 1.6 \times 10^{-19} \times 10^5 = 1.6 \times 10^{-14} J$

36. (A) Any charge in the universe is given by

$q = ne \Rightarrow e = \frac{q}{n}$ (where n is an integer)

$q_1 : q_2 : q_3 : q_4 : q_5 : q_6 :: n_1 : n_2 : n_3 : n_4 : n_5 : n_6$

$6.563 : 8.204 : 11.5 : 13.13 : 16.48 : 18.09$

$:: n_1 : n_2 : n_3 : n_4 : n_5 : n_6$

Divide by 6.563

$1 : 1.25 : 1.75 : 2.0 : 2.5 : 2.75$

Multiplied by 4

$4 : 5 : 7 : 8 : 10 : 11 :: n_1 : n_2 : n_3 : n_4 : n_5 : n_6$

$$e = \frac{q_1 + q_2 + q_3 + q_4 + q_5 + q_6}{n_1 + n_2 + n_3 + n_4 + n_5 + n_6} = \frac{73.967 \times 10^{-19}}{45}$$

$$= 1.641 \times 10^{-19} C$$

Note : If you take 45.0743 in place of 45, you will get the exact value

37. (D) Because magnetic force always points perpendicular to the particle velocity. That is why velocity remains unchanged thereby keeping energy $\left(\frac{1}{2}mv^2\right)$ and momentum (mv) unchanged.

38. (B)

39. (C) Mass is basically a constant term for any physical application at low velocity. But in accordance with Einstein's theory of relativity, at higher speeds the mass of the particle change according to formula

$$m = \frac{m_0}{\sqrt{1 - (v^2/c^2)}}$$

40. (B) Refer Q.No. 9. Here the velocity of electron increases, so as per Einstein's equation mass of the electron increases, hence the specific charge $\frac{e}{m}$ decreases.

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41. (C) If the voltage given is V, then the energy of electron

$$\frac{1}{2}mv^2 = eV \Rightarrow v = \sqrt{\frac{2eV}{m}}$$

$$= \sqrt{\frac{2\times1.6\times10^{-19}\times1000}{9.1\times10^{-31}}} = 1.875\times10^7 \approx 1.9\times10^7 \text{ m/s}$$

42. (B)

43. (D) Momentum $p = mv$ and $v = \sqrt{\frac{2QV}{m}}$

$$\Rightarrow p = \sqrt{2QmV} \Rightarrow p \propto \sqrt{Qm} \Rightarrow \frac{p_e}{p_\alpha} = \sqrt{\frac{e\times m_e}{2e\times m_\alpha}} = \sqrt{\frac{m_e}{2m_\alpha}}$$

44. (B) In an electric field, a force opposite to the direction of electric field acts on negatively charged particles (*i.e.* from lower potential to higher potential).

45. (D)

46. (C) $QE = mg \Rightarrow Q = \frac{mg}{E} \Rightarrow n = \frac{mgd}{Ve}$

$$\Rightarrow n = \frac{1.8\times10^{-14}\times10\times0.9\times10^{-2}}{2\times10^3\times1.6\times10^{-19}} = 5$$

47. (C)

48. (B) In Millikan's experiment, the charges present on the oil drops are the integral multiples, so $2e$ and $10e(1.6\times10^{-18}\text{C})$ charges are present.

49. (C) $eE = evB \Rightarrow v = \frac{E}{B} = \frac{3\times10^4}{2\times10^{-3}} = 1.5\times10^7 \text{ m/s}$

50. (B) **51. (B)**

52. (C) According to de-Broglie hypothesis.

53. (A) $\lambda = \frac{h}{p} = \frac{h}{mv}$

54. (A) $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mE}}$: $\therefore E = \frac{h^2}{2m\lambda^2}$

λ is same for all, so $E \propto \frac{1}{m}$. Hence energy will be maximum for particle with lesser mass.

55. (A) Particle is photon and it travels with the velocity equal to light in vacuum.

56. (B) $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}}$; $\therefore \lambda \propto \frac{1}{\sqrt{E}}$ (h and m = constant)

57. (A) $\lambda = \frac{h}{m_1v_1} = \frac{h}{m_2v_2}$; $\therefore \frac{v_1}{v_2} = \frac{m_2}{m_1} = \frac{4}{1}$

58. (A) $\frac{1}{2}mv^2 = E \Rightarrow mv = \sqrt{2mE}$; $\therefore \lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mE}}$

59. (D) $\left.\begin{matrix}\text{Photoelectric effect} \rightarrow \text{Particle nature}\\ \text{Diffraction} \rightarrow \text{Wave nature}\end{matrix}\right\}$ Dual nature

60. (A) $mvr = \frac{nh}{2\pi}$ According to Bohr's theory

$$\Rightarrow 2\pi r = n\left(\frac{h}{mv}\right) = n\lambda \quad \text{for } n = 1,\ \lambda = 2\pi r$$

61. (D) $p = \frac{h\nu}{c} \Rightarrow \nu = \frac{pc}{h} = \frac{3.3\times10^{-29}\times3\times10^8}{6.6\times10^{-34}}$

$$= 1.5\times10^{13} Hz$$

62. (D)

63. (C) $p = \frac{E}{c} \Rightarrow E = p\times c = 2\times10^{-16}\times(3\times10^{10})$

$$= 6\times10^{-6} erg.$$

64. (A)

65. (A) $p = \frac{h}{\lambda} = \frac{6.6\times10^{-34}}{(5000\times10^{-10})} = 1.3\times10^{-27} kg\text{-}m/s$

66. (B) $p = \frac{E}{c} = \frac{h\nu}{c}$

67. (D) $E = h\nu = mc^2 \Rightarrow m = \frac{h\nu}{c^2}$

68. (B) $p = \frac{E}{c} = \frac{h\nu}{c} \Rightarrow \nu = \frac{pc}{h}$

69. (B) $P = \frac{W}{t} = \frac{nhc}{\lambda t} \Rightarrow \left(\frac{n}{t}\right) = \frac{P\lambda}{hc}$

$$= \frac{10\times10^3\times300}{6.6\times10^{-34}\times3\times10^8} = 1.5\times10^{31}$$

70. (A) Momentum of photon $p = \frac{E}{c}$

Velocity of photon $c = \frac{E}{p}$

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71. (B) By using $E(eV)=\frac{12375}{\lambda(\text{Å})}$

$\Rightarrow \lambda=\frac{12375}{2.48}=4989.9\,\text{Å}\approx 5000\,\text{Å}$

72. (B) $E=\frac{hc}{\lambda}=\frac{3\times10^{8}\times6.62\times10^{-34}}{0.21\times1.6\times10^{-19}}=5.9\times10^{-6}\,eV$

73. (B) Momentum of photon

$p=\frac{h}{\lambda}=\frac{6.6\times10^{-34}}{10^{-10}}=6.6\times10^{-24}\,kg\text{ - }m/sec.$

74. (C) $E\propto\frac{1}{\lambda}\Rightarrow\frac{2.5}{E'}=\frac{1}{5000}\Rightarrow E'=(2.5)\times5000\,eV$

75. (A) $E=h\nu=6.6\times10^{-34}\times10^{15}=6.6\times10^{-19}\,J$

76. (A) Since $h\nu=mc^2$, hence $p=mc=\frac{h\nu}{c}=\frac{h}{\lambda}$

77. (B) $E=h\nu\Rightarrow\nu=\frac{E}{h}=\frac{1\times10^{6}\times1.6\times10^{-19}}{6.6\times10^{-34}}$

$=2.4\times10^{20}\,Hz$

78. (A) $p=\frac{h\nu}{c}=\frac{6.6\times10^{-34}\times1.5\times10^{13}}{3\times10^{8}}$

$=3.3\times10^{-29}\,kg\text{-}m/sec$

79. (A) $E=\frac{hc}{\lambda}=\frac{6.62\times10^{-34}\times3\times10^{8}}{450\times10^{-9}}=4.4\times10^{-19}\,J$

80. (C) $E=h\nu\Rightarrow\nu=\frac{E}{h}=\frac{66\times1.6\times10^{-19}}{6.6\times10^{-34}}=16\times10^{15}\,Hz$

81. (D) $E\propto\frac{1}{\lambda}$; also $\lambda_{infrared}>\lambda_{visible}$ so $E_{infrared}<E_{visible}$

82. (C) Energy of photon $E=\frac{hc}{\lambda}\,(Joules)=\frac{hc}{e\lambda}(eV)$

$\Rightarrow E_{(eV)}=\frac{6.6\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}\times\lambda(\text{Å})}=\frac{12375}{\lambda(\text{Å})}$

$\Rightarrow E(keV)=\frac{12.37}{\lambda(\text{Å})}\approx\frac{12.4}{\lambda}$

83. (B) $E=h\nu\Rightarrow100\times1.6\times10^{-19}=6.6\times10^{-34}\times\nu$

$\Rightarrow\nu=2.42\times10^{16}\,Hz$

84. (A) $p=\frac{h}{\lambda}=\frac{6.6\times10^{-34}}{4400\times10^{-10}}=1.5\times10^{-27}\,kg.m/s$

and mass $m=\frac{p}{c}=\frac{1.5\times10^{-27}}{3\times10^{8}}=5\times10^{-36}\,kg$

85. (A) **86. (A)**

87. (A) $E=\frac{hc}{\lambda}\Rightarrow\lambda=\frac{hc}{E}$

88. (C)

89. (D) $E(eV)=\frac{h\nu}{e}=\frac{6.0\times10^{-34}\times10^{12}\times10^{6}}{1.6\times10^{-19}}$

$=4.14\times10^{3}\,eV$

90. (C) $E=nh\nu\Rightarrow\nu\propto\frac{1}{n}\Rightarrow\frac{n_1}{n_2}=\frac{\gamma_2}{\gamma_1}$

91. (C) $\lambda_{min}=\frac{12375}{50\times10^{3}}\,Å=0.247=0.25\,Å.$

92. (C) *X*-rays are electromagnetic waves of wavelength ranging from 0.1 to 100Å.

93. (A) Penetrating power is greater for lower wavelength.

94. (A)

95. (D) From the formula

$V=\frac{12375}{\lambda_{min}}=\frac{12375}{0.3094}=39.99\;kV\approx40\,kV$

96. (B) Refer to the application of *X*-rays.

97. (A) **98. (B)** **99. (C)**

100.(C) The voltage applied across the X-ray tube is of the range of $10\,kV-80\,kV$.

101.(C)

102.(B) In *X*-ray tube, target must be heavy element with high melting point.

103.(C) $\nu\propto(Z-b)^2\Rightarrow\nu=a(Z-b)^2$

Z = atomic number of element (a, b are constant).

104.(C)

105.(B) *X*-rays and gamma rays are electromagnetic waves.

106.(C) Since $\lambda_{min}=\frac{12375}{V}Å=\frac{12375}{10^{5}}Å=0.123\,Å$

$E_{max}=\frac{hc}{\lambda_{min}};$

On putting the values. $E_{max}\cong10^{-1}\,MeV.$

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107.(B) $\lambda_{min} = \frac{hc}{eV}$. where h, c and e are constants. Hence

$\lambda_{min} \propto \frac{1}{V}$

108.(C) Range of X-rays is $0.1\mathring{A}$ to $100\ \mathring{A}$.

109.(D) The production of X-rays is an atomic property whereas the production of γ-rays is a nuclear property.

110.(A) $\lambda_{min} = \frac{12375}{40,000} = 0.30\mathring{A}$ Hence wavelength less than $0.30\ \mathring{A}$ is not possible.

111. (B)

112.(C) Neutrons are neutral particles.

113.(C) James Chadwick discovered the neutron.

114.(D) In hydrogen, atomic number and mass number are equal.

115.(D) $E = mc^2 = 1\times(3\times10^8)^2 = 9\times10^{16} \approx 10^{17}\,J$

116.(D) $B.E. = \Delta m\ amu = \Delta m \times 931\ MeV.$

117.(D) Mass defect $\Delta m = \frac{2.23}{931} = 0.0024.$

118.(B) Positron is the antiparticle of electron.

119.(B) **120.(C)**

121. **(A)** B.E.$=\Delta mc^2$

$= [2(1.0087+1.0073) - 4.0015] = 28.4\ MeV$

122. **(B)** $\frac{\text{Binding energy}}{\text{Nucleon}} = \frac{0.0303\times931}{4} \approx 7$

123. **(D)** Energy / day $= 200\times10^6\times24\times3600$

$= 2\times2.4\times3.6\times10^{12} = 1728\times10^{10}\,J$

124. **(C)** $E = \Delta mc^2 = 10^{-6}\times(3\times10^8)^2 = 9\times10^{10}\,J$

125. **(C)**

126. **(C)** Mass of ${}_1H^2 = 2.01478$ *a.m.u.*

Mass of ${}_2He^4 = 4.00388$ *a.m.u.*

Mass of two deuterium $= 2\times2.01478 = 4.02956$

Energy equivalent to ${}_2{}_1H^2$

$= 4.02956\times1.112\ MeV = 4.48\ MeV$

Energy equivalent to ${}_2H^4$

$= 4.00388\times7.047\ MeV = 28.21\ MeV$

Energy released $= 28.21 - 4.48 = 23.73\ MeV = 24\ MeV$

127. (C) Energy released while forming a nucleus is known as binding energy (by definition).

128.(C) Nuclear force is stronger than coulomb force.

129. (D) **130. (C)**

131. (B) $Q = 4\,(x_2 - x_1)$

132. (D)

133. (A) Rest energy of an electron $= m_ec^2$

Here $m_e = 9.1\times10^{-31}kg$ and c = velocity of light

$\therefore$ Rest energy $= 9.1\times10^{-31}\times(3\times10^8)^2\ joule$

$= \frac{9.1\times10^{-31}\times(3\times10^8)^2}{1.6\times10^{-19}}\ eV = 510\ keV$

134. (B) ${}_zX^A = {}_{88}Ra^{226}$

Number of protons $= Z = 88$

Number of neutrons $= A - Z = 226 - 88 = 138$.

135.(C) Out side the Nucleus, neutron is unstable (life $\approx$ 932 *sec*).

136.(B) The order of magnitude of mass and volume of uranium nucleus will be

$m \simeq A(1.67\times10^{-27}\,kg)$ (A is atomic number)

$V = \frac{4}{3}\pi r^3 \simeq \frac{4}{3}\pi\,[(1.25\times10^{-15}m)A^{1/3}]^3$

$\simeq (8.2\times10^{-45}m^3)A$

Hence, $\rho = \frac{m}{V} = \frac{A(1.67\times10^{-27}kg)}{(8.2\times10^{-45}m^3)A}$

$\simeq 2.0\times10^{17}\,kg/m^3$.

137. (C) We have $r \propto A^{1/3} \Rightarrow \frac{r_2}{r_1} = \left(\frac{A_2}{A_1}\right)^{1/3} = \left(\frac{206}{4}\right)^{1/3}$

$\therefore r_2 = 3\left(\frac{206}{4}\right)^{1/3} = 11.6\ Fermi$.

138.(C) Nucleus does not contains electron.

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139.(A) Let the percentage of B^{10} atoms be x, then Average atomic weight

$$= \frac{10x + 11(100 - x)}{100} = 10.81 \Rightarrow x = 19 \quad \therefore \frac{N_{B^{10}}}{N_{B^{11}}} = \frac{19}{81}$$

140. (A) **141. (A)**

142. (A) By formula $N = N_0\left(\frac{1}{2}\right)^{t/T}$ or $10^4 = 8 \times 10^4\left(\frac{1}{2}\right)^{t/3}$

or $\left(\frac{1}{8}\right) = \left(\frac{1}{2}\right)^{t/3}$ or $\left(\frac{1}{2}\right)^3 = \left(\frac{1}{2}\right)^{t/3} \Rightarrow 3 = \frac{t}{3}$

Hence $t = 9$ *years*.

143. (D) Fraction $= \frac{N}{N_0} = \left(\frac{1}{2}\right)^{\frac{6400}{1600}} = \left(\frac{1}{2}\right)^4 = \frac{1}{16}$

144. (C) Negative β – decay is expressed by the equation

$$n = p^+ + e^- + \nu^-$$

145. (A) No radioactive substance emit both α and β particles simultaneously. Some substances emit α – particles and some other emits β-particles. γ-rays are emitted along with both α and β-particles.

146. (C) γ-rays are highly penetrating.

147. (C) Average life $\frac{1}{\lambda} = \frac{1600}{0.693} = 2308 \approx 2319$ years.

148. (D) Fraction of atoms remains after five half lives

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^{t/T} = \left(\frac{1}{2}\right)^{5T/T} = \frac{1}{32}$$

$\Rightarrow$ Percentage atom remains $= \frac{1}{32} \times 100 = 3.125\%$

149. (C) β-rays emitted from nucleus and they carry negative charge.

150. (C)

151. (B) ${}_ZX^A \xrightarrow{-1\beta^0} {}_{Z+1}Y^A \xrightarrow{2He^4(\alpha)}$

${}_{Z-1}K^{A-4} \xrightarrow{0\gamma^0} {}_{Z-1}K^{A-4}$

152. (C) $N_t = N_0\left(\frac{1}{2}\right)^{t/T} = 50000\left(\frac{1}{2}\right)^{10/5} = 12500$

153. (C) ${}_ZX^A \xrightarrow{-1\beta^0} {}_{Z+1}X^A$

154. (C) $N = N_0\left(\frac{1}{2}\right)^{t/T} \Rightarrow \frac{N_0}{64} = N_0\left(\frac{1}{2}\right)^{30/T}$

$$\Rightarrow T = \frac{30}{6} = 5\,\text{sec}$$

155. (A) **156. (C)**

157. (A) Average life

$$T = \frac{\text{Sum of all lives of all the atom}}{\text{Total number of atoms}} = \frac{1}{\lambda}$$

$\Rightarrow T\lambda = 1$

158. (C) Fraction remains after n half lives

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^{t/T}$$

$$\therefore \quad \frac{N}{N_0} = \left(\frac{1}{2}\right)^{\frac{T/2}{T}} = \left(\frac{1}{2}\right)^{1/2} = \frac{1}{\sqrt{2}}$$

159. (B)

160. (A) Penetration power of γ is 100 times of β, while that of β is 100 times of α.

EXERCISE - 2
AIIMS LEVEL

1. (C)

2. (B) Emission of photo electron is independent of external factor. It depends only on the nature of the material and wavelength of incident light

3. **(A)** The number of photo electron depends on the number of photons

$$\text{Number of photon} = \frac{I}{hc/\lambda} = \frac{\lambda \cdot I}{hc} \propto \lambda$$

$$\text{Ratio of no. of photo electrons} = \frac{\lambda_A}{\lambda_B}$$

4. **(B)** $\frac{hC}{\lambda} = \phi + eV$ ....(i)

$$\frac{hC}{2\lambda} = \phi + \frac{eV}{3} \quad \text{....(ii)}$$

$3 \cdot II - I$

$$\Rightarrow \left(\frac{3}{2} - 1\right)\frac{hc}{\lambda} = 2\phi \Rightarrow \phi = \frac{hc}{4\lambda} \qquad \therefore \lambda_{th} = 4\lambda$$

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5. **(A)**

6. **(D)** Frequency of light does not change with medium.

7. **(B)** Stopping potential = maximum kinetic energy of e = 4V.

8. **(B)**

9. **(B)** $C = \lambda \cdot \nu = \frac{h}{p} \cdot \frac{E}{h} = \frac{E}{p}$

10. **(A)** **11.** **(D)**

12. **(C)** $\lambda = \frac{h}{p}$

Since the momenta of the two particles are equal, λ are same.

13. **(D)** $r = a_0 \frac{n^2}{Z} = a_0 \cdot \frac{2^2}{4} = a_0$

14. **(C)** K.E. of neutron $E = \frac{3}{2}kT$

$$\lambda_d = \frac{h}{p} = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2m \times \frac{3}{2}kT}}$$

$$\Rightarrow \quad \lambda_2 = \lambda \sqrt{\frac{(927+273)}{27+273}} = 2\lambda.$$

15. **(B)** $E_n(Li^{2+}) = E_1(H) \Rightarrow -13.6 \frac{3^2}{n^2} = -13.6 \times \frac{1}{1} \Rightarrow n = 3$

16. **(B)** **17.** **(C)** **18.** **(B)**

19. **(C)** Since speed reduces to half , KE reduced to

$\frac{1}{4}$ th $\Rightarrow$ $n = 2 \Rightarrow mvr = \frac{nh}{2\pi}$

$mv_0 r = 1.\frac{h}{2\pi}$ I

$m\frac{v_0}{2} r` = 2 \cdot \frac{h}{2\pi}$ II

I and II

$r' = 4.r$

20. **(D)**

21. **(A)** $12.1 = E(n=3) - E(n=1)$

$10.2 = E(n=2) - E(n=1)$

$1.9 = E(n=3) - E(n=2)$

At least two atoms must be enveloped as there connot be two transition from same level from same atom.

22. **(C)**

23. **(D)** 12.1 eV radiation will excite a hydrogen atom in ground state to n = 3

state number of possible transition $= {}^nC_2 = {}^3C_2 = 3.$

24. **(A)** $\frac{1}{\lambda_1} = R\left(\frac{1}{4} - \frac{1}{9}\right) \Rightarrow \lambda_1 = \frac{4 \times 9}{5R}$

similarly $\frac{1}{\lambda_2} = R\left(\frac{1}{4} - \frac{1}{4^2}\right)$

$\Rightarrow \lambda_2 = \frac{16}{3R} = \frac{16}{3} \times \frac{5\lambda}{4 \times 9} = \frac{20}{27}\lambda$

26. **(C)** $E = 13.6\left(\frac{Z^2}{n^2}\right) \Delta E_H = \frac{13.6(1)^2}{(1)^2} - \frac{13.6(1)^2}{(2)^2}$

$= 10.2\ eV = h\nu$

$\Delta E_{Li} = \frac{13.6(3)^2}{(1)^2} - \frac{13.6(3)^2}{(2)^2} = 91.80\ eV = h(9\nu)$

27. **(A)** The contineous x-ray comes out because the striking electron loser its kinetic energy

28. **(A)** 10 eV electron cannot excite a hydrogen atom Hence collision is elastic.

29. **(B)** **30.** **(C)**

31. **(A)** $\xleftarrow{\ominus} \longrightarrow E$

32. **(A)** The energy of x–ray is more that of U.V. light. Hence, the K.E. of emitted photoelectron is more and hence stopping potential required is also more.

33. **(D)**

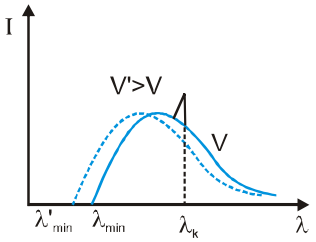
34. **(D)** $\frac{K}{\lambda_1} = E_\infty - E_1 \Rightarrow \frac{K}{\lambda_2} = E_\infty - E_2$

$\frac{K}{\lambda_3} = E_2 - E_3 \Rightarrow \frac{1}{\lambda_1} - \frac{1}{\lambda_2} = \frac{1}{\lambda_3}$

35. **(B)** **36.** **(A)**

37. **(A)** By increasing the operating voltage, l_k does not change but l_{min} decreases

Hence, $\lambda_k - \lambda_{min}$



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38. (D)

39. (D) $hf = 13.6(Z-1)^2 . \left(1-\frac{1}{4}\right) = 13.6 \times \frac{3}{4}(31-1)^2$

$hf' = 13.6 \times \frac{3}{4}(51-1)^2 \Rightarrow \frac{f'}{f} = \frac{50^2}{30^2} \Rightarrow f' = \frac{25}{9}.f$

40. (B)

41. (C) $P = P_- + P_+$

$= 200 \times (6.25 \times 10^{18} + 3.125 \times 10^{18}) \times 1.6 \times 10^{-19}\,W = 300\,W.$

42. (D)

43. (D) $\frac{1}{\lambda} = R(Z-1)^2 \times \left(1-\frac{1}{4}\right)$

$\Rightarrow \frac{1875R}{4} = R(Z_1-1)^2 \frac{3}{4}$

$\Rightarrow Z_1 = 26$

and $675\,R = R(Z_2-2)^2 . \frac{3}{4} \Rightarrow Z_2 = 31$

Hence number of elements = 4

44. (C)

45. (B) Number of photons emitted per second.

$N = \frac{\eta}{100} \times \frac{P\lambda}{hc}$

Potential of the sphere after time t is

$V' = V - \frac{(Ne)t}{4\pi\varepsilon_0 R} = V - \frac{\eta P \lambda e t}{400\pi\varepsilon_0 Rhc}$

46. (B)

47. (D) When the source is 3 times farther, number of photons falling on the surface becomes $\frac{1}{9}$ th but the frequency remains same. Hence stopping potential will be same i.e. 0.6V and saturation current become $\frac{1}{9} \times 18$ mA = 2mA,

48. (B)

49. (D) Some of the energy of photon will be absorbed by the electron. Hence, energy of the photon will reduce correspendingly wavelength will increase and frequency decreases.

50. (D)

51. (D) As the distance of the source doubles, the photons falling on the photon cell becomes $\frac{1}{4}$ th. Hence, number of photoelectrons will also become $\frac{1}{4}$ th.

52. (B) The threshold frequency for Al must be greater as it has higher work function.

53. (A) **54. (D)**

55. (C) Stopping potential depends on the K.E. of emitted electron. The K.E. of emitted electron depends on the frequency of the photon, not on the intensity of the photon.

56. (C) $E_n = 13.6 \frac{Z^2}{n^2}$

$\Delta E_H = \frac{13.6(1)^2}{(1)^2} - \frac{13.6(1)^2}{(2)^2} = 10.2eV$

$\Delta E_{He} = \frac{13.6(2)^2}{(1)^2} - \frac{13.6(2)^2}{(2)^2} = 40.8\,eV$

57. (D) **58. (A)**

59. (D) In photoelectric experiment, speed of fastest emitted electron is given by –

$\frac{1}{2}mv^2_{max} = \frac{hc}{\lambda} - w$

Case- I : $\frac{1}{2}mv^2 = \frac{hc}{\lambda} - w$ .....(i)

Case- II : $\frac{1}{2}mv'^2 = \frac{hc}{3\lambda/4} - w$

$\frac{1}{2}mv'^2 = \frac{4hc}{3\lambda} - w$ .....(ii)

From eqn. (i) & (ii)

$v'^2 = \frac{4}{3}v^2 + \frac{w}{3}$ Hence, $v' > v\sqrt{\frac{4}{3}}$.

60. (C) The maximum kinetic energy avaiable for transition to potential energy/excitation energy is :

$\frac{1}{2} . \frac{m_\alpha m_H}{m_\alpha + m_H} . (v_{rel})^2$

$= \frac{4m, m_H}{5m} . (v_\alpha + v_H)^2 = \frac{2m}{5} . (v_\alpha^2 + v_H^2 + 2v_\alpha v_H)$

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$$= \frac{2m}{5}\left[\frac{2.E_\alpha}{4m}+\frac{2E_4}{m}+2.\sqrt{\frac{2E.\alpha}{4m}.\frac{2E_H}{m}}\right]$$

$$= \frac{2}{5}\left[\frac{2.1}{2}+2\times8.4+2\times\sqrt{2.1\times8.4}\right] = 10.5\text{ eV} > 10.2\text{ eV}$$

Hence, inelastic collision is possible.

61. (D) Have speeds varying from zero up to a certain maximum value

62. (D)

63. (A) Radius of $Os^{189} = r_0\ A_{Os}^{1/3}$

$O_s^{189} = r_0\ A_{Os}^{1/3}$

Radius of that nucleus $= \frac{1}{3}\times r_0\left(A_{O_s}\right)^{\frac{1}{3}}$

$= r_0\left(\frac{189}{27}\right)^{\frac{1}{3}} = r_0\ 7^{1/3}$

$\therefore$ A for that nucleus $= 7 \Rightarrow A = 7$

64. (D)

65. (F) The binding energy per nucleon in a nucleus varies in a way that depends on the actual value of A.

66. (A) The energy of the reaction $Li^7 + p \longrightarrow 2\ He^4$ is (the binding energy per nucleon in Li^7 and He^4

$Q = (2BE_{He} - BE_{Li})$

$= (2\times7.06\times4 - 5.60\times7)$ Mev $=$ **17.28 Mev.**

67. (D) **68. (B)**

69. (B) $^4_2He + {}^{14}_7N \rightarrow {}^{17}_8O + {}^1_1H$

70. (A)

71. (D) Energy of γ photon

= Difference in energies of α particles = 0.4 MeV

72. (D) No. of nucleus of P, $N_P = \frac{m}{10}\times N_A$

No. of nucleus of Q, $N_Q = \frac{m}{20}\times N_A$

No. of Isotope P after 20 days, $N_P' = \frac{N_P}{4}$

Let no. of Isotope Q after 20 days be N_Q'

$N_Q' = 2\times N_P' = \frac{N_P}{2} = NQ$

Thus no change in number of Q. Hence its half life is infinity.

73. (C) $T_{avg.} = \frac{1}{\lambda} \Rightarrow T_{1/2} = \frac{\ln 2}{\lambda} < T_{avg.}$

74. (B)

75. (B) $\frac{dN_2}{dt} = \lambda N_1 - 2\lambda N_2$

for N_2 to be maximum, N_2

$\frac{dN_2}{dt} = 0 \Rightarrow \lambda N_1 = 2\lambda N_2$ or $\frac{N_1}{N_2} = 2$

76. (A)

77. (D) $_{92}U^{235} + n \longrightarrow {}_{54}Xe^{139} + {}_{38}Y^{94} + 3n$

78. (D) **79. (D)** **80. (C)**

81. (D) No. of nuclear spliting per second is

$$N = \frac{100MW}{200MeV} = \frac{100}{200\times1.6\times10^{-19}}\ S^{-1}$$

$$\text{No. of neutrons Liberated} = \frac{100}{200}\times\frac{1}{1.6\times10^{-19}}\times2.5\ S^{-1}$$

$$= \frac{125}{16}\times1018\ S^{-1}$$

82. (C)

83. (D) Fusion reaction is possible at high temperature because kinetic energy is high enough to overcome repulsion between nuclei.

84. (A)

85. (C) Energy released $= [(80\times7)+(120\times8)]-[200\times6.5]$

$= 220$ MeV **Ans.**

86. (B)

87. (A) $R = R_0\ A^{1/3}$

$\ln\frac{R}{R_0} = \frac{1}{3}\ln A$

It is similar to $y = mx$.

88. (A) $R = \frac{mv}{2B} \Rightarrow R_P = \frac{m_P v}{eb} \Rightarrow R_{235_U} = \frac{m_{235_U}.v}{eB}$

$\Delta x = 2\times\frac{3M_P v}{2B} = 6\times10\text{ mm} =$ **60 mm.**

89. (B) $A = A_{0l}\ e^{-\lambda t}$

$\ell n\ A = \ell n\ A_0 - \lambda t$

ℓn A versus t is a linearly decreasing graph with slope depending to λ. As λ does not change, slope remains same.

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90. (A)

91. (C) Initial activity $= \left|\frac{dN}{dt}\right| = \lambda N_0 = \lambda . \frac{m}{M} . NA$

92. (A) 93. (D) 94. (C)

EXERCISE - 3
P-1 (Matrix Match)

1. A → R ; B → Q,S; C → P; D → Q,S

2. A → R ; B → S ; C → P ; D →Q

Saturation photo current is directly proportional to intensity.

$K_{max} = h\upsilon - \phi$

Stopping voltage is independent of intensity.

3. A→ P,R ; B→ Q,S ; C→ Q,S D → P,R

(A) Frequency of orbiting electron $v_n \propto \frac{z^2}{n^3}$

$f = \frac{v}{2\pi r}$.

(B) angular momentum of orbiting electron $L = \frac{nh}{2\pi}$.

(C) Magnetic moment of orbiting electron ∝ n.

$M = i \times \pi R^2 = \frac{e}{T} \pi R^2$

(D) Average current due to orbiting of electron

$i \propto \frac{z^2}{n^3}$.

4. A → Q,R,S; B → Q,R,S; C → Q,R,S; D → P,Q,R,S

5. A→P,Q,R,S; B →P,Q,R,S; C→P,Q,R,S; D→P,Q,R,S

(A) Energy is released in all the four processes. Hence mass will decrease

(B) Since energy is released, Binding energy per nucleon will increase.

(C) Mass number conserves in all the processes.

(D) Total charge also conserves in all the processes

EXERCISE - 3
P-2 (Assertion & Reason)

1. (D)

2. (A) Striking two photons simultaneously the same electron is rare.

3. (D) Any $2e^-$ may make same number of collision and may have same kinetic energy as they come out the metal.

4. (D) As electron jumps from n = 2 to n = 1, angular momentum (nh/2π) does not remain conserved. Hence statement-1 is false.

5. (D)

EXERCISE - 4
P-1 (NEET/AIPMT)

1. (B) In 1905, Einstein realized that the photoelectric effect could be understood if the energy in light is not spread out over wavefronts but is concentrated in small packets, or photons. Each photon of light of frequency ν has the energy hν. Thus, Einstein's work on photoelectric effect gives support to E = hν.

2. (B) If energy E is expressed in (eV) and wavelength λ (in Å), then energy of photon,

$$E = \frac{hc}{\lambda} = \frac{12375}{\lambda(Å)} eV$$

$$\therefore \quad \lambda = \frac{12375}{E(eV)} Å \qquad [\because hc = 12375 \text{ eV-Å}]$$

$$= \frac{12375}{3(eV)} Å = 4125 Å$$

$$= 412.5 \text{ m}$$

Note :

Energy of photon is $E = \frac{hc}{\lambda(Å)} = \frac{12375}{\lambda(Å)} eV$

Here, hc = 12375 eV-Å comes from the following procedure

hc = (Planck's constant) (velocity of light)

$$= \frac{(6.6 \times 10^{-34} J - s(3 \times 10^8 m/s)}{(1.6 \times 10^{-19} J/eV)}$$

$$= 12.375 \times 10^{-7} \text{ eV-m}$$

$$= 12375 \text{ eV-Å}$$

3. (C) Intensity of light source is given by

$$I \propto \frac{1}{d^2}$$

where, d is the distance of ligth source from the cell.

So, for two different situations for intensities,

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or $\frac{I_1}{I_2} = \left(\frac{d_2}{d_1}\right)^2 = \left(\frac{1}{2}\right)^2 = \frac{1}{4}$

or $I_2 = 4\,I_1$

As number of photoelectrons emitted is directly proportion to intensity, so number of photoelectron emitted will become 4 times, i.e. 4 n.

4. **(D)** de-Broglie wavelength is given by

$$\lambda = \frac{h}{mv}$$

For same velocity, $\lambda \propto \frac{1}{m}$

Out of the given particles, the mass of β-particle which is a fast moving electron, is minimum. Thus, de-Broglie wavelength is maximum for β-particle.

5. **(B)** Cathode rays are negatively charged particles called as electrons

(A) Cathode rays possess very high kinetic energy due to their high velocity. When these highly energetic rays fall on platinum (a metal), their kinetic energy is converted to heat energy.

(B) Outside the discharge tube, if an electric field is applited, the cathode rays bend towards the positive plate.

(C) Cathode rays travel in straight lines. This can be proved by an arrangement which shows that cathode rays cast shadow of the object placed in straight line path of cathode rays.

(D) In certain substances like barium platinocyanides, zinc sulphate, diamond etc, they produce fluorescence.

Thus, **(B)** is right option.

6. **(B)** For photoelectric emission from given metal plate, the incident wavelength must be less than that of ultraviolet rays assuming the wavelength of ultraviolet rays as the trreshold value. Out of the given radiation, X-rays have wavelength less than that of ultraviolet rays. Thus, X-rays can cause photoelectric emission.

7. **(B)** Intensity of light source is inversely proportional to the distance **(D)**

i.e. $I \propto \frac{1}{d^2}$

When distance is doubled, intensity becomes one-fourth.

As number of photoelectrons ∝ intensity, so number of photoelectrons is quarter of the initial number.

8. **(D)** Einsteins' photoelectric equation is

$$KE = hv - W_0$$

where, W_0 = work function of metal, $(= hv_0)$

Comparing above Eq. (i) with equation of a straight line

$$y = mx + c$$

we get, $m = h, c = -W_0$

Therefore, if we draw a graph between kinetic energy and frequency, then a straight line cutting the frequency axis at v_0 and giveing an intercept of $(-W_0)$ on the kinetic energy axis, is obtained.

Note :

As we know that for emission of electrions, there is a certain threshold frequency after which emission starts. Considering this fact graph **(D)** is correct.

9. **(C)** Work function for wavelength of 4100 Å is given by

$$W_0 = \frac{hc}{\lambda} = \frac{6.62K \times 10^{-34} \times 3 \times 10^8}{4100 \times 10^{-10}}$$

$$= 4.8 \times 10^{-19}\,J$$

Energy in eV is given by

$$= \frac{4.8 \times 10^{-19}}{1.6 \times 10^{-19}}\,eV = 3\,eV$$

Now, we have

$W_A = 1.92\,eV,$

$W_B = 2.0\,eV,$

$W_C = 5\,eV$

Since, $W_A < W$

and $W_B < W$, hence, A and B will emit photoelectrons.

10. **(D)** Einstein's photoelectric equation can be written as

$$(KE)\frac{1}{2}mv^2 = hv - W_0$$

where, $[W_0 = \text{work function}]$

When photon of energy $2hv_0$ falls then

$$\Rightarrow \quad \frac{1}{2}m \times (4 \times 10^6)^2 = 2\,hv_0 - hv_0 \qquad ...(i)$$

When photon of energy $2hv_0$ falls then

$$\frac{1}{2}m \times v^2 = 5\,hv_0 - hv_0 \qquad ...(ii)$$

Dividing Eq. (i) by (ii), we get

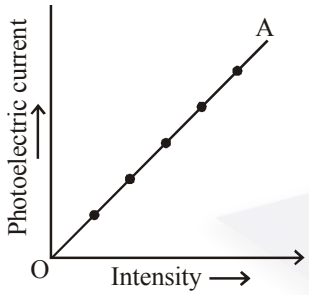
$$\frac{v^2}{(4 \times 10^5)^2} = \frac{4hv_0}{hv_0}$$

or $v^2 = 4 \times 16 \times 10^{12}$

or $v^2 = 64 \times 10^{12} \qquad \therefore \quad v = 8 \times 10^6\,m/s$

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11. **(B)** In a photoelectric effect, when monochromatic radiations of suitable frequency fall on the photosensitive plate called cathode, the photoelectrons are emitted which get accelerated towards anode. These electrons flow in the outer circuit resulting in the photoelectric current.



Using the incident radiations of a fixed frequency, it is found that the photoelectric current increases linearly with the intensity of incident light as shown in figure. Hence, a photocecll employs photoelectric effect to convert change in the intensity of illumination into a charge in photoelectric current.

12. **(B)** In a discharge tube, after being accelerated though a high potential difference the ions in the gas strike the cathode with huge kinetic energy. This collision liberates electrons from the cahtode. These free electrons can further liberates ions from gas molecules through collisions. The positive ions are attracted towards the cathode and negatively charged electrons move towards anode. Thus, ionisation of gas results.

13. **(D)** Energy of photon is given by

$$E = \frac{hc}{\lambda} \qquad ...(i)$$

where h is Planck's constant, c the velocity of liquid and λ its wavelength.

$$\lambda = \frac{h}{p} \qquad ...(ii)$$

p being momentum of photon.

From Eqs. (i) and (ii), we have

$$E = \frac{hc}{h/p} = pc \text{ or } p = \frac{E}{c}$$

Given, $E = 1\ MeV = 1 \times 10^6 \times 1.6 \times 10^{-19}\ J$,

$1\ eV = 1.6 \times 10^{19}\ J$

$c = 3 \times 10^8\ m/s$

Hence, after putting numerical values, we obtain

$$p = \frac{1\times10^6\times1.6\times10^{-19}}{3\times10^8}\ kg-m/s = 5\times10^{-22}\ kg\text{-}m/s$$

14. **(A)** Intensity of light is inversely proportional to square of distance of source

i.e. $$I \propto \frac{1}{d^2}$$

For two different situations, $\frac{I_2}{I_1} = \frac{(d_1)^2}{(d_2)^2}$

Given, $d_1 = 0.5\ m, d_2 = 1.0\ m$

Therefore, $\frac{I_2}{I_1} = \frac{(0.5)^2}{(1)^2} = \frac{1}{4}$

Since, number of photoelectrons emitted per second is directly proportional to intensity, so number of electrons emitted would decrease by factor of 4.

15. **(A)** Power emitted,

$P = 2 \times 10^{-3}\ W$

Energy of photon,

$E = hv = 6.6 \times 10^{-34} \times 6 \times 10^{14}\ J$

Here, h being Planck's constant.

$$n = \frac{Power(P)}{Energy(E)}$$

$$= \frac{2\times10^{-3}}{6.6\times10^{-34}\times6\times10^{14}} = 5\times10^{15}$$

16. **(D)** According to Einstein's photoelectric equation, kineric energy of photoelectron

$KE = hv - W_0$ or $hv = KE + W_0$

As maximum KE of ejected elctrons is given by

$KE = eV_0$

where, V_0 is stopping potential.

$hv = 5\ eV + 6.2\ eV \quad [\because eV_0 = 5\ eV]$

$= 11.2\ eV$ (lies in X-ray region)

17. **(C)** In the phenomenon of electric discharge through gases at low pressure, as the charged particles emitted from the cathode collides with the atoms of the gas, coloured glow appears in the tube.

18. **(A)** According to de-Broglie relation, wavelength of a particle is given by

$$\lambda = \frac{h}{p}$$

where, h is Planck's constant and wavelength of an electron is given by

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$$\lambda_e = \frac{h}{p_e}$$

but $\lambda = \lambda_{e'}$ so $p = p_e$

or $m_e v_e = mv$

or $v = \frac{m_e v_e}{m}$

Hence, $m_e = 9.1 \times 10^{-31}$ kg

$v_e = 3 \times 10^6$ ms^{-1}

and $m = 1$ mg

$= 1 \times 10^{-6}$ kg

$\therefore \quad v = \frac{9.1\times10^{-31}\times3\times10^{6}}{1\times10^{-6}}$

$= 2.7 \times 10^{-18}$ m/s

19. (B) Here, $\lambda = 667 \times 10^{-9}$ m, $P = 9 \times 10^{-3}$ W

$$\text{Power} = \frac{\text{energy}(E)}{\text{time}(t)}$$

$$= \frac{nhc}{\lambda t} = \frac{Nhc}{\lambda}$$

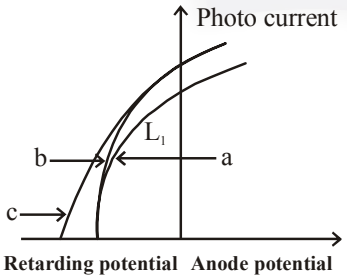
$$\left[E = \frac{hc}{\lambda}, n = \text{Total number of photons}\right.$$

$$\left.N = \text{Number of photons emitted per second} = \frac{n}{t}\right]$$

So, $N = \frac{P\times\lambda}{hc} = \frac{9\times10^{-3}\times667\times10^{-9}}{6.6\times10^{-34}\times3\times10^{8}}$

$= 3 \times 10^{16}$ m/s

20. (B)



Since in the graph retarding potential is same in graph **(A)** and **(B)** and photo current is different so, for curves they have same frequency but different intenisty of light.

21. (C) Independent of frequency (v) of light, it only depends on the intensity of incident light. If intensity increases, number of photo electrons increases.

22. (A) Number of photons emitted per second is given by

$$n = \frac{P}{\left(\frac{hc}{\lambda}\right)} \qquad \left[\begin{matrix}P = \text{Power}\\ \frac{hc}{\lambda} = \text{Energy}\end{matrix}\right]$$

So, $P = \frac{nhc}{\lambda}$

So, for two different situations,

$$\Rightarrow \frac{P_2}{P_1} = \frac{n_2\lambda_1}{n_1\lambda_2} = \frac{1.02\times10^{15}}{10^{15}\times5100} = 1$$

23. (B) As we know that stopping potential gives the maximum KE of ejected electrons, so

$KE_{max} = eV_0$

So, $1.6 \times 10^{-19} \times V_0 = 0.5 \times 1.6 \times 10^{-19}$

$\Rightarrow V_0 = 0.5$ V

24. (C) According to the concept of threshold minimum frequency needed for photoelectric emission i.e.

$KE = h\nu - \phi_0$

or $\frac{1}{2}mv^2 = h\nu - h\nu_0$

So, $\nu \geq \nu_0$

25. (A) Kinetic energy in photoelectric effect can also be written as

$$KE = \phi - \phi_0 \qquad \left[\begin{matrix}\phi = \text{incident energy}\\ \phi_0 = \text{work function}\end{matrix}\right]$$

Given, $KE_1 = 1 - 0.5 = 0.5$ eV

$KE_2 = 2.5 - 0.5 = 2$ eV

So, $\frac{KE_1}{KE_2} = \frac{0.5}{2} = \frac{1}{4}$ or $\frac{v_1^2}{v_2^2} = \frac{1}{4}$ $\left[\because KE = \frac{1}{2}mv^2\right]$

or $\frac{v_1}{v_2} = \sqrt{\frac{1}{4}} = \frac{1}{2}$

26. (A) Efficient power (P) is given by

$P = \frac{N}{t} \times \frac{hc}{\lambda}$ (N = total number of photons)

$\frac{N}{t} = \frac{P\times\lambda}{hc}$

$= \frac{50\times0.6\times10^{-6}}{6.6\times10^{-34}\times3\times10^{8}}$ $[\because = 25\% \text{ of } 200 \text{ W} = 50\text{W}]$

$= 1.5 \times 10^{20}$

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27. (C) Concept When an electron in hydrogen atom jumps from first excited state (n = 2) to ground staste (n = 1) energy is released and is given by

$$E = E_{(n=2)} - E_{(n=1)}$$

where, $E_n = -\frac{13.6}{n^2}eV$

Energy released from emission of electron is given by

$$E = -3.4 - (-13.6)$$
$$= 10.2\ eV$$

Now, from photoelectric equation,

work function,

$$\phi = E - eV = h\nu$$

$$\nu = \frac{E - eV}{h} = \frac{(10.2 = 3.57)}{6.67 \times 10^{-34}}$$

$$\nu = \frac{6.63 \times 1.6 \times 10^{-19}}{6.67 \times 10^{-34}} = 1.6 \times 10^{15}\ Hz$$

28. (A) Wavelength of electron is given by

$$\lambda_e = \frac{h}{p_e} = \frac{1}{\sqrt{2mE}} \qquad [\because\ p_e = \sqrt{2mE}\ ]$$

and for photon,

$$\lambda_p = \frac{hc}{E} \Rightarrow \lambda_e^2 = \frac{h^2}{2mE} \text{ or } E = \frac{hc}{\lambda_p}$$

$$\therefore \quad \lambda_e^2 = \frac{h^2}{2m \cdot \frac{hc}{\lambda_p}} \Rightarrow \lambda_e^2 = \frac{h^2}{2mhc}\lambda_p$$

$$\Rightarrow \quad \lambda_e^2 \propto \lambda_P$$

29. (C) As we know that,

$$\frac{1}{2}m(v_{max})^2 = h\nu$$

So, $v_{max} = \sqrt{\frac{2h\nu}{m}}$

30. (B) For de-Broglie wavelength,

$$\lambda = \frac{h}{p}$$

For 1st case, $\lambda_1 = \frac{h}{p} = \frac{h}{\sqrt{2mK}}$

For 2nd case $\lambda_2 = \frac{h}{\sqrt{2m16K}} = \frac{h}{4\sqrt{2mK}} = \frac{\lambda_1}{4}$

$$\lambda_2 = 25\% \text{ of } \lambda_1$$

So, 75% change in the wavelength takes place.

31. (B) For photo electric equation,

Einstein's equation can be written as

$$(KE)_{max} = h\nu - \phi_0$$

For the first condition,

$$0.5 = E - \phi_0 \qquad ...(i)$$

For the second condition,

$$0.8 = 1.2\,E - \phi_0 \qquad ...(ii)$$

From Eqs. (i) and (ii)

$$-0.3 = -0.2\,E$$

$$E = \frac{0.3}{0.2} = 1.5\ eV$$

From Eq. (i) $0.5 = 1.5 - \phi_0$

$$\phi_0 = 0.5 - 0.5 = 1\ eV$$

32. (C) As, energy of photon, $E = h\nu \Rightarrow E = \frac{hc}{\lambda}$

$$\Rightarrow \quad E = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{500 \times 10^{-9}}$$

$$\Rightarrow \quad E = \frac{0.0397 \times 10^{-34} \times 10^8}{10^{-9}} = 0.0397 \times 10^{-21}\ J$$

$$= \frac{0.0397 \times 10^{-21}}{1.6 \times 10^{-19}} = 0.0248 \times 10^2\ eV = 2.48\ eV$$

According to Einsteins' photoelectric emission, we have

$$KE_{max} = E - W = 2.48 - 2.28 = 0.2\ eV$$

For de-Broglie wavelength of the emitted electron,

$$\lambda_{e\,min} = \frac{12.27A}{\sqrt{KE_{max}(eV)}} = \frac{12.26}{\sqrt{0.2}}$$

Thus, minimum wavelength of the emitted electron is

$$\lambda_{min} = 2.7436 \times 10^{-9}\ m$$

i.e. $\lambda \geq \lambda_{min}$

33. (A) According to Einstein's photoelectric equation,

$$E = K_{max} + \phi$$

where, K_{max} is maximum kinetic energyv of emitted electron and ϕ is work function of an electron.

$$K_{max} = E - \phi = h\nu - \phi$$

$$K_{max} = \frac{hc}{\lambda} - \phi \qquad (i)$$

Similary, in second case, maximum kinetic energy of emitted electron is 3 times that in first case, we get

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$$3K_{max} = \frac{hc}{\frac{\lambda}{2}} - \phi \qquad \text{(ii)}$$

Solving Eqs. (i) and (ii), we get work function of an emitted electron from a metal surface.

$$\phi = \frac{hc}{2\lambda}$$

34. **(B)** The de -Broglie wavelength is given by

$$\lambda = \frac{h}{P} \Rightarrow P\lambda = h$$

This equation is in the form of yx = c, which is the equation of a rectangular byperbola. Hence, the graph given in option **(B)** is the correct one.

35. **(B)** From photoelectric equation

$$hv = W + eV_0$$

(where, W = work function)

So, $\frac{hc}{\lambda} = W + 3eV_0$ .....(i)

Also, $\frac{hc}{2\lambda} = W + eV_0$

$\Rightarrow$ $\frac{hc}{\lambda} = 2W + 2eV_0$ .....(ii)

Subtracting Eq. (i) from Eq. (ii) we get

$0 = W - eV_0 \Rightarrow W = eV_0$

From Eq. (i)

$$\frac{hc}{\lambda} = eV_0 + 3eV_0 = 4eV_0$$

The threshold wavelength is given by

$$\lambda_{th} = \frac{hc}{W} = \frac{4eV_0\lambda}{eV_0} = 4\lambda$$

36. **(B)** The radiation energy is given by $E = \frac{hc}{\lambda}$

Initial momentum of the radiation is

$$P_i = \frac{h}{\lambda} = \frac{E}{c}$$

The reflected momentum is

$$P_r = -\frac{h}{\lambda} = -\frac{E}{c}$$

So the change in momentum of light is

$$\Delta P_{light} = P_r - P_i = -\frac{2E}{C}$$

Thus, the momentum transferred to the surface is

$$\Delta P_{light} = \frac{2E}{C}$$

37. **(D) Key idea** Use einsteine photoelectric equation.

We know that, $E = (KE)_{max}$ + Work function (ϕ)

where $\phi = hv_0$, $E = hv$

$$(KE)_{max} = \frac{1}{2}mv_0^2$$

$\Rightarrow (KE)_{max} = hv - \phi$

$\Rightarrow 2eV = 5eV - \phi$ (given)

$\Rightarrow \phi = 3ev$

Thus, $V_{cathode} - V_{anode} = 3V$

$\Rightarrow$ $v_{anode} - V_{cathode} = -3V$

38. **(A)** Key Idea Cut off wavelength occurs when incoming electron looses its complete energy in collision. This energy appears in the form of X - rays.

Given, mass of electrons = m

de-Broglie wvelength = λ

So, kinetic energy of electron = $\frac{p^2}{2m}$

$$= \frac{\left(\frac{h}{\lambda}\right)^2}{2m} = \frac{h^2}{2m\lambda^2}$$

Now, maximum energy of photon can be given by

$$E = \frac{hc}{\lambda_0} = \frac{h^2}{2m\lambda^2}$$

$$\Rightarrow \lambda_0 = \frac{hc \times 2\lambda^2.m}{h^2} = \frac{2mc\lambda^2}{h}$$

39. **(C)** In Ist case, when a metallic surface is illuminated with radiation of wavelength λ, the stopping potential is V.

So, photoelectric equation can be written as

$$eV = \frac{hc}{\lambda} - \frac{hc}{\lambda_0} \qquad \text{.....(i)}$$

In IInd case, when the same surface is illuminated with radiation of wavelength 2λ, the stopping potential is $\frac{V}{4}$

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So, photoelectric equation can be written as

$$\frac{eV}{4}=\frac{hc}{2\lambda}-\frac{hc}{\lambda_0}$$

$$\Rightarrow \quad eV=\frac{4hc}{2\lambda}=\frac{4hc}{2\lambda}-\frac{4hc}{\lambda_0} \qquad \text{.....(ii)}$$

From Eqs. (i) and (ii) we get

$$\Rightarrow \quad \frac{hc}{\lambda}-\frac{hc}{\lambda_0}=\frac{4hc}{2\lambda}-\frac{4hc}{\lambda_0}$$

$$\Rightarrow \quad \frac{1}{\lambda}-\frac{1}{\lambda_0}=\frac{2}{\lambda}-\frac{4}{\lambda_0}$$

$$\Rightarrow \quad \lambda_0=3\lambda$$

40. (D) Since, it is given that electron has mass m. de-Broglie's wavelength for an electron will be given as

$$\lambda_e=\frac{h}{P} \qquad \text{.....(i)}$$

where, h = Planck's constant

P = Linear momentum of electron

As kinetic energy of electron

$$E=\frac{P^2}{2m} \Rightarrow P=\sqrt{2mE} \qquad \text{.....(ii)}$$

From Eqs. (i) and (ii) we get

$$\lambda_e=\frac{h}{\sqrt{2mE}} \qquad \text{.....(iii)}$$

Energy of a photon can be given as

$$E=h\nu$$

$$\Rightarrow \quad E=\frac{hc}{\lambda_p}$$

$$\Rightarrow \quad \lambda_p=\frac{hc}{E} \qquad \text{.....(iv)}$$

Hence , λ_p = de-Broglie's wavelength of photon.

Now, divide Eq. (iii) by (iv) we get

$$\frac{\lambda_e}{\lambda_p}=\frac{h}{\sqrt{2mE}}\cdot\frac{E}{hC}$$

$$\Rightarrow \quad \frac{\lambda_e}{\lambda_p}=\frac{1}{C}\cdot\sqrt{\frac{E}{2m}}$$

41. (B) Thinking Process de - Broglie wavelength associated with a moving particle can be given as

$$\lambda\frac{h}{p}=\frac{h}{\sqrt{2m(KE)}}$$

At thermal equilibrium, temperature of neutron and heavy water will be same.

This common temperature is given as, T.

Also, we know that, kinetic energy of a particle

$$KE=\frac{p^2}{2m}$$

where, p = momentum of the prticle

m = mass of the particle

Kinetic energy of the neutron is

$$KE=\frac{3}{2}kT$$

$\therefore$ de-Broglie wavelength of the neutron

$$\lambda=\frac{h}{p}=\frac{h}{\sqrt{2m(KE)}}$$

$$=\frac{h}{\sqrt{2m\times\frac{3}{2}kT}}=\frac{h}{\sqrt{3mkT}}$$

42. (a,b) Thinking Process Applying Einstein's photoelectric equation, kinetic energy of emitted electron can be given by

$$K=\frac{1}{2}mv^2=h\nu-h\nu_0=\frac{hc}{\lambda}-\frac{hc}{\lambda_0}$$

Given threshold wavelenght,

$$\lambda_0=3250\times10^{-10}m$$

Wavelength of ultraviolet light,

$$\lambda=2536\times10^{-10}m$$

Let, velocity of ejected electron be v.

Now, applying Einstein's photoelectric equation, we have

$$E=K+\phi_0$$

$$\Rightarrow \quad h\nu=\frac{1}{2}m_ev^2+h\nu_0$$

$$\Rightarrow \quad \frac{1}{2}m_ev^2=h\nu-h\nu_0=hc\left(\frac{1}{\lambda}-\frac{1}{\lambda_0}\right)$$

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$\Rightarrow$ Velocity of electron $V = \sqrt{\frac{2hC}{m_e}\left(\frac{1}{\lambda}-\frac{1}{\lambda_0}\right)}$

$$\sqrt{\frac{2\times4.14\times10^{-15}\times1.6\times10^{-19}\times3\times10^{8}}{9.1\times10^{-31}\,ms^{-1}}\left(\frac{3250-2536}{3250\times2536}\right)}$$

$= 0.6 \times 10^6 ms\ 6 \times 10^5\ ms^{-1}$

43. (B)

(A) Second line of Lyman series corresponds to the transition $n = 3 \rightarrow n = 1$

(B) Second line of Balmer series corresponds to the transition $n = 4 \rightarrow n = 2$

(C) Second line of paschen series corresponds to the transition $n = 5 \rightarrow n = 3$

(D) An absorption line of Balmer series arises when electron jumps from n = 2 to any other higher state.

Thus choice **(B)** is coreect

44. (B) Energy levels of H-atom are given by

$$E_n = -\frac{13.6Z^2}{n^2}eV \qquad (Z=1)$$

$\Rightarrow E_n = -13.6/n^2\ eV$

Photons are emitted only when electron jumps from bigher energy level (higher n-value) to lower energy level (lower n-value). So, altemative **(A)** and **(C)** are wrong.

Energy difference from n= 2 to n = 1 level is

$$\Delta E_{2\rightarrow1} = 13.6\left(\frac{1}{1^2}-\frac{1}{2^2}\right)eV = 13.6\times\frac{3}{4} = 10.2eV$$

$$= 13.6\times\left(\frac{1}{4}-\frac{1}{36}\right) = 13.6\times\frac{2}{9} = 3.02eV$$

Thus, it is evident that difference is larger for n = 2 to n= 1 transition. Hence, maximum energy photon or shortest wavelength will be emitted during transition from n = 2 to n = 1

45. (A) According to Bohr's hypothesis, electron can revolve only in those orbits in which its, angular momentum is an integral multiple of $\frac{h}{2\pi}$, where h is Planck's constant. In these orbits, angular momentum of electron can have magnitude as $\frac{h}{2\pi}, \frac{2h}{2\pi}, \frac{3h}{2\pi}$.....etc., but never as $\frac{1.5h}{2\pi}, \frac{2.5h}{2\pi}, \frac{3.5h}{2\pi}$ ..... etc. This is called the quantisation of angular momentum .

46. (D) Given, $E_n = -\frac{13.6}{n^2}eV$

Energy of photon ejected when electron jumps from n = 3 to n = 2 state is given by

$\Delta E = E_3 - E_2$

Energy of third orbit

$$E_3 = -\frac{13.6}{(3)^2}eV = -\frac{13.6}{9}eV$$

Energy of second orbit $E_2 = -\frac{13.6}{(2)^2}eV = -\frac{13.6}{4}eV$

$$\Delta E = E_3 - E_2 = -\frac{13.6}{9}-\left(-\frac{13.6}{4}\right)$$

$= 1.9$ eV (approximately)

47. (D) Kinetic energy of electron

$$KE = \frac{Ze^2}{8\pi\varepsilon_0 r}$$

Potential energy of electron

$$U = -\frac{1}{4\pi\varepsilon_0 r}$$

$\therefore$ Total energy $E = KE + U = \frac{Ze^2}{8\pi\varepsilon_0 r} - \frac{ze^2}{4\pi\varepsilon_0 r}$

or $E = -\frac{Ze^2}{8\pi\varepsilon_0 r}$ or $E = -KE$

or $KE = -(-3.4) = 3.4$ eV

48. (B) Ionisation energy corresponding to ionisation potention ($E_1 = -13.6$ eV)

Photon energy incident (ΔE) = 12.1eV

So, the energy of electron in excited state (E_2) is given by

$E_2 - E_1 = \Delta E$

$\Rightarrow E_2 = \Delta E + E_1$

$\Rightarrow E_2 = -13.6 + 12.1$

$\Rightarrow E_2 = -1.5$ eV

i.e. $E_2 = -\frac{13.6}{n^2}eV$

$$-1.5 = \frac{-13.6}{n^2}$$

$\Rightarrow n^2 = \frac{-13.6}{-15} = 9 \qquad \therefore \quad n = 3$

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49. (A) The energy of hydrogen atom when the electron revolves in nth orbit is given by

$$E = \frac{-13.6Z^2}{n^2}\text{ eV} \qquad [Z = 1]$$

In the ground state, n = 1

$$E = \frac{-13.6}{1^2} = -13.6\text{ eV}$$

For n = 2,

$$E = \frac{-13.6}{2^2} = -3.4\text{ eV}$$

So, kinetic energy of electron in the first excited state (i.e. for n = 2) is

$$KE = -E = -(-3.4) = 3.4\text{ eV}$$

50. (C) In the ground state, n = 1

$$E_1 = -\frac{-13.6}{1^2} = -13.6\text{eV}$$

For the first excited state (i.e. for n = 2)

$$E_2 = \frac{-13.6}{2^2} = -3.4\text{eV}$$

$$\Delta E = E_2 - E_1$$
$$= -3.4 + 13.6$$
$$= 10.2\text{ eV}$$

51. (B) A particle of mass M_1 and charge Z_1 possass initial velocity u, when it is at a large distance from the nucleus of an atom having atomic number Z_2. At the distance of closest approach, the kinetic energy of particle is completely converted to potential energy. Mathematically,

$$\frac{1}{2}M_1u^2 = \frac{1}{4\pi\varepsilon_0}\frac{Z_1Z_2}{I_0}$$

So, the energy of the particle is directly proportional to Z_1Z_2.

52. (D) Number of spectral line

$$N = \frac{n(n-1)}{2} \Rightarrow \frac{n(n-1)}{2} = 6$$

or $n^2 - n - 12 = 0$

or $(n-4)(n+3) = 0$

or $n = 4$

Now as the first line of the series has the maximum wavelength, therefore electron jumps from the fourth orbit to the third orbit.

53. (A) Energy E of an atom with principal quantum number n is given by $E = \frac{-13.6}{n^2}Z^2$ for first excited state n = 2 and for He^+, Z = 2

So, $E = \frac{-13.6 \times (2)^2}{2} = -13.6\text{ eV}$

54. (C) For Lyman series for H-atom

$$\frac{hc}{\lambda} = Rhc\left(\frac{1}{1^2} - \frac{1}{2^2}\right)$$

and for H-like ion

$$\frac{hc}{\lambda} = Z^2Rhc\left(\frac{1}{2^2} - \frac{1}{4^2}\right) \quad \frac{hc}{\lambda} = Z^2Rhc\left(\frac{1}{2^2} - \frac{1}{4^2}\right)$$

$$\therefore \quad \left(\frac{1}{1^2} - \frac{1}{2^2}\right) = Z^2\left(\frac{1}{4} - \frac{1}{16}\right)$$

$$\left(1 - \frac{1}{4}\right) = Z^2\left(\frac{1}{4} - \frac{1}{16}\right)$$

$$Z = 2$$

55. (A) *Concept* According to third postulate of Bohr' model, when an atom makes a transition from higher energy state to lower energy state, the difference of energy is carried away by a photon such that

$$h\nu = E_{n_i} - E_{n_f} \text{ or } \frac{hc}{\lambda} Rhc\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$

[where n_i = quantum number of higher energy state and n_f = quantum number of lower energy state]

Energy difference between fifth and first orbit is

$$E_5 - E_1 = \frac{hc}{\lambda} \text{ and } Rhc - \frac{Rhc}{25} = \frac{hc}{\lambda}$$

$$\frac{24}{25}R = \frac{1}{\lambda}$$

As $p = \frac{h}{\lambda}$ and $v = \frac{h}{m\lambda}$

$$= \frac{24Rh}{25m}$$

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56. **(D)** According to question,

for wavelength λ_1.

$n_1 = 4$ and $n_2 = 3$

and for λ_2, $n_1 = 3$ and $n_2 = 2$

and we know that, $\frac{hc}{\lambda} = -13.6\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

so, for λ_1

$$\Rightarrow \quad \frac{hc}{\lambda_1} = -13.6\left[\frac{1}{(4)^2} - \frac{1}{(3)^2}\right]$$

$$\frac{hc}{\lambda_1} = -13.6\left[\frac{7}{144}\right]$$

Similarly for λ_2

$$\Rightarrow \quad \frac{hc}{\lambda_2} = -13.6\left[\frac{1}{(3)^2} - \frac{1}{(2)^2}\right]$$

$$\frac{hc}{\lambda_2} = 13.6\left[\frac{5}{36}\right]$$

hence, from Eqs. (i) and (ii),we get

$$\frac{\lambda_1}{\lambda_2} = \frac{20}{7}$$

57. **(A)** Wavelength for Lyman series

$$\lambda_L = \frac{1}{\left(1 + \frac{1}{4}\right)} = \frac{4}{3R}$$

and wavelength for Balmer series

$$\lambda_B = \frac{1}{\left(\frac{1}{4} + \frac{1}{9}\right)} = \frac{4}{R\left(\frac{5}{36}\right)} = \frac{36}{5R}$$

$$\therefore \quad \frac{\lambda_L}{\lambda_B} = \frac{4}{3R} \times \frac{5R}{36} = \frac{5}{27} \Rightarrow \lambda_L : \lambda_B = 5 : 27$$

58. **(C)** Energy provided to the ground state electron

$$= \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{975 \times 10^{-10}} = \frac{6.6 \times 3}{2} \times 10^{-16}$$

$$= 0.020 \times 10^{-10} = 2 \times 10^{-18} \text{J}$$

$$= \frac{20 \times 10^{-19}}{1.6 \times 10^{-19}} \text{eV} = \frac{20}{1.6} \text{eV} = 12.75 \text{ eV}$$

It means the electron jumps to n = 4 from n = 1. When electron will fall back, number of spectral lines emitted =

$$\frac{n(n-1)}{2} = \frac{4(4-1)}{2} = 6$$

59. **(B)** Energy of electron in the 3rd orbit of He^+ is

$$E_3 = -13.6 \times \frac{Z^2}{n^2} \text{eV} = -13.6 \times \frac{4}{3^2} \text{eV}$$

$$= -13.6 \times \frac{4}{9} \times 1.6 \times \text{v } 10^{-19} \text{ J}$$

From Bohr's model,

$$E_3 = -KE_3 = -\frac{1}{2} m_e v^2$$

$$\Rightarrow \quad \frac{1}{2} \times 9.1 \times 10^{-31} \times v^2 = -13.6 \times \frac{4}{9} \times 1.6 \times 10^{-19}$$

$$\Rightarrow \quad v^2 = \frac{136 \times 16 \times 4 \times 2 \times 10^{-11}}{9 \times 91}$$

or, $v = 1.46 \times \text{v } 10^6$ m/s

60. **(D)** In hydrogen atom, wavelength of characteristic spectrum

$$\frac{1}{\lambda} = Rz^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

For Lyman series n1 = 1, $n_2 = 2$

$$\frac{1}{\lambda_1} = Rz^2\left[\frac{1}{(1)^2} - \frac{1}{(2)^2}\right] \qquad \text{.....(i)}$$

For Balmer series n1 = 2, $n_2 = 3$

$$\frac{1}{\lambda_1} = Rz^2\left[\frac{1}{(2)^2} - \frac{1}{(3)^2}\right] \qquad \text{.....(ii)}$$

Dividing Eq. (ii) by Eq. (i) we get

$$\frac{\lambda_1}{\lambda_2} = \frac{Rz^2}{Rz^2} \frac{\left[\frac{1}{4} - \frac{1}{9}\right]}{\left[1 - \frac{1}{4}\right]} = \frac{\frac{5}{36}}{\frac{3}{4}}$$

$$\frac{\lambda_1}{\lambda_2} = \frac{5}{36} \times \frac{4}{3} = \frac{5}{27}$$

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61. (D) Radius in magnetic fields of circular orbit,

$$R = \frac{mV}{qB} = \frac{\sqrt{2mE}}{qB}$$

and total energy of a moving particle in a circular orbit,

$$E = \frac{q^2B^2R^2}{2m}$$

For a proton enter in a region of magnetic field

$$E_1 = \frac{e^2 \times B^2 \times R^2}{2 \times m_P} \quad \text{.....(i)}$$

where m_p is the mass of proton.

Similarly, for a α-particle moves in a uniform magnetic field

$$E_2 = \frac{(2e)^2 \times B^2 \times R^2}{2 \times (4m_P)} \quad [\because m_\alpha = 4m_P] \text{ .....(ii)}$$

Dividing Eq. (ii) by Eq. (i), we get

$$\frac{E_2}{E_1} = \frac{(2e)^2 \times B^2 \times R^2}{2 \times (2m_P)} \times \frac{2 \times m_P}{e^2 \times B^2 \times R^2}$$

$$\frac{E_2}{E_1} = 1 \Rightarrow E_2 = E_1 = 1 \text{ MeV}$$

62. (C) *Key Idea* Excess energy of e^- appears s photon. From Rydberg's formula

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right) = \frac{5R}{36}$$

$$\frac{1}{\lambda'} = R\left(\frac{1}{3^2} - \frac{1}{4^2}\right) = \frac{7R}{144}$$

$$\frac{1}{\lambda} / \frac{1}{\lambda'} = \frac{5R}{36} + \frac{7R}{144}$$

$$\Rightarrow \quad \frac{\lambda'}{\lambda} = \frac{5R}{36} \times \frac{144}{7R} = \frac{20}{7}$$

$$\Rightarrow \quad \lambda' \frac{20}{7}\lambda$$

63. (C) Wavelength of spectral lines are given by

$$\frac{1}{\lambda} = z^2R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

For last line of Balmer series

$n_1 = 2$ and $n^2 = \infty$

$$\Rightarrow \quad \frac{1}{\lambda_B} = z^2R\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right) = \frac{R}{4} \qquad [\because z = 1]$$

Similarly, for last line of Lyman series,

$n_1 = 2$ and $n_2 = \infty$

$$\Rightarrow \quad \frac{1}{\lambda_2} = z^2R\left(\frac{1}{1^2} - \frac{1}{\infty^2}\right) = R$$

$$\therefore \quad \frac{\frac{1}{\lambda_B}}{\lambda_L} = \frac{\frac{R}{4}}{R} = \frac{1}{4}$$

$$\Rightarrow \quad \frac{\lambda_L}{\lambda_B} = \frac{1}{4} \quad \Rightarrow \quad \frac{\lambda_B}{\lambda_L} = 4$$

64. (B) Let initial number of nuclei in A and B is N_0.

Number of nuclei of A after time t is

$$N_A = N_0e^{-\lambda t} \quad \text{.....(i)}$$

Similarly, number of nuclei of A after time t is

$$N_B = N_0e^{-\lambda t} \quad \text{.....(ii)}$$

It is given that $\frac{N_A}{N_B} = \frac{1}{e}$ $\qquad [\because N_B > N_A]$

Now, from Eqs. (i) and (ii)

$$\frac{e^{-8\lambda t}}{e^{-\lambda t}} = \frac{1}{e}$$

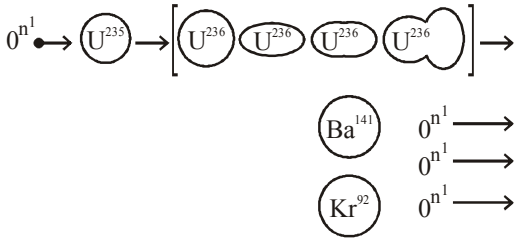
Rearranging

$$\Rightarrow \quad e^{-1} = e^{-7\lambda t} \Rightarrow 7\lambda t = 1$$

$$\Rightarrow \quad \text{Time } t = \frac{1}{7\lambda}$$

65. (B) Neil Bohr and J. A. wheeler exdplained the nuclear fissioon on the basis of liquid drop model of the nucleus. The $_{92}U^{235}$ nucleus behaves like a liquid drop and owing to surface tension is perfectly spherical in shape. When the neutron strikes the nucleus, some energy called the excitation energy is imparted to the nucleus

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The phenomenon of surface tension tries to keep the nucleus spherical in shape whereas the excitation energy tries to deform it. Deue to the struggle between the surface tension and the excitation energy, the oscillations are set up inside the compound nucleus.

As a result, the nucleus gets deformed from spherical shape to ellipsoidal and then to a dumb bell as shown, till the coulomb's repulsive force between protons succeeds in tearing the two bells apart

66. (B) The time required for the number of parent nuclei to fall to 50% is called half-life T and may be related to disintegration constant λ as follows.

Since,

$$0.5\,N_0 = N_0 e^{-\lambda T} \qquad \begin{bmatrix} N = \text{Final no. nuclei} \\ \lambda = \text{decay constant} \end{bmatrix}$$

N_0 = Initial No of nuclei

λ = decay constant

we have $\lambda T = \log_e 2$

$$\therefore \quad \lambda = \frac{\log_e 2}{T}$$

67. (A) Number of half-lives

$$n = \frac{t}{T_{1/2}} = \frac{18}{3} = 6 \qquad [T_{1/2} = \text{half life period}]$$

Amount remaine after n half-lives

$$N = N_0\left(\frac{1}{2}\right)^n \begin{bmatrix} N_0 = \text{in itial count} \\ N = \text{final count} \end{bmatrix}$$

Given, $N_0 = 300$ g

$$\therefore \quad N = 300\left(\frac{1}{2}\right)^6 = 300 \times \frac{1}{64} = 4.86\text{g}$$

Alternative

Total time of decay given

$$t = \frac{2.303}{\lambda}\log_{10}\left(\frac{300}{N}\right)$$

but $\lambda = \dfrac{0.693}{T} = \dfrac{0.693}{3} = 0.231/\text{h}$

$$\therefore \quad t = \frac{2.303}{0.231}\log_{10} = \left(\frac{300}{N}\right)$$

Given $t = 18$ h

So $18 = \dfrac{2.303}{0.231}\log_{10}\left(\dfrac{300}{N}\right)$

or $\log_{10}\left(\dfrac{300}{N}\right) = \dfrac{0.231}{2.303} \times 18$

or $\dfrac{300}{N} = (10)^{18}$ or $N = \dfrac{300}{(10)^{18}} = 4.68\text{g}$

68. (D) 69. (A) 70. (C) 71. (B)

72. (D) The activity of a radioactive substance is

$$R = R_0\left(\frac{1}{2}\right)^n \qquad \begin{bmatrix} R = \text{Fina l number} \\ R_0 \text{ Initia l number} \end{bmatrix}$$

Here, N = number of half - lives

$$= \frac{t}{T_{1/2}} = \frac{24}{6} = 4 \qquad [T_{1/2} = \text{half life period}]$$

and $R = 0.01\ \mu C$

So, $0.01 = R_0\left(\dfrac{1}{2}\right)^4$

or $R_0 = 0.01 \times (2)^4$

$= 0.01 \times 16$

$= 0.16\ \mu C$

73. (B) The mass of radioactive substance reminaed is ,

$$M = M_0\left(\frac{1}{2}\right)^n$$

Here, final mass, M = 1g, initial mass,

$M_0 = 256$ g, half life period, $T_{1/2} = 12.5$ h

So, $1 = 256\left(\dfrac{1}{2}\right)^n$ or $\dfrac{1}{256} = \left(\dfrac{1}{2}\right)^n$

or $\left(\dfrac{1}{2}\right)^8 = \left(\dfrac{1}{2}\right)^n$

Comparing the powers on both the sides, we get

$$n = 8 = \frac{t}{T_{1/2}}$$

$\therefore \quad t = 8T_{1/2}$

$= 8 \times 12.5 = 100$ h

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74. (B) The given nuclear reaction cn be written as

$${}_{Z}X^{A} + {}_{0}n^{1} \rightarrow 3Li7 + {}_{2}He^{4}$$

Conservation of mass number gives,

$$A + 1 = 7 + 4 \Rightarrow A = 10$$

Conservation of charge number / Atomic No. gives,

$$Z + 0 = 2 + 3 \Rightarrow Z = 5$$

hence, Z = 5, A = 10 corresponds to boron ($_5B^{10}$)

75. (C) Number of half - lives

$$n = \frac{t}{T_{1/2}} = \frac{30\text{days}}{10\text{days}} = 3$$

[$T_{1/2}$ = half life period]

So, number of undecayed radioactive nuclei is given by

$$\frac{N}{N_0}\left(\frac{1}{2}\right)^n \qquad \begin{bmatrix} N = \text{Final number} \\ N_0 = \text{Initial number} \end{bmatrix}$$

or $$N = N0\left(\frac{1}{2}\right)^n = 4\times10^{10}\left(\frac{1}{2}\right)^3$$

$$= 4 \times 1010 \times \frac{1}{8} = 0.5 \times 10^{10}$$

Thus, number of nuclei decayed after 30 days

$$= N_0 - N$$
$$= 4 \times 10^{10} - 0.5 \times 10^{10}$$
$$= 35 \times 10^{10}$$

76. (A) Binding energy for light nuclei (A < 20) is much smaller than the binding energy for heavier nuclei THis suggests a process that is reverse of fission. When two light nuclei combine to form a heavier nucleus, the process is called nuclear fusion. The union of two light nuclei into heavier nuclei also lead to a transfer of mass and a consequent liberation of large amount energy.

77. (D) Let the unknown product nucleus be ${}_{Z}X^{A}$

The reaction can be written as

$$\underset{(\text{Oxygen})}{{}_{8}O^{16}} + \underset{(\text{deuterium})}{{}_{1}H^{2}} \rightarrow \underset{(\text{unknownnucleus})}{{}_{Z}X^{A}} + \underset{\alpha-\text{particle}}{{}_{2}He^{4}}$$

Conservation of mass number between product and reactant of above reaction gives,

$$16 + 2 = A + 4 \quad \Rightarrow \quad A = 14$$

Conservation of atomic number between reactant and product of above reaction gives

$$8 + 1 = Z + 2 \quad \Rightarrow \quad Z = 7$$

Thus, the unknown product nucleus is nitrogen ($_7N^{14}$)

Note

Fusion reaction can take place at very high temperature (=10^8K) and very high pressure which can be provided at sun or by fission of atom bomb.

78. (B) Order of Radius of atom $\approx 10^{-10}$m

Order of Radius of nucleus $\approx 10^{-15}$m

Ratio of volume of atom to volume of nucleus

$$= \frac{\text{volume of atom}}{\text{volume of nucleus}}$$

$$= \frac{\frac{4}{3}\pi r_1^3}{\frac{4}{3}\pi r_2^3} = \left(\frac{10^{-10}}{10^{-15}}\right) = 10^{15}$$

79. (A) Mass number

= No. of protons + No. of neutrons

For example, in case of hydrogen

Number of neutrons = 0

Thus, mass number = atomic number

Hence, sometimes the atomic number is equal to the mass number.

80. (A) ${}_{2}He^{4}$ contains 2 neutrons and 2 protons

So, mass of 2 protons = 2 × 1.0073 = 2.146 u

So, mass of 2 neutrons = 2 × 1.0087 = 2.0174 u

Total mass of 2 protons and 2 neutrons

$$= (2.0146 + 2.0174)\,u = 4.032\,u$$

Mass of helium nucleus = 4.0015 u

Thus, mass dedect is lacking of mass in forming the helium nucleus from 2 protons and 2 neutrons.

$$\therefore \quad \Delta m = \text{mass defect} = (4.032 - 4.00015)\,u$$
$$= 0.0305\,u$$

As we know that , 1u = 931 MeV

Hence, binding energy

$$\Delta E = (\Delta m) \times 931$$
$$= 0.0305 \times 931 = 28.4\,\text{MeV}$$

81. (A) In sun, huge amount of energy is produced due to fusion of 4 protons (hydrogen nucleus) into a helium nucleus. According to the reaction .

$${}_{1}H^{1} + {}_{1}H^{1} + {}_{1}H^{1} + {}_{1}H^{1} \rightarrow {}_{2}He^{4} + 2\,{}_{+1}\beta^{0} + g\,(\text{energy}) + 2\upsilon$$

82. (C) Since in the given reaction ${}_{-1}e^{0}$ and antineutrino ($\bar{\nu}$) are released, so it can be considered β-decay.

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83. **(C)** Mean life of radioactive substance is given by

$\tau = \frac{1}{\lambda}$ (λ is decay constant)

Also, it is given that $t = 2\tau$

So $= t = 2 \times \frac{1}{\lambda} = \frac{2}{\lambda}$

Thus, mass remained after time t is

$$M = M_0 e^{-\lambda t} \begin{bmatrix} M = \text{Final mass} \\ M_0 \text{ Inital mass} \\ \lambda = \text{Decay constant} \end{bmatrix}$$

$= 10e^{-\lambda \times \frac{2}{\lambda}}$ $[\because M_0 = 10g]$

$= 10\, e^{-2}$

$= \frac{10}{e^2}$

$= 1.35$ g

84. **(C)** In a nuclear fusion, when two light nuclei of different masses are combined to form a stable nucleus, then some mass is lost and appears in the form of energy, called the mass defect, So, the mass of resultant nucleus is always less than than the sum of masses of initial nuclei i.e.

$$m_3 < (m_1 + m_2)$$

85. **(D)** Amount of substance remained is

$$M = M_0 \left(\frac{1}{2}\right)^n \begin{bmatrix} M = \text{substance remained} \\ M_0 = \text{initial amount} \end{bmatrix}$$

Given, $M_0 = 100g$, $M = 25g$

Half-life of radioactive substance $T_{1/2} = 1600$ yr

So, $25 = 100\left(\frac{1}{2}\right)^n$

or $\frac{25}{100} = \left(\frac{1}{2}\right)^n$ or $\left(\frac{1}{2}\right)^2 = \left(\frac{1}{2}\right)^n$

Comparing the power, we have

$n = 2$

or $\frac{t}{T_{1/2}} = 2$

or $t = 2T_{1/2} = 2 \times 1600$

$= 3200$ yr

86. **(C)** .Binding energy of a nucleus containing N neutrons and Z protons is

$BE = [Nm_n + Zm_p - m(N, Z)]c^2$

$\Rightarrow \frac{BE}{c^2} = Nm_n + Zm_p - m(N, Z)$

$\Rightarrow m(N, Z) = Nm_n + Zm_p - BE/c^2$

87. **(B)** Given, binding energy of $({}_1^2H + {}_1^3H) = a + b$ Binding energy of ${}_1^4He = c$

In a nuclear reaction, the resultant nucleus is more stable than the reactants. hence, binding energy of ${}_1^4He$ will be more than that $\left({}_1^2H + {}_1^3H\right)$.

Thus, energy released per nucleon

= resultant binding energy

Binding energy of product – Binding energy of reactant

$= c - (a + b) = c - a - b$

88. **(A)** The nuclei which have same number of neutrons but different atomic number and mass number are known as isotones. In choice **(A)** nuclei of Se^{74} and ${}_{31}Ga^{71}$ are isotones as

$A - Z = 74 - 34 = 71 - 31 = 40$

89. **(B)** The binding energy per nucleon for the middle nuclides (from A = 20 to A = 56) is maximum. Hence, these are more stable.

As the mass number increases, the binding energy per nucleon gradually decreases and ultimately binding energy per nucleon of heavy nuclides (such as uranium etc.) is comparatively low. Hence, these nuclides are relatively unstable. So, they can be fissioned easily.

90. **(A)** In fission process, shen a parent nucleus breaks into daughter products, then some mass is lost in the form of energy. Thus, mass of fission products < mass of parent nucleus

$\Rightarrow \frac{\text{Mass of fission products}}{\text{Mass of parent nucleus}} < 1$

91. **(B)** The reaction can be written as

${}_1H^2 + {}_1H^2 \rightarrow {}_2He^4 + \text{energy}$

The energy released in the reaction is the difference of binding energies of daughter and parent nuclei

Hence, energy released = binding energy of ${}_2He^4$

$- 2 \times$ binding energy of ${}_1H^2$

$= 28 - 2 \times 2.2 = 23.6$ MeV

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92. (A) The decay rate R of a radioactive material is the number of decays per second.

From radioactive decay law

$$-\frac{dN}{dt} \propto N$$

or $$-\frac{dN}{dt} = \lambda N$$

i. e. Rate of reaction is directly proportional to the initial concentration of reactants.

Thus. $R = -\frac{dN}{dt}$ or $R \propto N$

or $R = \lambda N$ or $R = \lambda N_0 e^{-\lambda t}$ .....(i)

where $R_0 = \lambda N_0$ is the activity of the radioactive material at time $t = 0$

At time t_1, $R_1 = R_0\ e^{-\lambda t_1}$ .....(ii)

At time t_1, $R_2 = R_0\ e^{-\lambda t_1}$ .....(iii)

Dividing Eq. (ii) by Eq. (iii) we have

$$\frac{R_1}{R_2} = \frac{e^{-\lambda t_1}}{e^{-\lambda t_2}} = e^{-\lambda(t_1 - t_2)}$$

or $R_1 = R_2\ e^{-\lambda(t_1 - t_2)}$

93. (D) According to question, radius of ${}^{9}_{4}Be$ nucleus be r, and radius of germmanium (Ge) nucleus will be 2r.

Radius of a nucleus is given by

$R = R_0 A^{1/3}$

R = Radius of atom having mass number. A

$R \propto A^{1/3}$

So $\frac{R_1}{R_2}\left(\frac{A_1}{A_2}\right)^{1/3}$

$\Rightarrow \frac{r}{2r}\left(\frac{9}{A_2}\right)^{1/3}$ $(\because A_1 = 9)$

or $\left(\frac{1}{2}\right)^3 = \frac{9}{A_2}$

Hence, $A_2 = 9 \times (2)^3$

$= 9 \times 8 = 72$

Thus, in germanium (Ge) nucleus number of nucleons is 72

94. (B) Beta decay involves the emission of either electrons or positrons. The electrons or positrons emitted in a β-decay do not exist inside the nucleus. They are only created at the time of emission, iust as photons are created when an atom makes a transition from higher to a lower energy state.

In negative β-decay, a neutron in the nucleus is transformed into a proton, an electron and an antineutrino. Hence, in radioactive decay process, the negatively charged emitted β-particles are the electrons produced as a result of the decay of neutrons present inside the nucleus.

95. (B) In the case of formation of a nucleus, the evolution of energy equal to the binding energy of the nucleus takes place due to disappearance of a fraction of the total mass. If the quantity of mass disappearing is Δm, then the binding energy is

$$BE = \Delta mc^2$$

From the above discussion, it is clear that the mass of the nucleus must be less than the sum of the masses of the consituent neutrons and protons. We can then write.

$$\Delta m = Zm_p + Nm_n - m(A, Z)$$

where m(A,Z) is the mass of the atom of mass number A and atomic number Z. Hence, the binding energy of the nucleus is

$BE = [Zm_p + Nm_n - m(A, Z)]c^2$

$B\,E = [Zm_p + (A - Z)m_n - m(A, Z)]c^2$

where, $N = A - Z$ = number of neutrons.

96. (A) If R is the radius of the nucleus, the corresponding volume $\frac{4}{3}\pi R^3$ has been found to be proportional to A

This relationship is expressed in inverse form as

$R = R_0 A^{1/3}$

The value of R_0 is 1.2×10^{-15} m, i.e. 1.2 fm

Therefore, $\frac{R_{Al}}{R_{Te}} = \frac{R_0 (A_{Al})^{1/3}}{R_0 (A_{Te})^{1/3}}$

$$\frac{R_{Al}}{R_{Te}} = \frac{(A_{Al})^{1/3}}{(A_{Te})^{1/3}} = \frac{(27)^{1/3}}{(125)^{1/3}} = \frac{3}{5}$$

or $R_{Te} = \frac{5}{3} \times R_{Al} = \frac{5}{3} \times 3.6 = 6$ fm

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97. (D) Number of nuclei remained after time t can be written as

$$N = N_0 e^{-\lambda t} \quad \text{.....(i)}$$

Where, N_0 is initial number of nuclei of both the substances

$$\frac{N_1}{N_2} = e^{(-5\lambda+\lambda)t} = e^{-4\lambda t} = \frac{1}{e^{4\lambda t}}$$

But, we have given

$$\frac{N_1}{N_2} = \left(\frac{1}{e}\right)^2 = \frac{1}{e^2}$$

Hence, $\frac{1}{e^2} = \frac{1}{e^{4\lambda t}}$

Comparing the powers, we get

$$2 = 4\lambda t \quad \text{or} \quad t = \frac{2}{4\lambda} = \frac{1}{2\lambda}$$

98. (C) $N_1 = N_0 e^{5\lambda t}$ .....(i)

$N_2 = N_0 e^{-\lambda t}$ .....(ii)

Dividing Eq. (i) by Eq. (ii), we obtain

$$\frac{N_1}{N_2} = \frac{1}{e} = \frac{e^{-5\lambda t}}{e^{-\lambda t}} = e^{-4\lambda t}$$

$$\therefore \quad e^{-1} = e^{-4\lambda t}$$

$$1 = 4\lambda t$$

or $t = \frac{1}{4\lambda}$

99. (A) Alpha particles are positively charged particles with charge +2e and mass 4m. Emission of an α-particle reduces the mass of the radionuclide by 4 and its atomic number by 2. β-particles are negatively charged particles with rest mass as well as charge same as that of electrons. γ-particles carry no charge and mass.

Radioactive transition will be as follows

$${}^{A}_{Z}X \rightarrow {}^{A}_{z+1}Y + \beta^0_{-1}$$

$${}^{A}_{Z+1}X \rightarrow {}^{A-4}_{z+1}\beta + \alpha^4_2$$

$${}^{A-4}_{Z+1}\beta \rightarrow {}^{A-4}_{z-1}\beta + \gamma^0_0$$

100. (D) Let the radioactive substance be ${}^{A}_{Z}X$

Radioactive transition is given by

$${}^{A}_{Z}X \xrightarrow{-\alpha} {}^{A-4}_{Z-2}X \xrightarrow{-2\beta} {}^{A-4}_{Z}X$$

The atoms of element having same atomic number but different mass numbers are called isotopes.

So, ${}^{A}_{Z}X$ and ${}^{A-4}_{Z}X$ are isotopes.

101. (D) Fraction remains after n half lives

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^{t/T}$$

Given $N = \frac{N_0}{e} \Rightarrow \frac{N_0}{eN_0} = \left(\frac{1}{2}\right)^{5/T}$

or $\frac{1}{e} = \left(\frac{1}{2}\right)^{5/T}$

Taking log on both sides, we get

$$\log 1 - \log e = \frac{5}{T}\log\frac{1}{2}$$

$$-1 = \frac{5}{T}(-\log 2)$$

$$\Rightarrow \quad T = 5\log_e 2$$

Now let t' be the time after which activity reduces to half

$$\left(\frac{1}{2}\right) = \left(\frac{1}{2}\right)^{t'/5\log_e 2} \Rightarrow t' = 5\log_e 2$$

102. (B) If m = 1 u, $c = 3 \times 10^8 ms^{-1}$, then

E = 931 MeV i.e. 1 u = 931 MeV

$\therefore$ Binding energy per nucleon

$$= \frac{39.10}{7} 5.58 = 5.6 \text{ MeV}$$

103. (B) ${}^{m}_{n}X \xrightarrow{\alpha} {}_{n-2}X^{m-4} \xrightarrow{2\beta} {}_{n}X^{m-4}$

104. (B) Fusion reaction takes place at high temperature because kinetic energy is high enough to overcome the couloumb repulsion between nuclei.

105. (A) We know that

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^{t/T_{1/2}}$$

$$\Rightarrow \quad \frac{1}{1+15} = \frac{1}{16} = \left(\frac{1}{2}\right)^4 = \left(\frac{1}{2}\right)^{t/50}$$

$$t = 4 \times 50$$

$$t = 200 \text{ yr}$$

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106. (A) Momentum of a photn

$$p = \frac{hv}{c}$$

Hence, recoil energy, $E = \frac{p^2}{2M}$

$$\therefore \quad E = \frac{\left(\frac{hv}{C}\right)^2}{2M} \text{ or } E = \frac{h^2v^2}{2Mc^2}$$

107. (D) For 40 g amount,

$$40g \xrightarrow[\text{half-life}]{20s} 20g \xrightarrow{20s} 10g$$

For 160 g amount

$$160\ g \xrightarrow{10s} 80g \xrightarrow{20s} 10g$$

$$\xrightarrow{10s} 20g \xrightarrow{10s} 10g$$

So, after 40 s A_1 and A_2 will become equal.

108. (C) Given, $\Delta m = 0.02866$ u

$\therefore$ Energy liberated $= \Delta mc^2$

$\Rightarrow$ Energy liberated per u

$$= \frac{0.02866 \times 931}{4} = \frac{26.7}{4} \text{MeV}$$

$$= \frac{E_b}{A}$$

$= 6.675$ MeV

109. (B) As we know that

$$N = N_0\left(\frac{1}{2}\right)^n$$

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^3 = \frac{1}{1+7} = \frac{1}{8}$$

So, number of half lires = 3

$\Rightarrow \quad T = 20$yr

$$\therefore \quad T = \frac{t}{n}$$

$\Rightarrow \quad t = Tn = 20 \times 3$ yr $= 60$ yr

110. (C) Ratio of X :Y is given = 1:7

$$\frac{m_x}{m_y} = \frac{1}{7} \Rightarrow 7m_x = m_y$$

Let the initial total mass be m.

$$\Rightarrow m_x + m_y = \Rightarrow \frac{m_y}{7} + m_y = m$$

$$\Rightarrow \frac{8m_y}{7} + m \Rightarrow m_y = \frac{7}{8}m$$

only $\frac{1}{8}$ part remains

$$\Rightarrow 1 \xrightarrow{T_{1/2}} \frac{1}{2} \xrightarrow{T_{1/2}} \frac{1}{4} \xrightarrow{T_{1/2}} \frac{1}{8}$$

So, time taken to become $\frac{1}{8}$ unstable part

$= 3 \times T_{1/2} = 3 \times 1.4 \times 10^9 = 4.2 \times 10^9$y

Alternative

X Y

$\rightarrow$

Active Stable

As we know that

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n$$

$$\frac{1}{1+7} = \frac{1}{8} = \left(\frac{1}{2}\right)^3$$

$\Rightarrow \quad n = 3$

As $T_{1/2} = \frac{t}{n}$

$t = T_{1/2} \times n$

$= 1.4 \times 10^9 \times 3 = 4.2 \times 10^9$ y

111. (D) The binding energy for $_1H^1$ is around zero and also not given in the question so we can ignore it

$Q = 2(4 \times 7.06) - (7 \times 5.60)$

$= 2(E_{bn}$ of He)(E_{bn} of Li)

$= (8 \times 7.06) - (7 \times 5.60)$

$= (56.48 - 39.2)$MeV

$\therefore \quad Q = 17.28$ MeV $= 17.3$ MeV

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112. (4) $_{92}U^{238} \rightarrow {}^{92}TH^{238} + {}_{2}He^{4}$

According to law of conservation of linear momentum, we have.

$$|P_{Th}| = |P_{He}| = P$$

$\Rightarrow$ As, kinetic energy of an element,

$$KE = \frac{P^2}{2m}$$

where, m is mass of an element.

Thus, $KE \propto \frac{1}{M}$

So, $M_{He} < M_{Th} \rightarrow > K_{Th}$

113. **(B)** Radius of the nucleus is given by

$R = R^0 A^{1/3} \Rightarrow R \propto A^{1/3}$

$$\frac{R_{Al}}{R_{Te}} = \left(\frac{A_{Al}}{A_{Te}}\right)^{1/2} = \left(\frac{27}{125}\right)^{1/3} = \frac{3}{5}$$

$$R_{Te} = \frac{5}{3} R_{Al}$$

114. **(D) Key Idea** Half - life of a radioactive substance is

$$T_{1/2} \propto \log\left(\frac{N_0}{N}\right)$$

Given $N_1 = 0.6\, N_0$ ($\because$ 40% decay)

$N_2 = 0.15\, N_0$ ($\because$ 85% decay)

Putting these in the formula,

$$\frac{N_2}{N_1} = \frac{0.15N_0}{0.6N_0} = \frac{1}{4} = \left(\frac{1}{4}\right)^2$$

So, two half-life periods has passed.

Thus time taken $= 2 \times t_{1/2} = 2 \times 30 = 60$ min

115. **(D)** When an α-particle of mass m moving with velocity v bombards on a heavy nucleus of charge Ze, then there will be no loss of energy as in this case, inital kinetic energy of α-particle = potential energy of α-particle at closest approach

$$\Rightarrow \quad \frac{1}{2}mv^2 = \frac{2Ze^2}{4\pi\varepsilon_0 r_0}$$

$$\Rightarrow \quad r_0 \propto \frac{1}{m}$$

This is the required distance of closest approach to α-praticle from the nucleus

EXERCISE - 4

P-2 (AIIMS)

1. **(B)** Charge on ions $= 2.9 \times 10^{18} \times 1.6 \times 10^{-19}$ C

Charge on electrons $= 1.2 \times 10^{18} \times 1.6 \times 10^{-19}$ C

Total charge $= 4.1 \times 1.6 \times 10^{-1}$ C

$= 6.56 \times 10^{-1}$ C $= 0.66$ C.

$$\text{Current} = \frac{\text{Charge}}{\text{Time}} = \frac{0.66\ (C)}{1\ (s)} = 0.66\ A.$$

The direction of current in a circuit is, by convention, taken along the direction in which positive charges flow. Hence the current in the discharge tube flows towards right.

2. **(D)** The charge on a proton = e. Hence when the proton is accelerated through a potential difference of 1 V, its K.E. = 1 eV.

3. **(A)** The work function of a metal is an inherent property of the metal itself and it does not change with the frequency of the incident light.

4. **(A)** Wavelength $(\lambda) = 10^{-10}$ m.

Velocity of the electron, $v = h/m\lambda$

$$= \frac{6.6\times10^{-34}}{(9.1\times10^{-31})(10^{-10})} = 7.25\times10^{6}\ \text{m/s}.$$

where m = mass of electron equal to 9.1×10^{-31} kg and h is Planck constant equal to 6.6×10^{-34} Js.

5. **(C)** The charge on a proton is equal to e, the electronic charge. The potential difference is V = 1 kV. Hence the kinetic energy of the proton is E = 1 kev.

6. **(B)** The de-Broglie wavelength of a particle or a photon is given by $l = h/p$

where h is the Planck's constant and p is the momentum.

As the electron and the photon are having the same wavelength λ, the momentum of both of them will be the same.

7. **(B)**

8. **(A)** When stopping potential is applied no electron will reach the cathode and the current will becomes zero.

$$\therefore \quad eV_0 = \frac{1}{2}mv_{max}^2$$

Also, $\frac{1}{2}mv_{max}^2 = h\upsilon - \text{work function}$

$= 4\text{ eV} - 2\text{eV} = 2\text{ eV}.$

$\Rightarrow eV_0 = 2$ eV $\Rightarrow$ stopping potential = 2 V.

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9. **(B)** In electron microscope, electrons are used as the light source. The resolving power of a microscope is approximately equal to that of wavelength of the light used. The de Broglie wavelength λ of a particle is related to its momentum p by

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

The speed of required electron is

$$v = \frac{h}{m\lambda} = \frac{6.63\times10^{-34}\,Js}{9.11\times10^{-31}\,kg\cdot10^{-11}\,m} = 7.28\times10^{7}\ m/s$$

This corresponds to kinetic energy of $E = \frac{1}{2}mv^2$

$$= \frac{1}{2}\times9.11\times10^{-31}\times(7.28\times10^{7})^2\times\frac{1\ eV}{1.6\times10^{-19}\,J}$$

$= 15.1$ keV.

10. **(B)** Minimum energy i.e. minimum frequency is needed.

11. **(A)** If the momentum of a and b particles are p, it this is also equal to hυ/c of the photon - γ-rays,

$\lambda_{de\ Broglie} = h/p$

As p is the same, the wavelength will be the same. For α and β particles, they are de Broglie waves and in the case of photons (γ-rays), it is the wavelength of the associated electromagnetic wave.

12. **(A)** $\lambda = 6840$ Å

$$\therefore \quad \upsilon = \frac{c}{\lambda} \Rightarrow h\upsilon = \frac{hc}{\lambda};\ = 12400\ eV\,Å$$

$$\text{Energy of the photon} = \frac{12400\,eVÅ}{6840\,Å} = 1.81\ eV$$

13. **(D)**

14. **(C)** $\lambda \propto \frac{1}{\sqrt{T}}$

15. **(B)** $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mE}}$ or $\lambda \propto \frac{1}{\sqrt{E}}$

$$\therefore \quad \frac{\lambda'}{\lambda} = \sqrt{\frac{E}{E'}} = \sqrt{\frac{1}{16}} = \frac{1}{4}$$

$$\%\text{ change in wavelength} = \left(\frac{\lambda-\lambda'}{\lambda}\right)\times100$$

$$= \left(1-\frac{\lambda'}{\lambda}\right)\times100 = \left(1-\frac{1}{4}\right)\times100 = 75\%$$

16. **(C)** In a photon-particle collision (such as photon-electron), the total energy and total momentum are conserved. However, the number of photons may not be conserved in a collision. The photon may be absorbed or a new photon may be created.

17. **(B)** $K_1 = \frac{hc}{\lambda_1} - \phi_0$ ....(i)

and $K_2 = \frac{hc}{\lambda_2} - \phi_0$ or $\frac{hc}{\lambda_2} = (K_2 + \phi_0)$ ....(ii)

$$\therefore \quad K_1 - K_2 = hc\left[\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right]$$

$$= hc\left[\frac{1}{3\lambda_2} - \frac{1}{\lambda_2}\right] = -\frac{2hc}{3\lambda_2} = -\frac{2}{3}(K_2 + \phi_0)\ \text{from (ii)}$$

$$\text{or } K_1 = K_2 - \frac{2}{3}K_2 - \frac{2}{3}\phi_0 = \frac{K_2}{3} - \frac{2}{3}\phi_0 \text{ or } K_1 < \frac{K_2}{3}$$

18. **(C)** For photon, $\lambda_{Ph} = \frac{hc}{E}$

Here, E is energy of photon.

For proton, $\lambda_p = \frac{h}{\sqrt{2mK}}$

Here, m and K be mass and kinetic energy of proton respectively.

$$\therefore \quad \frac{\lambda_p}{\lambda_{Ph}} = \frac{E}{c}\sqrt{2mK} \propto E^{1/2} \quad (\because E = K\ \text{Given})$$

19. **(C)** The relation between kinetic energy, threshold frequency and frequency of photon is given as

$$\frac{1}{2}mv^2 = (h\upsilon - h\upsilon_0) = h(1\times10^{14} - 5\times10^{13})$$

$k = h\,(5\times10^{13}) = 6.67\times10^{-34}\times5\times10^{13}$

$= 3.3\times10^{-20}$ J.

20. **(C)** de broglie wavelength,

$$\lambda = \frac{h}{\sqrt{2mk}} \quad \text{or} \quad k = \frac{h^2}{2m\lambda^2}$$

$$= \frac{(6.67\times10^{-34})^2}{2\times9.1\times10^{-31}\times(1\times10^{-9})^2} = 1.5\ eV.$$

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21. **(A)** de broglie wavelength, $\lambda = \frac{h}{p}$

or $\lambda = \frac{h}{mv}$

$\therefore \quad \frac{\lambda_p}{\lambda_e} = \frac{m_e v_e}{m_p v_p} \Rightarrow m_p = \frac{m_e v_e}{v_p} \times \frac{\lambda_e}{\lambda_p}$

Here, $m_e = 9.1 \times 10^{-31}$ kg, $v_p = 3v_e$

and $\frac{\lambda_p}{\lambda_e} = 1.814 \times 10^{-4}$

$\therefore \quad m_p = \frac{9.1 \times 10^{-31}}{1.814 \times 10^{-4} \times 3} = 1.672 \times 10^{-27}$ kg

Thus, the particle is neutron.

22. **(A)** As $K_{max} = \frac{hc}{\lambda} - \phi_0 = 3.1 \text{ eV} - 2\text{eV} = 1.1 \text{ eV}$

$V_0 = 1.1$ V

23. **(B)** de-Broglie wavelength, $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}}$

Here, $m = 1$ kg, $K = 0.5$ J

$h = 6.63 \times 10^{-34}$ J s, $\lambda = ?$

$\lambda = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 1 \times 0.5}} = 6.63 \times 10^{-34}$ m

24. **(D)** The three experimental facts listed under **(A)**, **(B)** and **(C)** cannot be explained on the basis of wave theory of light, All these facts support the quantum (photon) nature of light.

25. **(D)** de Broglie wavelength

$\lambda = \frac{h}{mv}$ or $\lambda \propto \frac{h}{m}$ (when v is constant)

As $m_\alpha > m_n > m_p > m_\beta \quad \therefore \quad \lambda_\alpha < \lambda_n < \lambda_p < \lambda_\beta$

Therefore, β-particle has the longest de Broglie wavelength.

26. **(D)** The maximum kinetic energy of the photoelectrons varies linearly with the frequency of incident radiation, but is independent of its intensity. The number of photoelectrons emitted per second is directly proportional to the intensity of incident radiation.

27. **(D)** Photoelectric effect can be explained on the basis of quantum theory or particle nature of light where wave nature of light fails to explain the photoelectric effect. The number of photoelectrons is proportional to the intensity of incident light, $I = nh\upsilon$ where n is the number of photons emitted/absorbed per unit area per second. n and $h\upsilon$ are independent factors.

28. **(A)** Momentum of a photon is given by

$p = h/\lambda$ (by de broglie hypothesis) ...(i)

Also the photon is a form of energy packet behave as a particle and having energy

$E = hc/\lambda$ ...(ii)

From (i) and (ii), $p = \frac{E}{c}$ or, $\frac{h\upsilon}{c}$.

29. **(C)** Assertion is correct, but the work function only depends on the photoelectric metal.

30. **(B)** Stopping potential is a measure of maximum kinetic energy of emitted photoelectron ($eV_0 = K_{max}$) and K_{max} depends upon the frequency of incident light but is independent of intensity.

31. **(A)** Equivalent mass of photon (m) is given from equation

$E = mc^2 = h\upsilon \qquad \therefore \quad m = \frac{h\upsilon}{c^2}$

Where E is energy, m is mass, c is speed of light, h is Planck's constant, υ is frequency.

$\therefore$ Momentum of photon $= m \times \frac{h\upsilon}{c^2} \times c = \frac{h\upsilon}{c}$

32. **(A)** **33.** **(A)** **34.** **(A)**

35. **(B)** Photoelectric emission have been adequately explained by Einstein on the basis of photon theory of light.

36. **(C)** As per Bohr's model of hydrogen atom, the angular momentum of the electron in allowed orbits is given by

$L = \frac{nh}{2\pi}$, n = 1, 2, 3,..... For the second orbit n = 2,

$L = 2\frac{h}{2\pi} = \frac{h}{\pi}$.

37. **(B)** When the high energy electron hits the target and takes out an electron from the inner orbit, there is a possibility of an outer electron to fall down to fill up that vacancy. And when such a transition of electron takes place from a higher energy level to a lower energy level, the difference of energy between the two levels is given off in the form of radiation known as characteristic X-rays.

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38. (B) Total energy = kinetic energy + potential energy
Potential energy = – 2 × kinetic energy
= 2 × 13.6 = – 27.2 eV.

39. (B) : According to Moseley's law

$(Z-\sigma)\propto\sqrt{f}$ or, $f\propto(Z-\sigma)^2$.

Note : The correct answer should have been f μ $(Z-\sigma)^2$ where σ is the screening constant. Many authors use at this level, σ = 1 approximately.

40. (A) $\vec{L}=n\cdot\frac{h}{2\pi}$, $\mu_n=\frac{e}{2m}\cdot n\frac{h}{2\pi}$ i.e. $\mu\propto n$.

41. (B) $\lambda_{min}=\frac{hc}{eV}=\frac{1.242\times10^{-6}}{V}$

$V=\frac{1.242\times10^{-6}}{10^{-11}}=124.2\,kV$

The accelerating voltage for electrons in X-ray machine should be greater than 124.2 kV.

42. (C) For hydrogen like atoms like He^+, Li^{++} etc, the energy of the electron in an n^{th} orbit is given by

$E_n=\frac{-Z^2 13.6}{n^2}eV$. For He^+, Z = 2

$\therefore\quad E_1=\frac{-(2)^2 13.6}{(1)^2}eV=-54.4\ eV$

43. (C) One has to use higher energy to produce radiation in the visible region. In CO_2 laser two electrodes produce discharge which is used. Therefore ultraviolet rays are used to produce light in any lower energy region.

44. (D)

45. (A) Magnetic moment associated with electrons orbitting around the nucleus is given in terms of Bohr magneton (μB)

$\mu_B=\frac{e\hbar}{2m_e}$

e = electronic charge, m_e = electronic mass.

In nuclear physics, magnetic moments associated with the spins of protons and neutrons are expressed in nuclear magnetons (μ_N)

$\mu_N=\frac{e\hbar}{2m_P}$

m_p = mass of a proton.

$\Rightarrow\quad\frac{\mu_B}{\mu_N}=\frac{m_P}{m_e}$

46. (A) Wavelengths of the K_α lines for given isotopes of lead (Pb) can be given by a general expression

$\frac{1}{\lambda}=R(Z-1)^2\left(\frac{1}{1^2}-\frac{1}{2^2}\right)$

where R = Rydberg's constant, Z = atomic number of the isotopes. Though Pb^{208}, Pb^{206} and Pb^{204} have different atomic mass, Z will be same for them i.e. 82.

$\therefore\quad\frac{1}{\lambda_1}=R(82-1)^2\left(\frac{1}{1^2}-\frac{1}{2^2}\right)=\frac{3}{4}R(81)^2$

$\frac{1}{\lambda_2}=\frac{3}{4}R(81)^2$ and $\frac{1}{\lambda_3}=\frac{3}{4}R(81)^2$

$\Rightarrow\quad\left(\frac{1}{\lambda_3}\right)=\frac{1}{\lambda_1}\times\frac{1}{\lambda_3}\Rightarrow\quad\lambda_2=\sqrt{\lambda_1\lambda_3}$

47. (C) For Brackett series, $n_1=4$, $n_2=5, 6, 7$ .....

$\frac{1}{\lambda}=R\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)$

where $R=1.09678\times10^7\ m^{-1}$, called Rydberg's constant.

$\frac{1}{\lambda}=R\left(\frac{1}{4^2}-\frac{1}{n_2^2}\right)$

For maximum wavelength, $n_2=5$

$\frac{1}{\lambda_{max}}=1.09687\times10^7\left(\frac{1}{4^2}-\frac{1}{5^2}\right)$

$\lambda_{max}=40519$ Å

48. (A) $r=\frac{n^2}{Z}\times0.529$

For He^+, n = 2, Z = 1

$r=\frac{4}{2}\times0.529=1.058$Å

49. (A)

50. (B) Lyman series is obtained when an electron jumps to the first orbit ($n_1=1$) from any outer orbit ($n_2=2, 3, 4...$)

$\frac{1}{\lambda}=RZ\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$

For H, Z = 1 and R is the Rydberg's constant $R=1.097\times107\ m^{-1}$. In this series, the shortest wavelength or the limit of this series

(For $n_1=1$ and $n_2=\infty$) is nearly = 911 Å

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51. (B) Magnetic dipole moment of electron in an atom is given as

$$M = \frac{neh}{2\pi m} = n\mu_B$$

where, n = number of orbit

μ_B = Bohr Magneton

For minimum dipole moment, n = 1

$$\therefore \quad M = \frac{eh}{4\pi m}$$

52. (A) Total energy of an electron in hydrogen atom above 0 eV leads to continuation of energy state.

53. (C) The transition equation for Lyman series is given by

$$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$$

for largest wavelength , n = – 2

$$\therefore \quad \frac{1}{\lambda_{max}} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$$

The transition equation for Balmer series is given by

$$\frac{1}{\lambda} = R9\left(\frac{1}{1^2}\frac{1}{2^2}\right) \frac{1}{\lambda} = R9\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

for largest wavelengths, n = 3

$$\therefore \quad = \frac{n(n-l)}{2} = \frac{3(3-l)}{2} = 3$$

Therefore, $\frac{\lambda_{L_{max}}}{\lambda_{B_{max}}} = \frac{\left(\frac{1}{2^2} - \frac{1}{3^2}\right)}{\left(\frac{1}{1^2} - \frac{1}{2^2}\right)} = \frac{\frac{5}{36}}{\frac{3}{4}} = \frac{5}{27}$

54. (B) For the first line of Balmer series,

$$\frac{1}{\lambda_1} = R\left(\frac{1}{2^2} - \frac{1}{3^3}\right) = \frac{5R}{36}$$

For the second line of Balmer series.

$$\frac{1}{\lambda_2} = R\left(\frac{1}{2^2} - \frac{1}{4^2}\right) = \frac{3R}{16}$$

$$\therefore \quad \frac{\lambda_2}{\lambda_1} = \frac{5R/36}{3R/16} = \frac{20}{27};$$

or $\lambda_2 = \frac{20}{27}(6561\ \text{Å}) = 4860\ \text{Å}$

55. (B) Radius of n^{th} orbit in hydrogen like atoms is

$$r_n = \frac{a_0 n^2}{Z}$$

where a_0 is the Bohr's radius

For hydrogen atom, Z = 1

$\therefore \quad r_1 = a_0$ ($\therefore$ n = 1 for ground state)

For Be^{3+}, Z = 4

$$\therefore \quad r_n = \frac{a_0 n^2}{4}$$

According to given problem

$$r_1 = r_n,\ a_0 = \frac{n^2 a_0}{4},\ n = 2$$

56. (A) When energy of electron in a hydrogen atom goes above 0 eV then it leaves the atom. Hence hydrogen atom becomes ionised.

57. (D) Energy in the excited state = – 13.6 + 12.1

= – 1.5 eV

$$\therefore \quad -\frac{13.6}{n^2} = -1.5 \quad \text{or} \quad n = \sqrt{\frac{13.6}{1.5}} = 3$$

$\therefore$ Number of spectral lines

$$= \frac{n(n-1)}{2} = \frac{3(3-1)}{2} = 3$$

58. (A) As laser is highly monochromatic and highly coherent, we can send as a laser beam to the moon, from where it comes back reflected without much loss of intensity. That's why the large distance can be measured accurately with the help of laser.

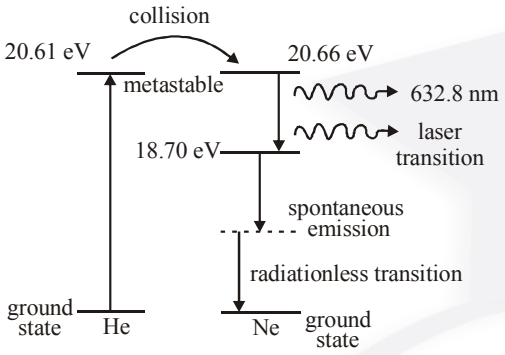
59. (D) The tube light is nothing but a gas discharge tube, which can emit light of different colours. This colour depends mainly upon the nature of the gas inside the tube and the nature of the glass. For neon gas the colour is bright red and for CO_2 it is bluish. Again the fluorescent glow looks yellowish green for soda glass. So it is the nature of the glass and the gas inside the tube which determines the colour of the fluorescent glow. As argon is filled inside a tube light, the colour of the light is white.

60. (B) According to classical physics, all moving charged particle radiate electromagnetic radiation. So moving electrons will also radiate energy. If we see the atomic structure we find the electrons revolve around the nucleus in some particular orbits. Bohr termed these orbits as the stationary orbits as the electrons do not radiate energy as long as they are moving in these orbits.

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This is one of Bohr's postulates. This postulate is based on the fact that if the moving electrons radiate thereby losing energy, they have got a chance to finally fall back onto the nucleus and the atom will be collapsed.

61. (A) Helium-neon laser uses a gaseous mixture of helium and neon. An electric discharge in the gas pumps the helium atoms to higher energy level, (which is meta stable energy level).



Sequence of transitions in He-Ne laser.

Then these helium atom excite the neon atoms to higher lever by collision and produce and inverted population of neon atom which emit radiation when they are stimulated to fall to lower level.

62. (A) For diffraction, the slit width should be of the order of the incident wavelength. The regular spacing of the atoms in crystal is of the order of wavelength ox X-rays (0.1 nm) because of which X-rays are diffracted from the crystals.

63. (C) The process of nuclear fusion can be explained with the help of concept of binding energy per nucleon of very light nuclei and the intermediate nuclei. Binding energy per nucleon of very light nuclei is less than that of intermediate nuclei. It means light nuclei are less stable than that of intermediate nuclei. As ^{35}Cl has a large binding energy therefore it cannot be used as fuel for fusion energy.

64. (C) Assertion is correct in the sense that the free electrons occupy a single energy band. But a ban has a distribution of energy. One can treat assertion as correct. But the reason is false because electrons in a metal follow Pauli's exclusion principle. It is because of this, one has different bands. Therefore the answer is **(C)**.

65. (D) Emission transitions can take place between any higher energy level and any energy level below it while absorption transitions start from the lowest energy level only and many end at any higher energy level. Hence number of absorptions transition between two given energy level. Hence number of absorptions transitions between two given energy level is always less than the number of emission transition between the same two levels.

66. (C) The earth's atmosphere is transparent to visible light and radio waves, but absorbs X-rays. Therefore X-rays telescope cannot be used on earth surface.

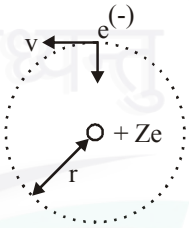
67. (B)

68. (C) We know that $E = -\frac{13.6}{n^2}eV$

It shows that total energy of electron in a stationary orbit in a hydrogen atom is negative, which means the electron is bound to the nuclear and is not free to leave it.

69. (C) According to postulates of Bohr's atom model, the electron revolve around the nucleus in fixed orbit of definite radii. As long as the electron is in a certain orbits it does not radiate and energy. Not only the centripetal force has to by the centrifugal force, even

the stable orbits are fixed by Bohr's theory.



70. (B) : Let number of nuclei at the beginning $= N_0$

Let the time required for 33% decay $= t_1$

Then $0.67N_0 = N_0e^{-\lambda t_1}$

$\Rightarrow e^{-\lambda t_1} = 0.67$ ...(i)

Time required for 67% decay $= t_2$

$\therefore \quad e^{-\lambda t_2} = 0.33$ ...(ii)

[Since after 33% decay, 67% will remain and after 67% decay, 3% will remain].

$\therefore \quad (ii) \div (i) \Rightarrow e^{-\lambda(t_2 - t_1)} = \frac{0.33}{0.67} = \frac{1}{2}$

$\therefore \quad -\lambda(t_2 - t_1) = \ln\left(\frac{1}{2}\right)$

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$$\therefore \quad t_2 - t_1 = -\frac{\ln\left(\frac{1}{2}\right)}{\lambda} = -\frac{\ln\left(\frac{1}{2}\right)\times T_{1/2}}{0.693}$$

$$= -\frac{\ln\left(\frac{1}{2}\right)\times 20}{-\ln\left(\frac{1}{2}\right)} = 20 \text{ minutes}$$

71. **(B)** $T_{1/2} = 20$ years, $N_0 = 10$ g, $N = 2.5$ g

$$N = N_0 e^{-\lambda t} \text{ where } \lambda = \frac{0.693}{T_{\frac{1}{2}}} \Rightarrow e^{-\lambda t} = \ln\left(\frac{N}{N_0}\right)$$

$$\Rightarrow \quad t = \frac{1}{\lambda}\ln\left(\frac{N_0}{N}\right) = \frac{T_{\frac{1}{2}}}{0.693}\times\ln\left(\frac{N_0}{N}\right)$$

$$t = \frac{20}{0.693}\times\ln\left(\frac{10}{2.5}\right) = 40 \text{ years}$$

72. **(C)** Activity of radioactive substance, $A = A_0 e^{-\lambda t}$

$$\Rightarrow \quad \frac{A}{A_0} = e^{-\lambda t} = e^{-\frac{0.693}{T_{1/2}}t} \qquad \left[\because T_{1/2} = \frac{0.693}{\lambda}\right]$$

$$\Rightarrow \quad \frac{1}{16} = e^{-\frac{0.693\times 40}{T_{1/2}}} \Rightarrow \frac{0.693\times 40}{T_{1/2}} = \ln 16$$

$$\Rightarrow \quad T_{1/2} = \frac{0.693\times 40}{\ln 16} = 9.997 \approx 10 \text{ days.}$$

73. **(A)** Nuclear fusion is possible only between light nuclei. The nuclear process of two light nuclei getting close enough to produce a larger nucleus is energetically favourable reaction.

74. **(C)**

75. **(C)** $^{A}X \rightarrow {}^{A-4}Y + \alpha^4$

(parent nucleus) (daughter nucleus)

As the parent nucleus is at rest, then according to conservation of momentum.

$$\Rightarrow \quad 0 = m_Y v_Y + m_\alpha v_\alpha \Rightarrow 0 = (A-4)v_Y \ \ 4v$$

$$\Rightarrow \quad v_Y = \frac{-4v}{A-4}, \text{ the recoil speed of daughter nucleus.}$$

76. **(B)** When electron-positron pari annihilate each other, the energy released is equal to rest mass of electron and positron.

$$e^- + e^+ \rightarrow \gamma_1 + \gamma_2$$

$[E_{\gamma_1} = E_{\gamma_2} = 0.511 \text{ MeV} = 0.8\times 10^{-13} \text{ J}]$

The total energy released = 1.6×10^{-13} J.

77. **(A)** MRI is extension of NMR or nuclear magnetic resonance imaging. Magnetic resonance imaging is a noninvasive technique which uses strong magnetic field for generating resonance at low radio frequency in the protons present in the body.

78. **(B)** Using carbon dating, samples of wood, charcoal, bones, and shells have been identified as having lived 1000 to 25000 years ago.

79. **(A)** The graph showing that greater the binding energy per nucleon, the more stable the nucleus is. The graph has its maximum of 8.8 MeV/nucleus that has 56 protons and neutron is $^{56}_{23}$Fe, an iron isotope. This is the most stable nucleus of them all, since maximum energy is needed to pull a nucleon away from it.

80. **(C)** $T_{1/2} = 10$ days, $T = 30$ days

$$T = n \times T_{1/2}. \quad n = \frac{T}{T_{1/2}} = \frac{30}{10} = 3$$

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^3 = \frac{1}{8} = 0.125.$$

81. **(A)** If multiplication factor K = 1, the operation of nuclear reactor is said to be critical. If it is less than one, reaction can be sustained and if the multiplication factor is more than one, the reaction becomes uncontrolled. It is an explosion.

82. **(B)** Emission of alpha particle, decrease the mass number by 4 and atomic number, = Z by 2.

$\therefore$ Decrease in mass number = 238 – 4 = 234

Decrease in charge number = 92 – 2 = 90

$^{234}_{90}$Th is emitted.

83. **(C)** After 5730 years, the number of C^{14} remaining is $\frac{1}{2}^{\text{th}}$ original. To have (1/16) original value, it takes (1/2)4, 4 half lives.

Therefore, the bone is 4 × 5730 years

= 22920 years old.

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84. **(C)** According to conservation of mass number,

$10+4=13+1$

According to conservation of charge number,

$5+2\neq 7+1$

Hence **(A)** is not possible.

According to conservation of charge number,

$93=94-1$

According to conservation of mass number,

$239=239$

Hence **(C)** is possible.

According to conservation of mass number,

$11+1=12$

According to conservation of charge number,

$7+1\neq 6-1$

Hence **(D)** is not possible.

$^{23}_{11}Na + {}^{1}_{1}H$ also satisfies both the conservation of mass number and charge.

85. **(C)** $\underset{\text{Deuterium}}{{}^{2}_{1}H} + \underset{\text{Tritium}}{{}^{3}_{1}H} \rightarrow \underset{\text{Helium}}{{}^{4}_{2}He} + \underset{\text{neutron}}{{}^{1}_{0}n} + Q$

The energy released in the process is given by

$$Q=\left[M_{{}^{2}_{1}H}+M_{{}^{3}_{1}H}-M_{{}^{4}_{2}He}-M_{{}^{1}_{0}n}\right]c^2$$

$$=[2.014102+3.016050-4.002603-1.008665]\,uc^2$$

$$=(0.018884\,u)\left[931.5\frac{MeV}{u}\right]=17.6\,MeV.$$

86. **(C)** Mass of $^{235}_{92}U$ used per second in the reactor is

$$m=\frac{2\times10^3}{30\times24\times60\times60}=7.72\times10^{-4}\,g/sec$$

$\therefore$ Number of fissions reaction per second

$$=\frac{6\times10^{23}}{235}\times m=\frac{6\times10^{23}\times7.72\times10^{-4}}{235}$$

$$=1.97\times10^{18}/sec$$

Power of nuclear reactor $=1.97\times10^{18}\times185$ MeV/s

$=1.97\times10^{18}\times185\times10^{6}\times1.6\times10^{-19}$ J/s.

$=58.3$ MW.

87. **(B)** $-\frac{dN}{dt}=\lambda N \Rightarrow N_2=\lambda N_1$ or $\lambda=N_2/N_1$.

88. **(C)** Let the reaction be represented as

$$\underset{Z}{^{220}X}\longrightarrow \underset{Z-2}{^{216}Y}+\underset{2}{^{4}He}$$

$\because$ energy released in the reaction is 5 MeV

$$\Rightarrow \frac{1}{2}m_Y v_Y^2+\frac{1}{2}m_\alpha v_\alpha^2=MeV$$

$$\Rightarrow \frac{1}{2}(216)v_Y^2+\frac{1}{2}4(v_\alpha)^2=5\ MeV \qquad ...(i)$$

Also using conservation of linear momentum.

$$M_Y v_Y=-m_\alpha v_\alpha \Rightarrow v_Y=\frac{-m_\alpha}{m_Y}v_\alpha$$

Putting in eqn. (i)

$$\frac{1}{2}(216)\left(\frac{v_\alpha}{54}\right)^2+\frac{1}{2}4(v_\alpha)^2=5\ MeV$$

$$\frac{1}{2}(216)\left(\frac{v_\alpha}{54}\right)^2+K.E._\alpha=5\ MeV$$

$$\Rightarrow \frac{1}{2}\times4\frac{v_\alpha^2}{54}+K.E._\alpha=5\ MeV$$

$$\Rightarrow \frac{1}{54}(K.E._\alpha)+K.E._\alpha=5\ MeV$$

$$K.E._\alpha=\frac{5\times54}{55}=\frac{54}{11}\ MeV$$

89. **(A)** $T=\frac{T_\alpha T_\beta}{T_\alpha+T_\beta}=\frac{4\times12}{4+12}$

$$n=\frac{t}{T}=\frac{12}{3}=4$$

$$\frac{N}{N_0}=\left(\frac{1}{2}\right)^n=\left(\frac{1}{2}\right)^4=\frac{1}{16}=6.25\%$$

90. **(D)** Maximum number of nuclei will be present, when rate of decay = rate of formation

$$\lambda\,.\,N=\alpha,\ N=\frac{\alpha}{\lambda}$$

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91. (C) At t = 0, N = N_0 for both the substances A and B

$\therefore \quad N_A = N_0 e^{-\lambda_A t}$ and $N_B = N_0 e^{-\lambda_B t}$

$$\frac{N_A}{N_B} = \frac{e^{-\lambda_A t}}{e^{-\lambda_B t}} = e^{(\lambda_B - \lambda_A)t} = e^{(\lambda - 5\lambda)t} = e^{-4\lambda t} = \left(\frac{1}{e}\right)^{4\lambda t}$$

As $\frac{N_A}{N_B} = \left(\frac{1}{e}\right)^2$ [According to question]

$\therefore \quad 4\lambda t = 2$

or $\quad t = \frac{2}{4\lambda} = \frac{1}{2\lambda}$

92. (B) $\because \quad I I_0 e^{-kx} \Rightarrow \frac{I}{I_0} = e^{-kx}$

$\therefore \quad \text{In}\left(\frac{I}{I_0}\right) = -kx$

In first case

$\text{In}\left(\frac{1}{8}\right) = -k \times 36$

$\text{In}\,(2-3) = -k \times 36$

or $3\ln 2 = k \times 36$ ...(i)

In second case, $\text{In}\left(\frac{1}{2}\right) = -k \times x$

or $\text{In}(2-1) = -kx$

or $\ln 2 = kx$ ...(ii)

From (i) and (ii)

$3 \times (kx) = k \times 36$

or $x = 12$ mm.

93. (A) Here $R_1 = 2$ fm, $R_2 = 1$ fm

The radius of nucleus is, $R \propto A^{1/3}$

$\therefore \quad \frac{A_1}{A_2} = \left(\frac{R_1}{R_2}\right)^3 = \left(\frac{2}{1}\right)^2 = 8$

94. (A) At k = 1, the chain reaction will be steady or sustained and the size of the fissionable material used is said to be the critical size.

95. (A) Here, t = 25 years, $T_{1/2} = 5$ years

Number of half lives, $n = \frac{t}{T_{1/2}} = \frac{25}{5} = 5$

Percentage of radio active material remained after 25 years

is $= \left(\frac{1}{2}\right)^n \times 100$

$= \left(\frac{1}{2}\right)^5 \times 100 = 3.125\%$

96. (C) In nuclear reactor, to control the chain reaction from becoming violent, rods of boron or cadmium called control rods are inserted in the holes of reactor core.

97. (D) The α-emission of S^{32} is as follows :

$_{16}S^{32} \rightarrow {}_{14}Si^{28} + 2He^4$

$_{14}Si^{28} \rightarrow {}_{12}Mg^{24} + 2He^4$

So after the emission of two a-particle $_{12}Mg^{24}$ is formed

98. (C) Here, $T_{1/2} = 8$ years

t = 32 years

Using, $N = N_0\left(\frac{1}{2}\right)^{\frac{t}{T_{1/2}}}$

$\left(\frac{N}{N_0}\right) = \left(\frac{1}{2}\right)^{\frac{32}{8}} = \left(\frac{1}{2}\right)^4$

$\left(\frac{N}{N_0}\right) = \frac{1}{16}$

99. (D) The Gamma decay due to instability of nucleus is excess energy of nucleus.

100. (D) Emission of α-particle decreases the mass number and the atomic number by 4 and 2 respectively. Emission of β-particle increases the atomic number by 1 while the mass number remains unchanged.

After the emission of the one α-particle and two β-particles

Decreases in mass number = 4 – 0 = 4

Decreases in atomic number = 2 – 2 = 4

$\therefore$ The resulting the nucleus is $_n^{m-4}X$.

i.e. the isotope of the given nucleus.

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101. (D) In nuclear fission or fusion both energy and mass are conserved.

102. (B) Number of fission per second

$$= \frac{\text{total power}}{\text{energy / fission}}.$$

Here, total power = 100 W

energy/fission = 200 MeV

$= 200 \times 10^6 \times 1.6 \times 10^{-19}\ J = 3.2 \times 10^{-11}\ J.$

$$\therefore \quad \text{fission rate} = \frac{100}{3.2\times10^{-11}} = 3.1\times10^{12}\,s^{-1}$$

103. (C) A free neutron is unstable $(n \rightarrow p + \bar{e} + \bar{\nu})$. But a simlar free proton decay is not possible, since a proton is (slightly) lighter than a neutron.

104. (B)

105. (C) As $R = \lambda N$, $n = \lambda N$, or $\lambda = (n/N)$

$$T_{1/2} = \frac{0.693}{\lambda} = \frac{0.693N}{n}s$$

106. (A) Half-life, T = 1600 years

Time of decay, t = 6400 years

Number of half-lives, $n = \frac{t}{T} = \frac{6400}{1600} = 4$

Fraction undecayed $= \frac{N}{N_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^4 = \frac{1}{16}$

107. (D) $_7X^{15} + 2He^4 \rightarrow {}_1H^1 + {}_zY^A$

Alpha particle — Proton

According to the law of conservation of charge, we get

$7 + 2 = 1 + Z$

$Z = 18$

According to the law of conservation of mass, we get

$15 + 4 = 1 + A$

$A = 18$

Hence, the resulting atom has mass number 18 and atomic number 8.

108. (C) Nuclear stability depends upon the ratio of neutron to proton. If the n/p ratio is more than the critical value, then a neutron gets converted into a proton forming a β^- particle in the process.

$n \rightarrow p + e^- + \bar{\upsilon}$

The β^- particle (e^-) is emitted from the nucleus in some radioactive transformation. So electrons do not exist in the nucleus but they result in some nuclear transformation.

109. (B) A radiation consists of a beam of charged particles. Normally the radiation that is used for cancer treatment is a light energy radiation which when imposed upon the cancerous tissues, destroys the cancer cells.

110. (B) Neutrons, because of the neutral charge penetrate matter more easily than do charged particles e.g., protons and electrons.

111. (A) A bombarding particle gives up most energy when it makes an elastic collision with a particle of similar mass. For neutrons, hydrogen atoms would be most effective but unfortunately absorption occurs. However, deuterium (heavy water) and carbon (as graphite) are both suitable in which less absorption occurs. Therefore they are used as moderators.

112. (B) The decrease in binding energy per nucleon for heavy nuclei (A > 100) due to increase in coulomb repulsion between the protons inside the nucleus.

113. (A) Magnetic Resonance Imaging is based on the nuclear magnetic resonance of protons.

114. (A)

115. (A) Assertion is true. $^{90}_{38}Sr$ decays to $^{90}_{39}Y$ by the emission of β-rays. Sr gets absorbed in bones along with calcium.

Reason is also true. $^{90}sr \xrightarrow{\beta} {}^{90}Y$

Strontium decays to Yitrium. This emits β-rays of very high energy. Sr does not emit γ-rays. The damage is by the β-rays only.

116. (C) The assertion is true because heavy - water is a better moderator than ordinary water. This is because heavy water absorbs fewer neutrons than normal water.

117. (B) Hardness penetrating power of X-ray depends upon accelerating voltage applied across X-ray tube. Characteristic X-ray relate to the material of target. X-ray can't pass through matter of heavier element like bones (which contain phosphorus and calcium) but can pass through matter of lighter element as flesh (which contain oxygen, hydrogen and carbon)

118. (B) The nuclei having mass number $A \approx 60$ have maximum binding energy per nuclear (about 8.7 MeV). So, these nuclei are most stable.

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119. (A) Multiplication factor (K) is a measure of the growth rate of neutrons in the reactor. For K = 1; the operation of the reaction is said to be critical condition at which sustained chain reaction occurs. If K becomes greater than the reaction rate and reactor power increases exponentially.

120. (A) **121. (D)**

122. (C) The average energy of a neutron produced in fission of U^{235} is 2 MeV. These neutrons unless slowed down will escape from the reactor without interacting with uranium nuclei, unless a large amount of fissionable material is used for sustaining the chain reaction. What we needs to do is to slow down the fast neutrons by elastic scattering with light nuclei. Chadwick's experiment showed that in an elastic collision with hydrogen neutron almost come to rest.

123. (A) **124. (B)** **125. (A)**

126. (C) The emission of γ rays by a $^{60}_{27}Co$ nucleus is subsequent to beta decay.

127. (A) Time taken for the light emission from an atom $\approx 10^{-8}$.

Time taken for release of energy in fission $\approx 10^{-6}$

Required ratio $= \frac{10^{-8}}{10^{-6}} = \frac{1}{100} = 1:100$

128. (A) **129. (B)**

130. (B) In heavy nuclei, the repulsive forces between the protons are more effective than the nuclear attractive forces and these forces reduce the stability of the nucleus.

131. (C) When two bodies of same mass undergo an elastic collision, their velocities are interchanged after collision. Water and heavy water are hydrogenic materials containing protons having approximately the same as that of a neutron. When fast moving neutrons collide with protons, the neutrons come to rest and protons move with the velocity of that of neutrons.

132. (B)

MOCK TEST

1. (B) We have $K_\alpha = \frac{m_y}{m_y + m_\alpha}.Q$

$\Rightarrow K_\alpha = \frac{A-4}{A}.Q$

$\Rightarrow 48 = \frac{A-4}{A}.50 \Rightarrow A = 100$

2. (C) Angular momentum $(mvr) = n.\frac{h}{2\pi}$

$= \frac{h}{2\pi}(n = 1)$

3. (C) First excitation energy $= RhC\left(\frac{1}{1^2} - \frac{1}{2^2}\right)$

$= RhC\,\frac{3}{4}$

$\therefore \frac{3}{4} RhC = V$ e.v.

$\therefore RhC = \frac{4V}{3}$ e.v.

4. (D) The electron ejected with maximum speed v_{max} are stopped by electric field E = 4N/C after travelling a distance d = 1m

$\therefore \frac{1}{2} mV_{max}^2 = eE\,d = 4eV$

The energy of incident photon $= \frac{1240}{200} = 6.2$ eV

From equation of photo electric effect

$\frac{1}{2} mv_{max}^2 = h\upsilon - \phi_0$

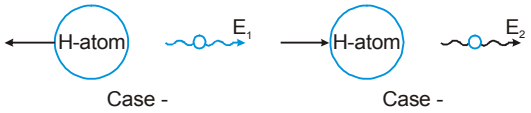
$\therefore \phi_0 = 6.2 - 4 = 2.2$ eV.

5. (B) $\lambda = \frac{h}{\sqrt{2mK}}$

$\Rightarrow \frac{\lambda_e}{\lambda_p} = \sqrt{\frac{M}{m}}$

K = qV is same for both proton and electron.

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6. **(B)** 

In the first case K.E. of H-atom increases due to recoil whereas in the second case K.E. decreases due to recoil but $E_1 + KE_1 = E_2 + KE_2$.

$\therefore \quad E_2 > E_1$

7. **(A)** Linear momentum $\Rightarrow mv \alpha \frac{1}{n}$

angular momentum $\Rightarrow mvr \alpha n$

$\therefore$ product of linear momentum and angular momentum α n

8. **(C)** Energy of photon is given by mc^2 now the maximum energy of photon is equal to the maximum energy of electron = eV

hence $mc^2 = ev$

$$\Rightarrow m = \frac{eV}{c^2}$$

$$= \frac{1.6\times10^{-19}\times18\times10^{3}}{(3\times10^{8})^2} = 3.2\times10^{-32}\,kg$$

9. **(D)** Using $\frac{1}{\lambda} = R(z-1)^2\left[\frac{1}{n_2^{\,2}} - \frac{1}{n_1^{\,2}}\right]$

For α particle ; $n_1 = 2, n_2 = 1$

For metal A ; $\frac{1875R}{4} = R(Z_1 - 1)^2\left(\frac{3}{4}\right)$

$\Rightarrow z_1 = 26$

For metal B; $675R = R(Z_2 - 1)^2\left(\frac{3}{4}\right)$

$\Rightarrow z_2 = 31$

Therefore, 4 elements lie between A and B, i.e. with Z= 27, 28 ,29 , 30

10. **(D)** For 2nd line of Balmer seires in hydrogen specturm

$$\frac{1}{\lambda} = R(1)\left(\frac{1}{2^2} - \frac{1}{4^2}\right) = \frac{3}{16}R$$

For Li^{2+} $\frac{1}{\lambda} = R(3)^2\left(\frac{1}{6^2} - \frac{1}{12^2}\right) = \frac{3}{16}R$

which is satisfied by only (D).

11. **(A)** We have : K.E. $= \frac{P^2}{2m_e} = \frac{hc}{\lambda_{min}}$.

$$\Rightarrow \quad P = \sqrt{\frac{2hcm_e}{\lambda_{min}}}$$

Also, $\lambda_{de\ broglie} = \frac{h}{p} = \sqrt{\frac{h\lambda_{min}}{2m_eC}}$

for $\lambda_{min} = 10Å$: $\lambda_{de\ broglie} \cong 0.3Å$

12. **(D)** Energy of n^{th} sate in Hydrogen is same as energy of $3n^{th}$ state in Li^{++}.

$\therefore$ $3 \rightarrow 1$ transition in H would give same energy as the $3\times3 \rightarrow 1\times3$ transition in Li^{++}.

13. **(D)** $\frac{1}{2}mv^2 = \frac{hc}{\lambda} - \phi$

$$\frac{1}{2}mv'^2 = \frac{hc}{(3\lambda/4)} - \phi$$

$$= \frac{4hc}{3\lambda} - \phi$$

Clearly $\quad v' > \sqrt{\frac{4}{3}}\,v$

14. **(B)** No. of photoelectron emitted per second,

$$n = \frac{\text{Power (watt)}\times\text{Emission \%}}{\text{Energy of 1 photon (inJ)}\times100}$$

$$= \frac{1.5\times10^{-3}\,W\times(10^{-3})\times0.1}{\frac{1240(nm)(eV)}{400(nm)}\times e\times100} = \frac{0.48}{e}\times10^{-6}.$$

(energy of 1 photon $= \frac{1240\,nm/eV}{400\,nm\times e}$ Joule)

$\therefore$ Photo current = ne $= 0.48\ \mu A$

15. **(A)** for K_α $\frac{1}{\lambda_\alpha} = \frac{3R}{4}(Z-1)^2$

transition is from n =2 to n =1

$$\Rightarrow \quad (Z-1) = \sqrt{\frac{4}{3R\lambda_\alpha}}$$

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$$= \sqrt{\frac{4}{3\times1.1\times10^{7}\times1.8\times10^{-10}}}$$

$$= \frac{200}{3}\sqrt{\frac{5}{33}} = \frac{78}{3} = 26. \Rightarrow Z = 27$$

16. **(B)** λ_m will increase to $3\lambda_m$ due to decrease in the energy of bombarding electrons. Hence no characteristic x-rays will be visible, only continous X-ray will be produced.

17. **(D)** $\because B = \frac{\mu_0 I}{2r}$ and $I = \frac{e}{T}$

$$B = \frac{\mu_0 e}{2rT} \quad [r \propto n^2, T \propto n^3]$$

$$\Rightarrow B \propto \frac{1}{n^5}$$

18. **(C)** $i = \frac{q}{T}$ Now $T^2 \propto r^3 \propto n^6$

$$\Rightarrow i \propto \frac{1}{n^3}$$

$$\Rightarrow T \propto n^3 \quad \frac{i_1}{i_2} = \frac{H_2^3}{H_1^3} = \frac{(1)^3}{(2)^3} = i_2 = 8i_1$$

19. **(C)** As a proton is lighter than a neutron, proton can not be converted into neutron without providing energy from outside. Reverse is possible. The weak interaction force is responsible in both the processes (i) conversion of p to n and (ii) conversion of n to p.

20. **(B)**

21. **(B)** $A_p = A_Q e^{-\lambda t} = A_Q e^{-\frac{1}{T}t} \quad \therefore \quad t = T\,\ell n \frac{A_Q}{A_P}$

22. **(B)**

23. **(D)** $n = \lambda N \quad = \lambda = \frac{n}{N} \quad \therefore \quad t_{1/2} = \frac{0.69}{\lambda} = \frac{0.69\ N}{n}$

24. **(D)**

25. **A → p,r ; B → p,r,t ; C → q ; D → s**

Consider two equation

$$eV_s = \frac{1}{2}mv^2_{max} = h\nu - \phi_0 \qquad \text{.... (1)}$$

no of photoelectrons ejected/sec.

$\propto$ no. of photons/second .... (2)

(A) As frequency is increased keeping intensity constant.

$|V_s|$ will increase, $\frac{1}{2}m(v^2_{max})$ will increase and saturation current will remains same.

(B) As frequency is increased and intensity is decreased.

$|V_s|$ will increase, $\frac{1}{2}m(v^2_{max})$ will increase and saturation current will decrease.

(C) It work function is increased photo emission may stop.

(D) If intensity is increased and frequency is decreased. saturation current will increase.

26. **(A)**

27. **(A)** Energy of photoelectron emitted is different because after absorbing the photon electrons within metals collide with other atom before being ejected out of metal.

Hence statement 2 is correct explanation of statement 1.

28. **(B)** de-Broglie wavelength associated with gas molecules varies as $\lambda \propto \frac{1}{\sqrt{T}}$.

29. **(A)** Statement-2 is true by definition and correctly explains the staement-1, namely, ${}_zX^A$ undergoes 2 α decays, 2β decays (negative β) and 2 γ decays. As a result the daughter product is ${}_{z-2}Y^{A-8}$.

30. **(C)** In spontaneous reaction, binding energy increases.

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CHAPTER 10

SOLID AND SEMICONDUCTORS

I have always consistently opposed high-tension and alternating systems of electric lighting, not only on account of danger, but because of their general unreliability and unsuitability for any general system of distribution.

"THOMAS EDISON"

INTRODUCTION

Electronic instruments are being utilized in various fields like telecommunication, entertainment, computers, nuclear physics and many more. Although the history started with the advent of vacuum tubes, however the rapid advancement in electronics which we see today is due to the valuable contributions of semiconductor devices.

Semiconductor devices are not only small in size, consumes less power, have long life times and are more efficient than vacuum tubes but also are of low cost. That is why these have replaced vacuum tubes nearly in all applications. As an Ex. we can consider the case of a computer. In early days, the vacuum tube based computers were as big as the size of a room and were capable of performing simple calculations only. At present the personal computer (PC) that you see in laboratory or at your home is much smaller in size and capable of performing many operations. Needless to say this is possible because of the advances in semiconductor technology.

We will learn the basic concept of semiconductors. This will enable us to understand the operation of many semiconductor devices and then we will be discussing few semiconductor devices like diode, transistor along with their applications.

CLASSIFICATION OF METALS, CONDUCTORS AND SEMICONDUCTORS

On the basis of conductivity

On the basis of the relative values of electrical conductivity (σ) or resistivity ($\rho = 1/\sigma$), the solids are broadly classified as:

(i) Metals: They possess very low resistivity (or high conductivity).

$\rho \sim 10^{-2} - 10^{-8}\ \Omega\,m$

$\sigma \sim 10^{2} - 10^{8}\ S\,m^{-1}$

(ii) Semiconductors: They have resistivity or conductivity intermediate to metals and insulators.

$\rho \sim 10^{-5} - 10^{6}\ \Omega\,m$

$\sigma \sim 10^{5} - 10^{-6}\ S\,m^{-1}$

(iii)Insulators: They have high resistivity (or low conductivity).

$\rho \sim 10^{11} - 10^{19}\ \Omega\,m$

$\sigma \sim 10^{-11} - 10^{-19}\ S\,m^{-1}$

The values of ρ and σ given above are indicative of magnitude and could well go outside the ranges as well. Relative values of the resistivity are not the only criteria for distinguishing metals, insulators and semiconductors from each other. There are some other differences, which will become clear as we go along in this chapter. Our interest in this chapter is in the study of semiconductors which could be:

(i) Elemental semiconductors: Si and Ge

(ii) Compound semiconductors: Ex.s are:

- Inorganic: CdS, GaAs, CdSe, InP, etc.
- Organic: anthracene, doped pthalocyanines, etc.
- Organic polymers: polypyrrole, polyaniline, polythiophene, etc.

Most of the currently available semiconductor devices are based on elemental semiconductors Si or Ge and compound inorganic semiconductors. However, after 1990, a few semiconductor devices using organic semiconductors and semiconducting polymers have been developed signalling the birth of a futuristic technology of polymerelectronics and molecular-electronics. In this chapter, we will restrict ourselves to the study of inorganic semiconductors, particularly elemental semiconductors Si and Ge. The general concepts introduced here for discussing the elemental semiconductors, by-and-large, apply to most of the compound semiconductors as well.

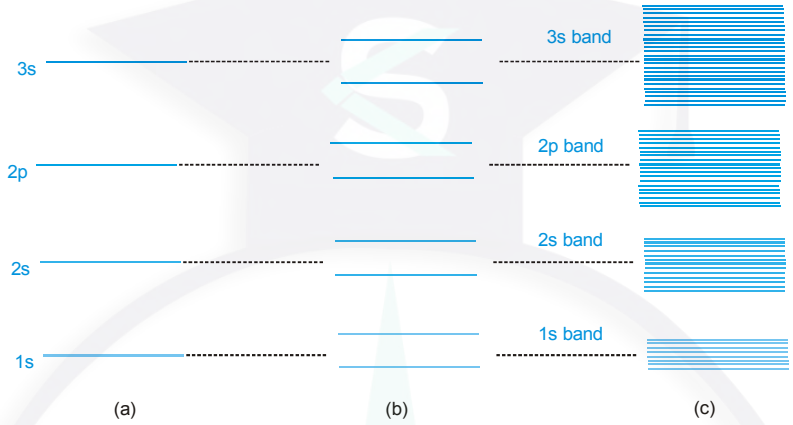
1. Energy Levels and Energy Bands in Solids

The electrons of an isolated atom are restricted to well defined energy levels. The maximum number of electrons which can be accommodated in any level is determined by the Pauli exclusion principle. The electrons belonging to the outermost energy level are called valence electrons. For Ex., the electronic configuration of sodium (atomic number 11) is $-1s^2\ 2s^2\ 2p^6\ 3s^1$, here the electron belonging to the 3s level is the valence electon. Most of the solids including metals with which we are familiar occur in crystalline form.As we know a crystal is a regular periodic arrangement of atoms separated from each other by very small distance called lattice costant.The value of lattice constant is different for diiferent crystalline solids, however it is of the order of linear dimension of atoms {~Å}.

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Obviously at such a short separation between various neighbouring atoms, electrons in an atom cannot only be subjected to the Coulombic force of the nucleus of this atom but also oby Coulombic forces due to nuclei and electrons of the neighbouring atoms. In fact it is this interaction which results in the bonding between various atoms which leads to the formation of crystals.

When atoms are interacting (such as in crystal) then the energy level scheme for the individual atoms as shown in figure(a) does not quite hold. The interaction between atoms affect the electron energy levels, as a result there occurs a splitting of energy levels belonging to various atoms. To understand this phenomenon in more clear terms, let us first consider the simplest case of two interacting identical atoms. Let us assume that initially they are far apart i.e. the forces of interaction between them can be neglected. [If the distance between two atoms is much larger (~50Å) compared to their linear dimensions (~ 10Å) this assumption is reasonably correct] .In such a case we may treat them as isolated with energy levels like that for the case of an isolated atom as shown in figure(a).

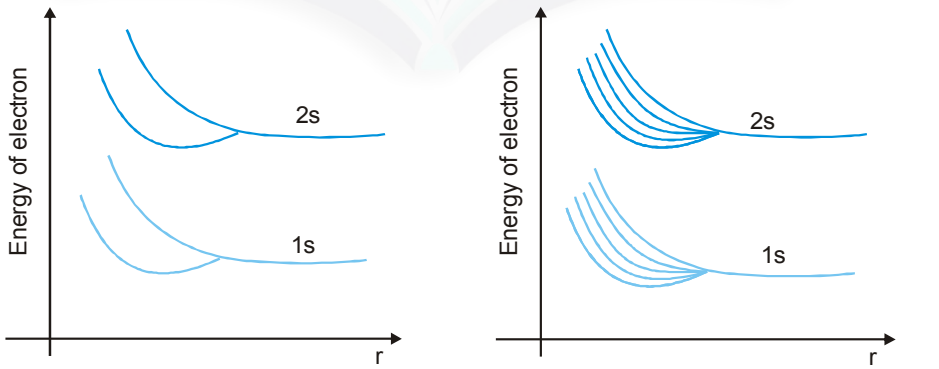


In crystals the number of atoms, N is very large of the order of 10^{22} to 10^{23} per cubic centimetre, so each energy band contains as many levels as the number of atoms. The spacing between various levels within a band is therefore very small. If for Ex. we assume the total width of a band of energies as 1 eV and 10^{22} levels are to be accommodated with in this band, then the average spacing between the adjacent levels is about 10^{-22} eV. For all practical purposes, therefore, energy within a band can be assumed to vary continuously. The formation of bands in a solid is shown schematically in figure(c).

Energy Bands :

This theory is based on the Pauli exclusion principle.

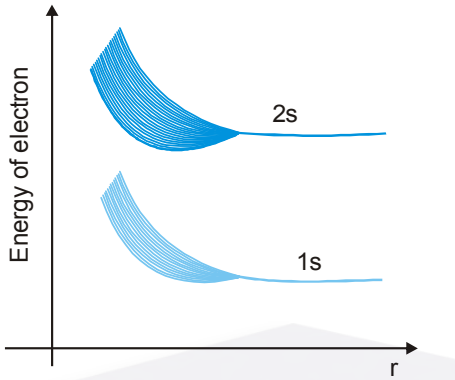
In isolated atom the valence electrons can exist only in one of the allowed orbitals each of a sharply defined energy called energy levels. But when two atoms are brought nearer to each other, there are alterations in energy levels and they spread in the form of bands.



Splitting of 1s and 2s levels when two sodium atoms are brought together

Splitting of 1s and 2s levels when five sodium atoms are brought together

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Formation of energy bands large no. of sodium atoms are assembled to form solid

Energy bands are of following types : –

(1) Valence band : The energy band formed by a series of energy levels containing valence electrons is known as valence band. At 0 K, the electrons fills the energy levels in valence band starting from lowest one.

(i) This band is always filled with electrons.

(ii) This is the band of maximum energy.

(iii) Electrons are not capable of gaining energy from external electric field.

(iv) No flow of current due to electron present in this band.

(v) The highest energy level which can be occupied by an electron in valence band at 0 K is called fermi level.

(2) Conduction band : The higher energy level band is called the conduction band.

(i) It is also called empty band of minimum energy.

(ii) This band is partially filled by the electrons.

(iii) In this band the electron can gain energy from external electric field.

(iv) The electrons in the conduction band are called the free electrons. They are able to move any where within the volume of the solid.

(v) Current flows due to such electrons.

(3) Forbidden energy gap (ΔEg) : Energy gap between conduction band and valence band

$$\Delta E_g = (C.B.)_{min} - (V.B.)_{max}$$

2. Energy Band Description of Conductor, Insulator and Semiconductor :

The electrical conductivity of materials is a physical quantity which varies over a large span. On one hand we know about metals having very large values of electrical conductivity and on the other hand we have insulators like quartz and mica having negligible conductivity. Beside these there are materials having conductivity (at room temperature) much smaller, than that of metals but much larger than that of insulators these materials are called semiconductors e.g. Silicon and Germanium. Not only that the conductivity of a semiconductor is intermediate, to that of metals and insulators the conductivity of semiconductor varies substantially with temperature.For very low temperature (around 0K) semiconductor behaves like insulator, however, its conductivity increases with increase in temperature.

(a) Conductors :

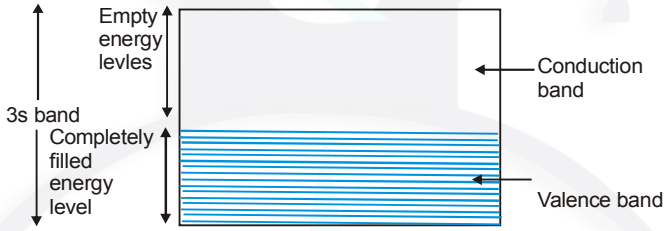
These are solids in which either the energy band containing valence band is partially filled or the energy band containing valence electrons overlaps with next higher band to give a new band which is partially filled too. For both these situations there are enough free levels available for electrons to which they can be excited by receiving energy from an applied electric field.

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Conduction band and valence band in monovalent metal

Let us consider an Ex. of sodium which is a monovalent metal. Its band structure is such that 1s, 2s and 2p bands are filled with electrons to their capacity however, the 3s band is only half filled. The reason for such a band structure is that for

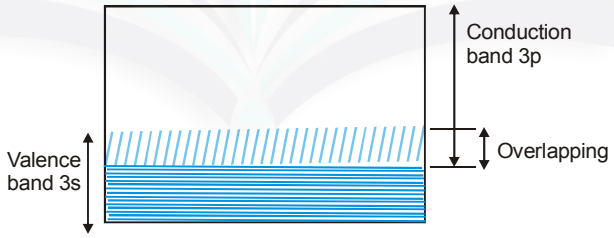
an isolated sodium atom in its electronic structure $1s^2$, $2s^2$, $2p^6$, $3s^1$ the energy levels 1s, 2s and 2p are filled while 3s contains only one electron against its capacity of accommodating two electrons. The completely filled 1s, 2s and 2p bands do not contribute to electrical conduction because an applied electric field cannot bring about intra band transitions in them. Electrons can also not make band to band transitions from 1s to 2s or from 2s to 2p band as for both these situations unfilled energy levels are not available. However, electrons belonging to 3s band can take part in intra band transitions as half of the energy levels present in this band are available. An applied electric field can impart them an amount of energy sufficient for the transition to free energy levels, and take part in the process of conduction. Thus the conduction properties of sodium are due to this partially filled band which is shown in figure(a). The lower half portion of this band is called valence band and upper half portion is called conduction band as it is in this part when electron reach after receiving energy from electric field the process of conduction starts. All monovalent metals have a half filled conduction band like sodium.



(a)

Conduction band and valence band in bivalent metal

The bivalent elements belonging to the second group of the periodic table e.g magnesium, zinc etc are also metallic. In the solid state of these materials there is an overlapping between the highest filled band and next higher unfilled band. For Ex. magnesium atom (atomic number = 12) has electronic structure - $1s^2$ $2s^2$ $2p^6$ $3s^2$ and in atomic state there is some energy gap between completely filled 3s level and next higher but unfilled 3p level. However, during the process of crystal formation, the splitting of energy levels take place in such a manner that the 3p band overlaps with 3s band. In the 'hybrid' band' so formed now electrons have sufficient number of unfilled levels for transition. In such situation if 3s band is called valence band then 3p band is conduction band and the two bands overlap as shown in figure (B).



(b)

We can conclude that for both the above metals there is no energy gap between maximum energy of valence band and the minimum energy of the conduction band.

The energy that an electron gains from an ordinary current source usually is 10^{-4} to 10^{-8} eV which is sufficient to cause transition between levels inside a partially filled band. As the difference between the adjacent levels is

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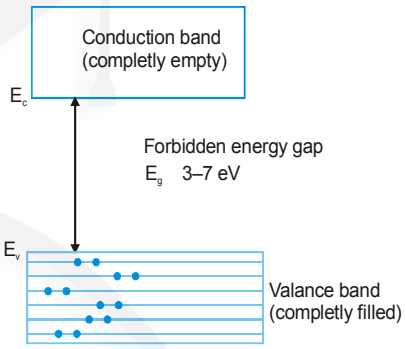
infinitesimal, for such bands the electron can absorb infinitesimal energy in a manner like free electron. Such electrons when reach unfilled higher levels contribute to the process of electric conduction. In metals both the number of free electrons and the vacant energy levels for transitions are very large that is why metals are good conductors of electricity and heat. For metals at ordinary temperature the electrical conductivities are in range 10^6 mho/metre to 10^8 mho/metre indicating this fact.

(b) Insulator :

It is a solid in which the energy band formation takes place in such a manner, that the valence band is completely filled while the conduction band is completely empty. In addition to this, these two bands are separated by a large energy gap called forbidden energy gap or band gap. If E_c and E_v respectively denotes the minimum energy in conduction band and the maximum energy in valence band then band gap E_g is defined as

$E_g = E_c - E_v$

For insulators $E_g \sim 3$ to 7 eV. As in an empty band no electron is there to take part in the process of electric conduction, such a band does not contribute in conduction. In a completely filled band very large number of electrons are present but no vacant levels to which these electrons make transition are available and hence again there will not be any conduction . As explained earlier ordinary current sources provide only a very small energy to an electron in a solid and so electrons cannot be excited from valence band to conduction band. Also not only at ordinary temperatures but at elevated temperatures too, the thermal energy is much smaller than the band gap energy E_g so electrons cannot be excited from valence band to conduction band by thermal means. Consequently solids with such large band gaps are insulators.



For diamond, $E_g \approx 6$ eV hence it is insulator.

In general electrical conductivities· of insulators are in the range 10^{-12} mho/metre to 10^{-18} mho/metre (resitivity in the range 10^{12} ohm-metre to 10^{18} ohm metre.]

(c) Semiconductors :

In case of semiconductors, the band structure is essentially of the same type as that for insulators with the only difference that of a relatively smaller forbidden gap. In case of a semiconductor this is typically of the order of 1eV. At absolute zero temperature, the valence band is completely filled and the conduction band is completely empty and consequently no electrical conduction can result. This is the same behaviour as observed in insulators. i.e at absolute zero a semiconductor behaves like an insulator.

At finite temperatures (room temperature and above) some of the electrons from near the top of valence band acquire enough thermal energy to move into the otherwise empty conduction band. These electrons contribute to the conduction of electricity in a semiconductor.

Also the above said transitions create some unfilled levels in the valence band and the electrons of this band can move into these levels again resulting in conduction. Thus the electrical conductivity of a semiconductor is larger than that of an insulator at room temperature. However since the number of electrons made available to conduction band via this process of thermal excitation is very small as compared to what available for conduction in metals, the conductivity of semiconductors is much smaller than that of metals at a given temperature. Thus the conductivity of semiconductor lies between that of metals and insulators, that is why these are named so. The conductivity of semiconductor increases with temperature.

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Note : Free electron and Hole in semiconductors.

(1) When an electron is removed from a covalent bond, it leaves a vacancy behind. An electron from a neighbouring atom can move into this vacancy, leaving the neighbour with a vacancy. In this way the vacancy formed is called hole (or cotter), and can travel through the material and serve as an additional current carriers.

(2) A hole is considered as a seat of positive charge, having magnitude of charge equal to that of an electron.

(3) Holes acts as virtual charge, although there is no physical charge on it.

(4) Effective mass of hole is more than electron.

(5) Mobility of hole is less than electron.

(6) Free electron move in CB, while hole in VB in opposite direction.

(7) Immobile ions are at rest.

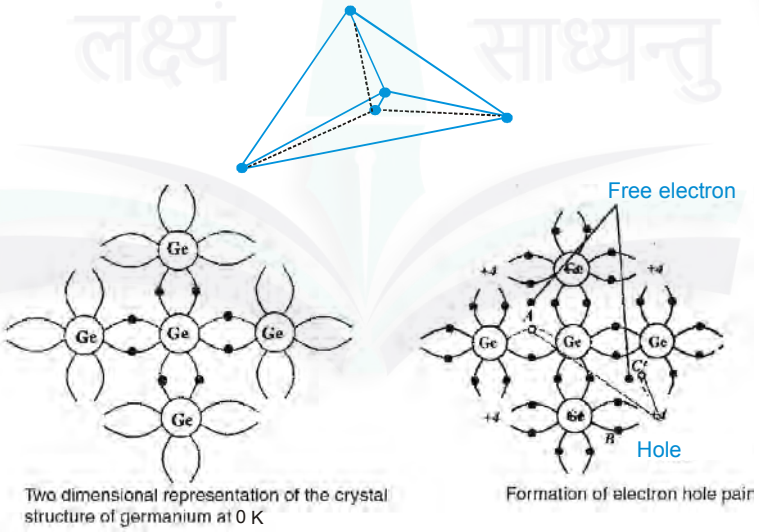
3. Intrinsic Semiconductors :

A semiconductor free from impurities is called an intrinsic semiconductor. Ideally an intrinsic semiconductor crystal should contain atoms of this semiconductor only but it is not possible in practice to obtain crystals with such purities. However if the impurity is less than 1 in 10^8 part of semiconductor it can be treated as intrinsic. For describing the properties of intrinsic semiconductor we are taking Ex.s of silicon and germanium. Both silicon and germanium are members of the group IV of periodic table of elements and are tetravalent. Their electronic configuration is as follows:

Si(14)=$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$

Ge(32)= $Is^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^2$

Both elements crystallize in such a way that each atom in the crystal is inside a tetrahedron formed by the four atoms which are closest to it. Figure shows one of these tetrahedral units. Each atom shares its four valence electrons with its immediate neighbours on a one to one basis, so that each atom is involved in four covalent bonds. For convenience, a two dimensional representation of the crystal structure for germanium is shown in figure, which can also be used for silicon (as only covalent bands are being shown).



Two dimensional representation of the crystal structure of germanium at 0 K

Formation of electron hole pair

At 0K, all the valence electrons amre involved in the bonding and so the crystal is a perfect insulator as there are no free electrons available for conduction. At higher temperatures, however, some of the valence electrons have sufficient energy to break away from the bond and move in the crystal in random manner. Under an applied electric field these electrons drift and conduct electricity.

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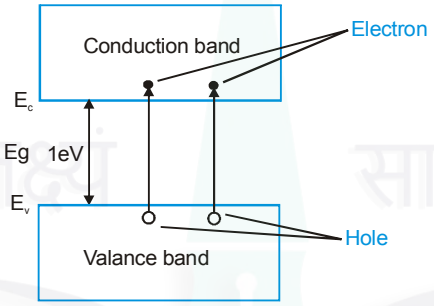
When an electron escapes from a band it leaves behind a vacancy in the lattice. This vacancy is termed as a "hole". The absence of electron amounts to the presence of a positive charge of same magnitude. As explained later, holes also take part in conduction in semiconductors. When a covalent bond is broken, all electron- hole pair is contributed. At room temperature (300K) many electron - hole pairs are present in the crystal. The process of electron - hole generation is explained in figure. Let due to thermal energy an electron is set free from the covalent bond at site A whereby a hole is created at this site. An electron from the covalent bond of a neighbouring atom site B may jump to vacant site A then bond is completed at A but a hole is created at B. In this process a very small energy is involved compared to what is required for an electron - hole pair generation. It is because the electron is jumping from one bond to the other and all electrons in bonding are on an average of same energy. As shown in the figure when an electron jumps from C to B a hole is created at C and so on. In effect then such a vacancy or hole can be considered as mobile. Thus in a semiconductor both electrons and holes act as charge carriers and contribute in electric conduction.



An intrinsic semiconductor at T = 0 K behaves like insulator.

At T > 0 K four thermally generated electron-hole pairs. The filled circles (.) represent electrons and empty fields (O) represent holes.

(a) (b)



The number of electrons and holes generated by thermal means is equal for an intrinsic semiconductor. If n_e and n_h represents the electron and hole concentrations respectively then

$$n_i = n_e = n_h$$

$$n_e n_h = n_i^2$$

Here n_i is intrinsic charge carriers concentration.

Note : **(1)** A pure semiconductor is called intrinsic semiconductor. It has thermally generated current carriers.

(2) They have four electrons in the outermost orbit of atom and atoms are held together by covalent bond.

(3) Free electrons and holes both are charge carriers and n_e (in C.B.) = n_h (in V.B.)

(4) The drift velocity of electrons (v_e) is greater than that of holes (v_h).

(5) For them fermi energy level lies at the centre of the C.B. and V.B.

(6) In pure semiconductor, impurity must be less than 1 in 10^8 parts of semiconductor.

(7) In intrinsic semiconductor

$n_e^{(0)} = n_h^{(0)} = n_i$; where $n_e^{(0)}$ = Electron density in conduction band, $n_h^{(0)}$ = Hole density in V.B., n_i = Density of intrinsic carriers.

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(8) The fraction of electron of valance band present in conduction band is given by $f \propto e^{-Eg/kT}$; where E_g = Fermi energy, k = Boltzmann's constant and T = Absolute temperature.

(9) Because of less number of charge carriers at room temperatre, intrinsic semiconductors have low conductivity so they have no partical use.

(10) Number of electrons reaching from valence band to conduction band $n = AT^{3/2}e^{-Eg/2kT}$ where A is positive con stant.

(11) Net charge of a pure semiconductor is zero.

(a) Electrical conductivity of intrinsic semiconductor:

A semiconductor, at room temperature, contains electrons in the conduction band and holes in the valence band. When an external electric field is applied, the electrons move opposite to the field and the holes move in the direction of the field, thus constituting current in the same direction. The total current is the sum of the electron and hole currents.

$$i = i_e + i_h$$

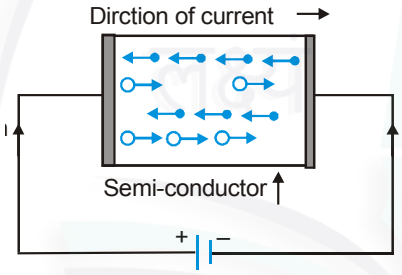
Hole Current (i_h):

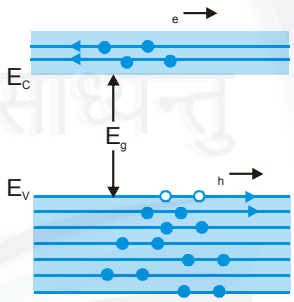
Electrons of covalent bond site jump from one position to another position in valency band so hole moves opposite to the jumping of electrons in valence band. Electron originally set free is not involved in the proces of hole motion. Motion of hole is only a convenient way of describing the actual motion of bonded electrons of valence band.

Electron Current (i_e)

Free electron moves completely independently as conduction electron and give electron current under the effect of electric field.

It may be noted that apart from the *process of generation* of conduction electrons and holes, a simultaneous *process of recombination* occurs in which the electrons *recombine* with the holes. At equilibrium, the rate of generation is equal to the rate of recombination of charge carriers. The recombination occurs due to an electron colliding with a hole.





Let us consider a semiconductor block of length ℓ, area of cross-section A and having electron concentration n_e and hole concentration is n_h, across the ends of the semiconductor creates an electric field E given by

$$E = \frac{V}{\ell} \qquad \text{.....(i)}$$

Under the field E, the electrons and the holes both drift in opposite directions and constiute currents i_e and i_h respectively in the direction of the field. The total current flowing through the semiconductor is

$$i = i_e + i_h$$

If v_e be the drift velocity of the electrons in the conduction band and v_h the drift velocity of the holes in the valence band, then we have

$$i_e = n_e e A v_e \qquad \text{and} \qquad i_h = n_h e A v_h$$

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Where e is the magnitude of electron charge

$\therefore \quad i = i_e + i_h = eA\,(n_e v_e + n_h v_h) \quad$ or $\quad \frac{i}{A} = e\,(n_e v_e + n_h v_h).$ .....(ii)

Let R be the resistance of the semiconductor block and ρ the resistivity of the block material. Then

$$\rho = RA/\ell\,.$$ .....(iii)

Dividing equation (i) by equation (iii), we have

$$\frac{E}{\rho} = \frac{V}{RA} = \frac{i}{A}, \quad \text{(Since } V = iR \text{ by Ohm's law).}$$

Substituting in it the value of i/A from eqauton (ii), we get

$$\frac{E}{\rho} = e\,(n_e v_e + n_h v_h) \quad \text{or} \quad \frac{1}{\rho} = e\left(n_e \frac{v_e}{E} + n_h \frac{v_h}{E}\right).$$ .....(iv)

Let us now introduce a quantity μ, called mobility which is defined as the drift velocity per unit field and is expressed in meter^2/(volt-second). Thus, the mobilities of electron and hole are given by

$$\mu_e = \frac{v_e}{E} \quad \text{and} \quad \mu_h = \frac{v_h}{E}$$

lntroducing μ_e and μ_h in eqaution (iv), we get

$$\frac{1}{\rho} = e\,(n_e \mu_e + n_h \mu_h)$$

The electrical conductivity σ is the reciprocal of the rsistivity ρ . Thus, the electrical conductivity of the semiconductor is given by

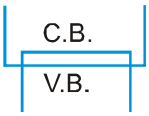
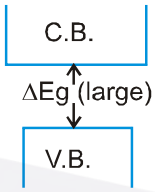
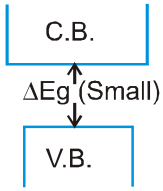
$$\sigma = e\,(n_e \mu_e + n_h \mu_h)$$ .....(v)

So $\quad \sigma = en_i\,(\mu_e + \mu_h) \quad \because\ n_e = n_h = n_i$

This is the required expression. It shows that the electrical conductivity of a semicondutor depends upon the electron and hole concentrations (number densities) and their mobilities. The electron mobility is higher than the hole mobility.

As temperature rises, both the concentrations n_e and n_h increase due to breakage of more covalent bonds. The mobilities μ_e and μ_h , however, slightly decrease with rise in temperature but this decrease is offset by the much greater increase in n_e and n_h. Hence, the conductivity of a semiconductor increases (or the resistivity decreases) with rise in temperature.

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Properties	Conductors	Insulators	Semiconductors
Electrical conductivity	10^2 to 10^8 ℧/m	10^{-8} ℧/m	10^{-5} to 10^0 ℧/m
Resistivity	10^{-2} to 10^{-8} Ω-m (negligible)	10^8 Ω-m	10^5 to 10^0 Ω-m
Band Structure			
Energy gap (E_g)	Zero or very small	Very large : for diamond it is 6 eV	Ge → 0.7 eV Si → 1.1 eV GaAs → 1.3 eV GaF_2 → 2.8 eV
Current carriers	Free electrons	—	Free electrons and holes
Condition of V.B. and C.B. at ordinary temperature	V.B. and C.B. are completely filled or C.B is some what empty	V.B – Completely .field C.B.–Completely unfilled	V.B– some what empty C.B.- some what filled
Temperature co-efficient of resistance	Positive	Zero	Negative
Effect of temperature on conductivity	Decreases	—	Increases
Effect of temperature on resistance	Increases	—	Decreases
Examples	Cu, Ag, Au, Na, Pt, Hg etc.	Wood, plastic, mica diamond, glass etc.	Ge, Si GaAs etc,
Electron density	$10^{29}/m^3$	—	Ge ~ $10^{19}/m^3$ Si ~ 10^{16} / m^3

4. Extrinsic semiconductors :

The conductivity of an intrinsic semiconductor depends on its temperature, but at room temperature its conductivity is very low. As such, no important electronic devices can be developed using these semiconductors. Hence there is a necessity of improving their conductivity. This can be done by making use of impurities.When a small amount, say, a few parts per million (ppm), of a suitable impurity is added to the pure semiconductor, the conductivity of the semiconductor is increased manifold. Such materials are known as e*xtrinsic semiconductors* or *impurity semiconductors*. The deliberate addition of a desirable impurity is called *doping* and the impurity atoms are called *dopants*. Such a material is also called a *doped semiconductor*. The dopant has to be such that it does not distort the original pure semiconductor lattice. It occupies only a very few of the original semiconductor atom sites in the crystal. A necessary condition to attain this is that the sizes of the dopant and the semiconductor atoms should be nearly the same. There are two types of dopants used in doping the tetravalent Si or Ge:

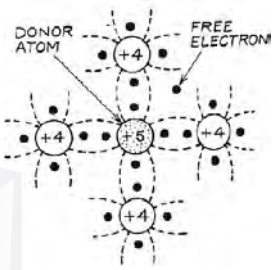
(i) Pentavalent (valency 5); like Arsenic (As), Antimony (Sb), Phosphorous (P), etc.

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(ii) Trivalent (valency 3); like Indium (In), Boron (B), Aluminium (Al), etc.

We shall now discuss how the doping changes the number of charge carriers (and hence the conductivity) of semiconductors. Si or Ge belongs to the fourth group in the Periodic table and, therefore, we choose the dopant element from nearby fifth or third group, expecting and taking care that the size of the dopant atom is nearly the same as that of Si or Ge. Interestingly, the pentavalent and trivalent dopants in Si or Ge give two entirely different types of semiconductors as discussed below.

Extrinsic semiconductor are of two types : n–type and p–type.



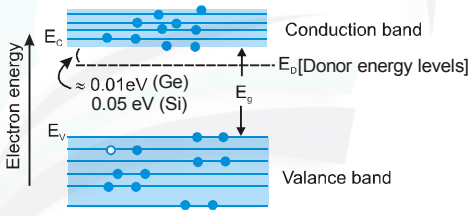
(a) **n–type semiconductor :** When a pentavalent impurity atom (antimony, phosphorus or arsenic) is added to a Ge(or Si) crystal, it replaces a Ge (or Si) atom in the crystal lattice. Four of the five valence electrons of the impurity atom form covalent bonds with one with each valence electron of four Ge (or Si) atoms surrounding.

Thus, by adding pentavalent impurity to pure Ge(or Si), the number of free electrons increases, that is, the conductivity of the crystal increases. The impure Ge (or Si) crystal is called an 'n–type' semiconductor because it has an excess of 'negative' charge–carrier (electrons). The impurity atoms are called 'donor' atoms because they donate the conducting electrons to the crystal.

The fifth valence electrons of the impurity atoms occupy some discrete energy levels just below the conduction band. These are called 'donor levels' and are only 0.01 eV below the conduction band in case of Ge, and 0.05 eV below in case of Si. Therefore, at room temperature, the "fifth" electrons of almost all the donor atoms are thermally excited from the donor levels into the conduction band where they move as charge–carriers when an external electric field is applied.

At ordinary temperature, almost all the electrons in the conduction band come from the donor levels, only a few come from the valence band. Therefore, the main charge–carriers responsible for conduction are the electrons contributed by the donors. Since the excitation from the valence band is small, there are very few holes in this band. The current contribution of the holes is therefore small. Thus, in an n–type semiconductor the electrons are the 'majority carriers' and the holes are the 'minority carriers.'

The adjecent figure shows n-type semiconductor at $T > 0$ K.
Its conduction band has One thermally generated electron-hole pair and 9 conduction electrons from donor atoms.



Some important facts about N-Type Semiconductor

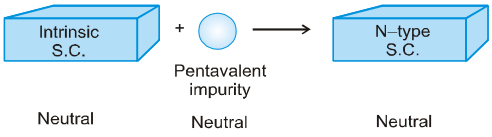
These are obtained by adding a small amount of pentavalent impurity to a pure sample of semiconductor (Ge).

(1) Majority charge carriers – electrons
Minority charge carriers – hole

(2) $n_e >> n_h$; $i_e >> i_h$

(3) Conductivity $\sigma = n_e \mu_e e$

(4) Donor energy level lies just below the conduction band.



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(5) **Electrons and hole concentration :** In a doped semiconductor, the electron concentration n_e and the hole concentration n_h are not equal (as they are in an instrinsic semiconductor). It can be shown that

$n_e n_h = n_i^2$

where n_i is the intrinsic concentration.

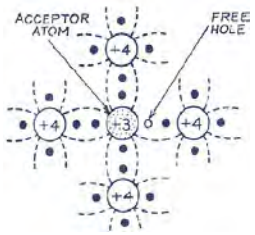
In an n–type semiconductor, the concentration of electrons in conduction band is nearly equal to the concentration of donar atoms (N_d) and very large compared to the concentration of holes in valence band. That is : $n_e \approx N_d >> n_h$

(6) Impurity atom called donar atom which is elements of V group of periodic table.

(7) Net charge on N type crystal is zero.

(8) Immobile charge is positive charge

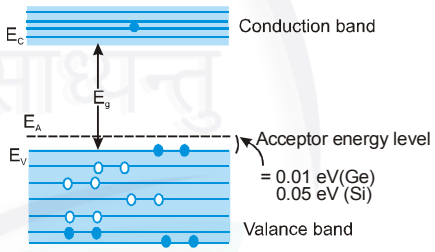
(b) **P–Type Semiconductor :** When a trivalent impurity atom (boron, aluminium, gallium or indium) is added to a Ge (or Si) crystal, it also replaces one of the Ge (or Si) atoms in the crystal lattice . Its three valence electrons form covalent bonds with one each valence electron of these Ge (or Si) atoms surrounding it. Thus, there remains an empty space, called a 'p–type' semiconductor because it has an excess of positive 'acceptor' atoms because they create holes which accept electrons.



The impurity atoms occupy vacant discrete energy levels just above the top of the valence band. These are called 'acceptor levels'. At room temperature, electrons are easily excited from the valence band into the acceptor levels. The corresponding holes created in the valence band are the main charge–carries in the crystal when an electric field is applied.
Thus, in a p–type semiconductor the holes are the 'majority carriers' and the few electrons, thermally excited from the valence band into the conduction band, are 'minority carriers'.

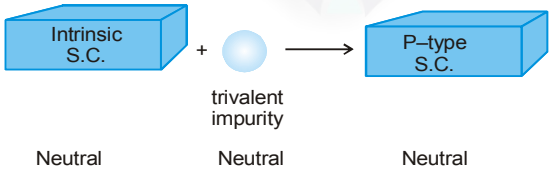
The adjecent figure shows Electron and hole concentration for p-type semiconductor at T > 0 K.

One thermally generated electron-hole pair + seven holes due to acceptor atoms.



Some Important Facts about P-Type Semiconductor

There are obtained by adding a small amount of trivalent impurity to a pure sample of semiconductor (Ge).



(1) Majority charge carries – holes

Minority charge carries – electrons

(2) $n_h >> n_e$; $i_h >> i_e$

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(3) Conductivity $\sigma \approx n_h \mu_h e$

(4) P–type semiconductor is also electrically neutral (not positively charged)

(5) Impurity is called Acceptor impurity which is element of III group of the periodic table.

(6) Acceptor energy level lies just above the valency band.

(7) **Electron and hole concentration :** In a p–type semiconductor, the concentration of holes in valence band is nearly equal to the concentration of acceptor atoms (N_a) and very large compared to the concentration of electron in conduction band. That is
$n_h = N_a >> n_e$

(8) Net charge on p-type crystal is zero.

(9) Imobile charge is negative charge.

Distinction between intrinsic and extrinsic semiconductors :

	Instrinsic Semiconductor		Extrinsic Semiconductor
1	It is a pure, natural semiconductor, such as pure Ge and pure Si.	1	It is prepared by adding a small quantity of impurity to a pure semiconductor, such as n-and p-type semiconductors.
2	In it the concentration of electrons and holes are equal.	2	In it the two concentrations are unequal. There is an excess of electrons in n-type semiconductors and an excess of holes in p-type semiconductors.
3	Its electrical conducitivity is very low.	3	Its electrical conductivity is siginifcantly high.
4	Its conductivity cannot be controlled.	4	Its conductivity can be controlled by adjusting the quantity of the impurity added.
5	Its conductivity increases exponentially with temperature.	5	Its conductivity also increases with temperature, but not exponentially.

Distinction between n–type and p–type semiconductor :

	N-Type Semiconductor		P-Type Semiconductor
1	It is an extrinsic semiconductor obtained by adding a pentavalent impurity to a pure intrinsic semiconductor.	1	It is also an extrinsic semiconductor obtained by adding a trivalent impurity to a pure intrinsic semiconductor.
2	The impurity atoms added provides extra free electrons to the crystal lattice and are called donor atoms.	2	The impurity atoms added create holes in the crystal lattice and are called acceptor atoms because the created holes accept electrons.
3	The electrons are majority carriers and the holes are minority carriers.	3	The holes are majority carriers and the electrons are minority carriers.
4	The electrons concentration is much more than the hole concentration ($n_e >> n_h$).	4	The hole concentration is much more than the electron concentration ($n_h >> n_e$).

Ex. A silicon specimen is made into a p-type semiconductor by doping on an average one indium atom per 5×10^7 silicon atoms. If the number density of atoms in the silicon specimen is 5×10^{28} atoms/m^3; find the number of acceptor atoms in silicon per cubic centimeter.

Sol. The doping of one indium atoms in silicon semiconductor will produce one acceptor atom in p-type semiconductor. Since one indium atom has been dopped per 5×10^7 silicon atoms, so number density of acceptor atoms

$$\text{in silicon} = \frac{5\times10^{28}}{5\times10^{7}} = 10^{21} \text{ atom/m}^3 = 10^{15} \text{ atoms/cm}^3.$$

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Ex. Pure Si at 300K has equal electron (n_e) and hole (n_h) concentrations of 1.5×10^{16} m^{-3}. Dopping by indium increases n_h to 3×10^{22} m^{-3}. Calculate n_e in the doped Si.

Sol. For a doped semi-conductor in thermal equilebrium $n_e n_h = n_i^2$ (Law of mass action)

$$n_e = \frac{n_i^2}{h_h} = \frac{(1.5\times10^{16})^2}{3\times10^{22}} = 7.5 \times 10^{9}\ m^{-3}$$

Ex. Pure Si at 300 K has equal electron (n_e) and hole (n_h) concentrations of 1.5×10^{16} m^{-3}. Doping by indium increases n_h to 4.5×10^{22} m^{-3}. Calculate n_e in the doped Si-

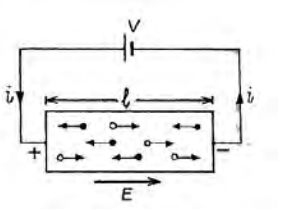
Sol. $n_e n_h = n_i^2$

$n_h = 4.5 \times 10^{22}\ m^{-3}$

So, $n_e = 5.0 \times 10^{9}\ m^{-3}$

(c) Electrical Conductivity of Extrinsic Semiconductors :

A semiconductor, at room temperature, contains electrons in the conduction band and holes in the valence band. When an external electric field is applied, the electrons move opposite to the field and the hole move in the direction of the field, thus constituting current in the same direction. The total current is the sum of the electron and hole currents.



Let us consider semiconductor block of length l, area of cross–section A and having electrons concentration n_e and hole concentration n_h . A potential difference V applied across the ends of the semiconductor creates an electric field E given by :

$$E = \frac{V}{\ell} \qquad \text{.....(i)}$$

Under the field E, the electrons and the holes both drift in opposite directions and constitute currents i_e and i_h respectively in the direction of the field. The total current flowing through the semiconductor is,

$$i = i_e + i_h$$

If v_e , be the drift velocity of the electrons in the conduction band and v_h the drift velocity of the holes in the valence band, then we have

$$i_e = n_e e A\, v_e \quad \text{and} \quad i_h = n_h e\, A\, v_h$$

where e is the magnitude of electron charge

$$\therefore \quad i = i_e + i_h = eA(n_e v_e + n_h v_h)$$

or $$\frac{i}{A} = e(n_e\, v_e + n_h\, v_h) \qquad \text{.....(ii)}$$

Let R be the resistance of the semiconductor block and ρ the resistivity of the block material. Then

$$\rho = R\, A / l \qquad \text{.....(iii)}$$

Dividing eq.(i) by eq.(ii) we have

$$\frac{E}{\rho} = \frac{V}{RA} = \frac{i}{A},$$

Because, V = iR (Ohm's law). Substituting in it the value of i/A from eq.(ii), we get

$$\frac{E}{\rho} = e(n_e v_e + n_h\, v_h)$$

or $$\frac{1}{\rho} = e\left(n_e \frac{v_e}{E} + n_h \frac{v_h}{E}\right) \qquad \text{.....(iv)}$$

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Let us introduce a quantity μ, called mobility which is defined as the drift velocity per unit field and is expressed in metre^2 / (volt/second). Thus, the mobilities of electrons and hole are given by :

$$\mu_e = \frac{v_e}{E} \quad \text{and} \quad \mu_h = \frac{v_h}{E}$$

Introducing μ_e and μ_h in eq. **(iv)**, we get

$$\frac{1}{\rho} = e(n_e\mu_e + n_h\mu_h)$$

The electrical conductivity ρ is the reciprocal of the resitivity ρ. Thus, the electrical conductivity of the semiconductor is given by

$$\sigma = e(n_e\,\mu_e + n_h\,\mu_h)$$

This is the required expression. It shows that the electrical conductivity of a semiconductor depends upon the electron and hole concentrations (number densities) and their mobilities. The electrons is higher than the hole mobility.

As temperature rises, both the concentration n_e and n_h increases due to breakage of more convalent bonds. The mobilities μ_e and μ_h , however, slightly decrease with rise in temperature but this decrease is offset by the much greater increase in n_e and n_h. Hence, the conductivity of a semiconductor increases (or the resistivity decreases) with rise in temperature.

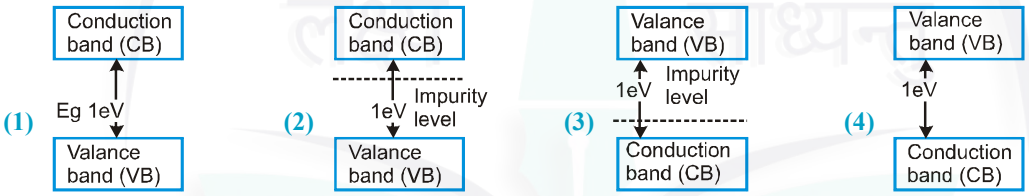
Ex. The majority charge carriers in P-type semiconductor are
(1) Electrons **(2)** Protons **(3)** Holes **(4)** Neutrons

Sol. (3) In P-type semiconductors, holes are the majority charge carriers

Ex. When a semiconductor is heated, its resistance
(1) Decreases **(2)** Increases **(3)** Remains unchanged **(4)** Nothing is definite

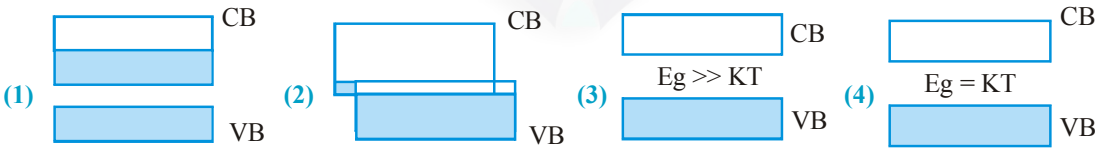
Ans. (1)

Ex. Which of the following energy band diagram shows the N-type semiconductor



Sol. (2) In N-type semiconductor impurity energy level lies just below the conduction band.

Ex. Which of the energy band diagram shown in the figure corresponds to that of a semiconductor



Sol. (4) In semiconductors, the forbidden energy gap between the valence band and conduction band is very small, almost equal to kT. Moreover, valence band is completely filled where as conduction band is empty.

Ex. The P-N junction is-
(1) an ohmic resistance **(2)** non ohmic resistance **(3)** a positive resistance **(4)** a negative resistance

Ans. (2)

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Ex. The mean free path of conduction electrons in copper is about 4×10^{-8} m. For a copper block, find the electric field which can give, on an average, 1eV energy to a conduction electron.

Sol. Let the electric field be E. The force on an electron is eE. As the electron moves through a distance d, the work done on it is eEd. This is equal to the energy transferred to the electron. As the electron travels an average distance of 4×10^{-8} m before a collision, the energy transferred is $eE(4 \times 10^{-8}\ m)$. To get 1 eV energy from the electric field,

$$eE(4 \times 10^{-8}\ m) = 1\ eV$$

or, $$E = 2.5 \times 10^{7}\ V/m.$$

Ex. The band gap in germanium is $\Delta E = 0.68$ eV. Assuming that the number of hole–electron pairs is proportional to $e^{-\Delta E/2kT}$, find the percentage increase in the number of charge carries in pure germanium as the temperature is increased from 300 K to 320 K.

Sol. The number of charge carries in an intrinsic semiconductor is double the number of hole–electron pairs. If N_1 be the number of charge carries at temperature T_1 and N_2 at T_2, we have

$$N_1 = N_0 e^{-\Delta E/2kT_1}$$

and $$N_2 = N_0 e^{-\Delta E/2kT_2}$$

The percentage increase as the temperature is raised from T_1 to T_2 is

$$f = \frac{N_2 - N_1}{N_1} \times 100 = \left(\frac{N_2}{N_1} - 1\right) \times 100 = 100 \left[e^{\frac{\Delta E}{2k}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)} - 1 \right]$$

Now $$\frac{\Delta E}{2k}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) = \frac{0.68 eV}{2 \times 8.62 \times 10^{-5}\ eV/K}\left(\frac{1}{300\ K} - \frac{1}{320\ K}\right) = 0.82$$

Thus $$f = 100 \times [e^{0.82} - 1] \approx 127.$$

Thus, the number of charge carries increase by about 127%.

Ex. The energy of a photon of sodium light (λ = 589 nm) equals the band gap of a semiconducting material. **(a)** Find the minimum energy E required to create a hole-electron pair. **(B)** Find the value of E/kT at a temperature of 300 K.

Sol. **(a)** The energy of the photon is $E = \frac{hc}{\lambda}$

$$= \frac{1242\ eV - nm}{589\ nm} = 2.1\ eV.$$

Thus the band gap is 2.1 eV. This is also the minimum energy E required to push an electron from the valence band into the conduction band. Hence, the minimum energy required to create a hole–electron pair is 2.1 eV. So it is difficult for the thermal energy to create the hole–electron pair but a photon of light can do it easily.

(b) At $T = 300$ K,

$kT = (8.62 \times 10^{-5}\ eV/K)\ (300\ K)$

$= 25.86 \times 10^{-3}$ eV.

Thus, $$\frac{E}{kT} = \frac{2.1\ eV}{25.86 \times 10^{-3} eV} = 81.$$

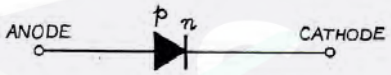
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5. Junction Diode

A junction diode is a basic semiconductor device. It is a semiconductor crystal having acceptor impurities in one region (P – type crystal) and donor impurities in the other region (n–type crystal). The boundary between the two regions is called 'p–n junction'.

Circuit Symbol for a p-n Junction Diode

In electronic circuits, the semiconductor devices are represented by their symbols. The symbol for the basic device, the p-n junction diode, is shown in Fig. The arrow-head represents the p -region and the bar represents the n -region of the diode. The direction of the arrow is from p to n and indicates the direction of conventional current flow under forward bias. The p -side is called 'anode' and the n -side is called 'cathode'.

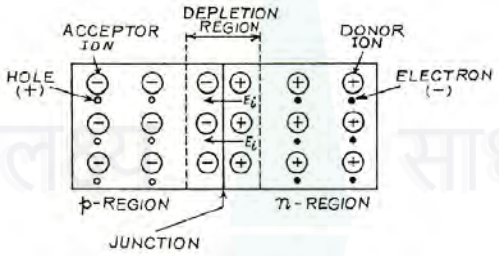


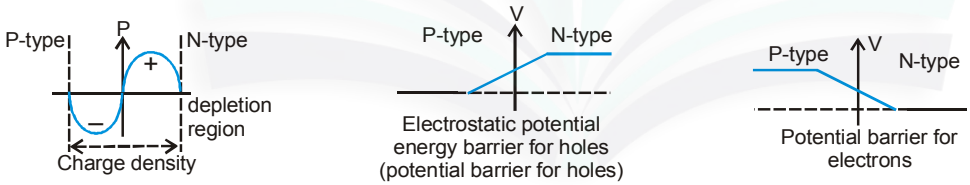
(a) Formation of p-n Junction :

A p-n junction is not the interface between p -type and n – type semiconductor crystals pressed together. It is a single piece of semiconductor crystal having an excess of acceptor impurities into one side and of donor impurities into the other.

(b) PotentiaI Barrier at the Junction: Formation of Depletion Region:

A p-n junction is shown in Fig. The p -type region has (positive) holes as majority charge-carriers, and an equal number of fixed negatively-charged acceptor ions. (The material as a whole is thus neutral). Similarly, the n -type region has (negative) electrons as majority charge-carriers, and an equal number of fixed positively-charged donor ions.





The region on either of the junction which becomes depleted (free) of the mobile charge-carriers is called the 'depletion region'. The width of the depletion region is of the order of 10^{-6} m. The potential difference developed across the depletion region is called the 'potential barrier'. It is about 0.3 volt for Ge, p-n junction and about 0·7 volt for silicon p-n junction. It, however, depends upon the dopant concentration in the semiconductor.

The magnitude of the barrier electric field for a silicon junction is

$$E_i \approx \frac{V}{d} \approx \frac{0.7}{10^{-6}} = 7 \times 10^5 \text{ Vm}^{-1}$$

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Diffusion & Drift Current

Due to concontration difference hole try to diffuse from p side to n side but due to depletion layer only those hole are able to diffuse from p to n side which have high kinetic energy. Similarly electron of high kinetic energy also diffuse from n to p so diffusion current flow from p to n side.

Due to thermal collision or increase in temperature some valence electron comes in conduction band. If this occurs in depletion region then hole move twords p side & electron move towards n side so a current produce from n to p side. It is called drift current, in steady state both diffusion & drift current are equal & opposite.

Ex. In a p-n junction with open ends,

(1) there is no systematic motion of charge carriers

(2) holes and conductor electrons systematically go from the p-side and from the n-side to the p-side respectively

(3) there is no net charge transfer between the two sides

(4) there is a constant electric field near the junction

Ans. (3,4)

Ex. A potential barrier of 0.50 V exists across a P-N junction. If the depletion region is 5.0×10^{-7} m wide, the intensity of the electric field in this region is

(1) 1.0×10^6 V/m **(2)** 1.0×10^5 V/m **(3)** 2.0×10^5 V/m **(4)** 2.0×10^6 V/m

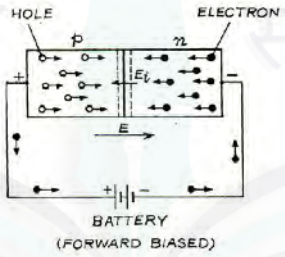
Sol. (1) $E = \frac{V}{d} = \frac{0.5}{5 \times 10^{-7}} = 10^6$ V/m

(c) Forward and Reverse Biasing of Junction Diode

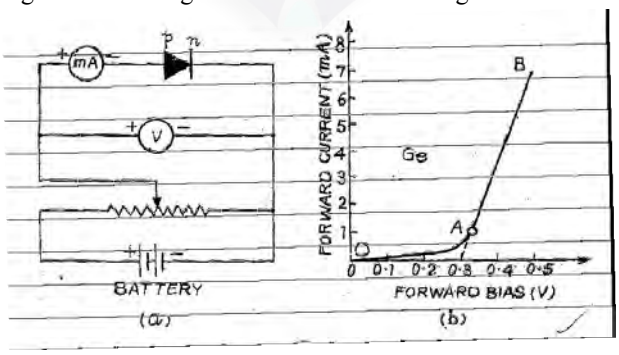
The junction diode can be connected to an external battery in two ways, called 'forward biasing' and 'reverse biasing' of the diode.It means the way of connecting emf source to P-N junction diode. It is of following two types:

(i) Forward Biasing :

A junction diode is said to be forward-biased when the positive terminal of the external battery is connected to the p -region and the negative terminal to the n -region of the diode.



Forward-Biased Characteristics : The circuit connections are shown in Fig. . The positive terminal of the battery is connected to the p -region and the negative terminal to the n -region of the



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junction diode through a potential-divider arrangement which enables to change the applied voltage. The voltage is read by a voltmeter V and the current by a milliammeter mA. Starting with a low value, the forward bias voltage is increased step by step and the corresponding forward current is noted. A graph is then plotted between voltage and current. The resulting curve OAB (Fig. b) is the forward characteristic of the diode.

In the beginning, when the applied voltage is low, the current through the junction diode is almost zero. It is because of the potential barrier (about 0·3 V for Ge p-n junction and about 0·7 V for Si junction) which opposes the applied voltage. With increase in applied voltage, the current increases very slowly and non-linearly until the applied voltage exceeds the potential barrier. This is represented by the portion OA of the characteristic curve. With further increase in applied voltage, the current increases very rapidly and almost linearly Now the diode behaves as an ordinary conductor. This is represented by the straight-line part AB of the characteristic. If this straight line is projected back. it intersects the voltage-axis at the barrier potential voltage.

Note :

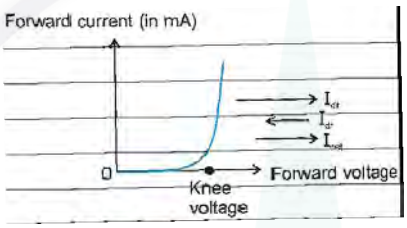
(i) In forward biasing width of depletion layer decreases

(ii) In forward biasing resitance offered $R_{Forward} \approx 10\Omega - 25\Omega$

(iii) Forward bias opposes the potential barrier and for $V > V_B$ a forward current is set up across the junction.

(iv) Cut-in (Knee) voltage : The voltage at which the current starts to in

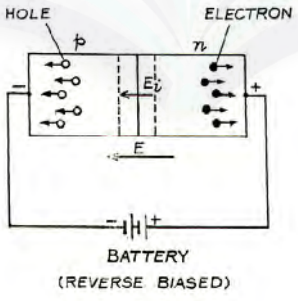
crease rapidily. For Ge it is 0.3 V and for Si it is 0.7V.



(v) I_{df}–diffusion current, I_{dr}–drift current

(ii) Reverse Biasing:

A junction diode is said to be reverse-biased when the positive terminal of the external battery is connected to the n -region and the negative terminal to the p -region of the diode (Fig.)

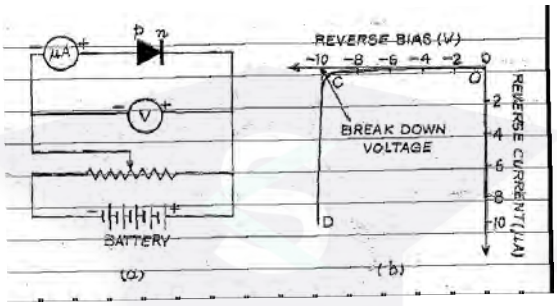


In this condition, the external field E is directed from n toward p and thus aids the internal barrier field E_i Hence holes in the p -region and electrons in the n -region are both pushed away from the junction, that is, they cannot combine at the junction. Thus, there is almost no current due to flow of majority carriers.

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Reverse-Biased Characteristic:

The circuit connections are shown in Fig. (a) in which the positive terminal of the battery is connected to the n -region and the negative terminal to the p -region of the junction diode. In reverse-biased diode, a very small current (of the order of μA) flows across the junction due to the motion of the few thermally-generated minority-carriers (electrons in p -region and holes in n -region) whose motion is aided by the applied voltage. The small reverse current remains almost constant over a sufficiently long range of reverse bias (applied voltage),increasing very little with increasing bias. This is represented by the part OC of the reverse characteristic curve (Fig b).



Note:

(i) In reverse biasing width of depletion layer increases

(ii) In reverse biasing resitance offered $R_{Reverse} \approx 10^5\Omega$

(iii) Reverse bias supports the potential barrier and no current flows across the juction due to the diffusion of the majority carriers.

(A very small reverse currents may exist in the circuit due to the drifting of minority carriers across the juction)

(iv) Break down voltage : Reverse voltage at which break down of semiconductor occurs. For Ge it is 25V and for Si it is 35 V.

(d) Avalanche Breakdown :

The avalanche breakdown occurs in lightly doped junction. If the reverse bias is made very high, the minority-carriers acquire kinetic energy enough to break the covalent bonds near the junction, thus liberating electron-hole pairs. These charge-carriers are accelerated and produce, in the same way, other electron-hole pairs. The process is cumulative and an avalanche of electron-hole pairs is produced. The reverse current then increases abruptly to a relatively large value (part CD of the characteristic). This is known as 'avalanche breakdown' and may damage the junction by the excessive heat generated. The reverse bias voltage at which the reverse current increase abruptly is called the 'breakdown voltage' .

Zener Breakdown

Zener breakdown occurs in heavily doped juctions. Under a high reverse - bias voltage, the p-n junction's depletion region expands, leading to a high strength electric field across the juction. A sufficiently strong electric field manages to break the covalent bonds of the semiconductor atoms, whcih liberates a large number of free minority carries. The sudden generation of carries rapidly incrases the revese currrent and gives rise to high slope resistance of Zener diode.

The reverse bias voltage at which the reverse current increase abruptly is called the 'ZENER breakdown voltage' or 'Zener voltage'. The numerical value of the breakdown voltage varies from tens of volts to several hundred volts depending on the number density of the impurity atoms doped into the diode.

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(e) Dynamic Resistance of a Junction Diode

The current-voltage curve of junction diode shows that the current does not vary linearly with the voltage, that is, Ohm's law is not obeyed. In such situation, a quantity known as 'dynamic resistance' (or a.c. resistance) is defined.

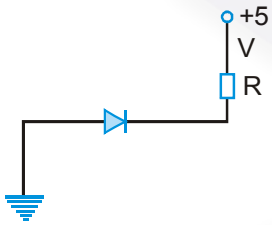
The dynamic resistance of a junction diode is defined as the ratio of a small change in applied voltage (ΔV) to the corresponding small change in current (Δi) , that is

$$R_d = \frac{\Delta V}{\Delta I}$$

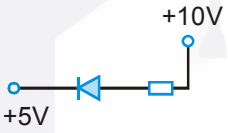
In the forward characteristic of p-n junction diode, beyond the turning point (knee), however, the current varies almost linearly with voltage. In this region, R_d is almost independent of V and Ohm's law is obeyed.

Ex. In the given figure, which of the diodes are forward biased ?

1.



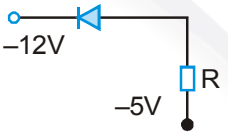
2.



3.



4.



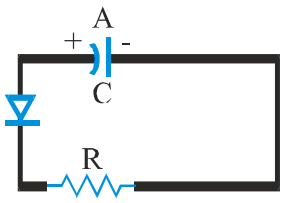
5.



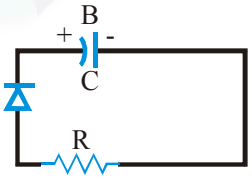
(1) 1, 2, 3 **(2)** 2, 4, 5 **(3)** 1, 3, 4 **(4)** 2, 3, 4

Sol. (2) In figure 2,4 and 5. P-crystals are more positive as compared to N-crystals.

Ex. Two identical capacitors A and B are charged to the same potential V and are connected in two circuits at t = 0 as shown in fig. The charges on the capacitor at a time t = CR are, respectively,



(A)



(B)

(1) VC, VC **(2)** VC/e, VC **(3)** VC, VC/e **(4)** VC/e, VC/e

Ans. 2

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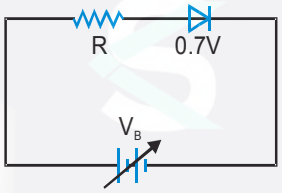
Ex. What is the current in the circuit shown below



(1) 0 amp **(2)** 10^{-2} amp **(3)** 1 amp **(4)** 0.10 amp

Sol. (1) The potential fof P-side is more negative that of N-side, hence diode is in reverse biasing. In reverse biasing it acts as open circuit, hence no current flows.

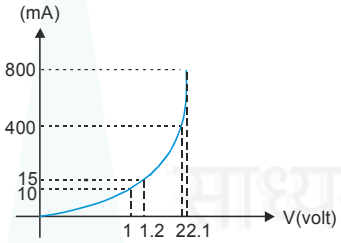
Ex. Assume that the junction diode in the following circuit requires a minimum current of 1 mA to be above the knee point (0.7V) of its I-V characteristic curve. Also assume that the voltage across the diode is independent of current above the knee point. If V_B = 5V, what should be the maximum value of R so that the voltage is above the knee point-



(1) 4.3 kΩ **(2)** 860 kΩ **(3)** 4.3 Ω **(4)** 860 Ω

Ans. (1)

Ex. The i-V characteristic of a p-n junction diode is shown in figure. Find the approximate dynamic resistance of the p-n junction when **(a)** a forward bias of 1 volt is applied, **(b)** a forward bias of 2 volt is applied



(a) The current at 1 volt is 10 mA and at 1.2 volt it is 15 mA. The dynamic resistance in this region is

$$R = \frac{\Delta V}{\Delta i} = \frac{0.2\,\text{volt}}{5\,\text{mA}} = 40\,\Omega$$

(b) The current at 2 volt is 400 mA and at 2.1 volt it is 800 mA. The dynamic resistance in the region is

$$R = \frac{\Delta V}{\Delta i} = \frac{0.1\,\text{volt}}{400\,\text{mA}} = 0.25\,\Omega\,.$$

6. p-n Junction Diode as a Rectifier

An electronic device which converts alternating current / voltage into direct current / voltage is called 'rectifier'.

A p-n junction diode offers a low resistance for the current to flow, when forward-biased, but a very high resistance, when reverse-biased. It thus passes current only in one direction and acts as a rectifier.

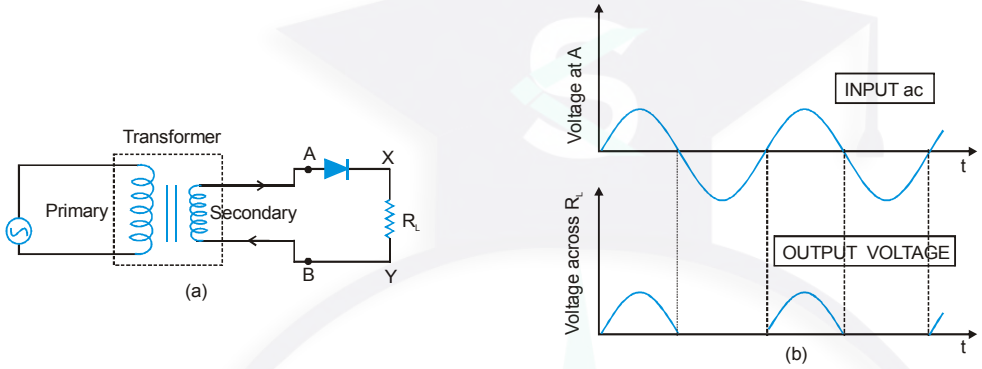
The junction diode can be used either as an half-wave rectifier, when it allows current only during the positive half-cycles of the input a.c. supply; or as a full-wave rectifier when it allows current in the same direction for both half-cycles of the input alternating current .

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(a) p-n Junction Diode as Half-wave Rectifier

The half-wave rectifier circuit is shown in Fig. (a) and the input and output wave forms in Fig. (b). The alternating input voltage is applied across the primary P_1P_2 of a transformer. S_1S_2 is the secondary coil of the same transformer. S_1 is connected to the p -type crystal of the junction diode and S_2 is connected to the n -type crystal through a load resistance R_L.

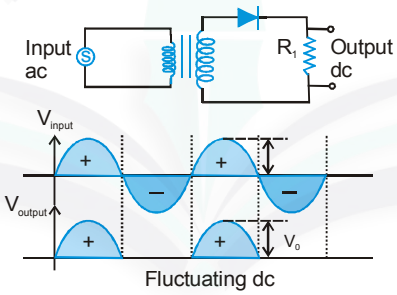
During the first half-cycle of the a.c. input, when the terminal S_1 of the secondary is positive and S_2 is negative, the junction diode is forward-biased. Hence it conducts and current flows through the load R_L in the direction shown by arrows. The current produces across the load an output voltage of the same shape as the half-cycle of the input voltage. During the second half-cycle of the a.c. input, the terminal S_1 is negative and S_2 is positive. The diode is now reverse-biased. Hence there is almost zero current and zero output voltage across R_L. The process is repeated. Thus, the output current is unidirectional, but pulsating, as shown in lower part of Fig. (b).



Since the output- current corresponds to one half of the input voltage wave, the other half being missing, the process is called half-wave rectification.

The purpose of the transformer is to supply the necessary voltage to the rectifier. If direct current at high voltage is to be obtained from the rectifier, as is necessary for power supply, then a step-up transformer is used, as shown in Fig. (a). In many solid-state equipments, however, direct current of low voltage is required. In that case, a step-down transformer is used in the rectifier.

Note:



(i) During positive half cycle

Diode ⟶ forward biased

Output signal ⟶ obtained

(ii) During negative half cycle

Diode ⟶ reverse biased

Output signal ⟶ not obtained

(iii) Output voltage is obtained across the load resistance R_L. It is not constant but pulsating (mixture of ac and dc) in nature.

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(iv) Average output in one cyle

$$I_{dc} = \frac{I_0}{\pi} \text{ and } V_{dc} = \frac{V_0}{\pi} ; I_0 = \frac{V_0}{r_f + R_L}$$

(r_f = forward biased resistance)

(v) r.m.s. output : $I_{rms} = \frac{I_0}{2}$, $V_{rms} = \frac{V_0}{2}$

(vi) The ratio of the effective alternating component of the output voltage or current o the dc component is known as ripple factor.

$$r = \frac{I_{ac}}{I_{dc}} = \left[\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1\right]^{1/2} = 1.21$$

(vii) Peak inverse voltage (PIV) : The maximum reverse biased voltage that can be applied before commoncement of Zener region is called the PIV. When diode is not conducting PIV across it = V_0

(viii) Efficiency : It is given by $\% \eta = \frac{P_{out}}{P_{in}} \times 100 = \frac{40.6}{1 + \frac{r_f}{R_L}}$

If $R_L >> r_f$ then $\eta = 40.6\ \%$

If $R_L = r_f$ then $\eta = 20.3\ \%$

(ix) Form factor $= \frac{I_{rms}}{I_{dc}} = \frac{\pi}{2} = 1.57$

(x) The ripple frequency (ω) for half wave rectifier is same as that of ac.

(b) p-n Junction Diode as Full-wave Rectifier: In a full-wave rectifier, a unidirectional, pulsating output current is obtained for both halves of the a.c. input voltage. Essentially, it requires two junction diodes so connected that one diode rectifies one half and the second diode rectifies the second half of the input.

The circuit for a full-wave rectifier is shown in Fig. 8 (a) and the input and output wave forms in Fig. (b). The a.c. input voltage is applied across the primary P_1P_2 of a transformer. The terminals S_1 and S_2 of the secondary are connected to the p -type crystals of the junction diodes D_1 and D_2 whose n -type crystals are connected to each other. A load resistance R_L is connected across the n -type crystals and the central-tap T of the secondary S_1S_2.

During the first half-cycle of the a.c. input voltage, the terminal S_1 is suppose positive relative to T and S_2 is negative. In this situation, the junction diode D_1 is forward-biased and D_2 is reverse-biased. Therefore, D_1 conducts while D_2 does not. The conventional current flows through diode D_1 , load R_L and the upper half of the secondary winding, as shown by soiid arrows. During the second half-cycle of the input voltage, S_1 is negative relative to T and S_2 is positive. Now, D_1 is reverse-biased and does not conduct while D_2 is forward-biased and conducts. The current now flows through D_2, load R_L and the lower half of the secondary, as shown by dotted arrows. It may be seen that the current in the load R_L flows in the same direction for both half-cycles of the a.c. input voltage. Thus, the output current is a continuous series of unidirectional pulses. However, it can be made fairly steady by means of smoothing filters.

Note :

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Diode ⟶ forward biased
Output signal ⟶ obtained

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Diode ⟶ reverse biased
Output signal ⟶ not obtained

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$$I_{dc} = \frac{I_0}{\pi} \text{ and } V_{dc} = \frac{V_0}{\pi}; I_0 = \frac{V_0}{r_f + R_L}$$

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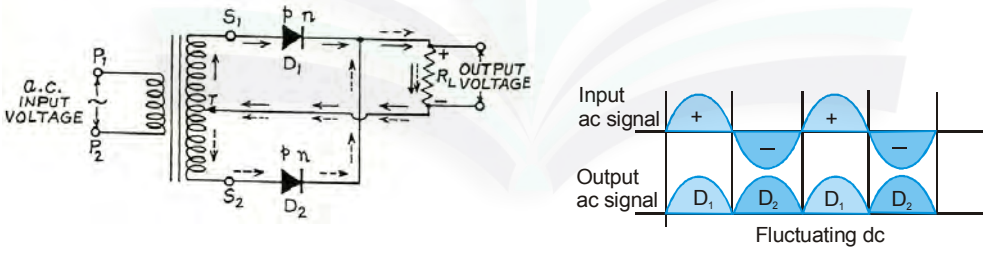
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Filter

The rectified voltage is in the form of pulses of the shape of half sinusoids. Though it is unidirectional it does not have a steady value. To get steady dc output from the pulsating voltage normally a capacitor is connected across the output terminals (parallel to the load R_L). One can also use an inductor in series with R_L for the same purpose. Since these additional circuits appear to filter out the ac ripple and give a pure dc voltage, so they are called filters.

Now we shall discuss the role of capacitor in filtering. When the voltage across the capacitor is rising, it gets charged. If there is no external load, it remains charged to the peak voltage of the rectified output. When there is a load, it gets discharged through the load and the voltage across it begins to fall. In the next half-cycle of rectified output it again gets charged to the peak value . The rate of fall of the voltage across the capacitor depends upon the inverse product of capacitor C and the effective resistance RL used in the circuit and is called the time constant. To make the time constant large value of C should be large. So capacitor input filters use large capacitors. The output voltage obtained by using capacitor input filter is nearer to the peak voltage of the rectified voltage. This type of filter is most widely used in power supplies.

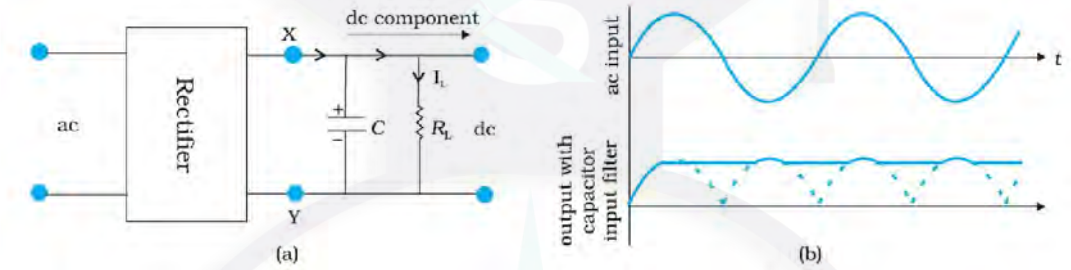


FIGURE (a) A full-wave rectifier with capacitor filter, (b) Input and output voltage of rectifier in(a).

(i) During positive half cycle

Diode : $D_1 \longrightarrow$ forward biased $\qquad D_2 \longrightarrow$ reverse biased

Output signal $\longrightarrow$ obtained due to D_1 only

(ii) During negative half cycle

Diode : $D_1 \longrightarrow$ reverse biased $\qquad D_2 \longrightarrow$ forward biased

Output signal $\longrightarrow$ obtained due to D_2 only

(iii) Fluctuating dc $\longrightarrow$ Filter $\longrightarrow$ constant dc.

(iv) Output voltage is obtained across the load resitance R_L. It is not constant but pulsating in nature.

(v) Average output : $V_{av} = \dfrac{2V_0}{\pi}$, $I_{av} = \dfrac{2I_0}{\pi}$

(vi) r.m.s. output = $V_{rms} = \dfrac{V_0}{\sqrt{2}}$, $I_{rms} = \dfrac{I_0}{\sqrt{2}}$

(vii) Ripple factor : $r = 0.48 = 48\%$

(viii) Ripple frequency : The ripple frequency of full wave rectifier = 2 × (Frequency of input ac)

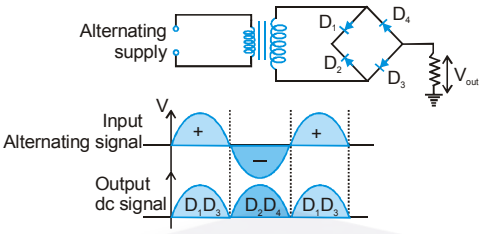
(ix) Peak inverse voltage (PIV) : It's value is $2V_0$.

(x) Efficiency : $n_{\%} = \dfrac{81.2}{1+\dfrac{r_1}{R_L}}$ for $r_f << R_L$, $\eta = 81.2\%$

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(3) Full wave bridge rectifier : Four diodes D_1, D_2, D_3 and D_4 are used in the circuit.

During positve half cycle D_1 and D_3 are forward biased and D_2 and D_4 are reverse biased. During negative half cycle D_2 and D_4 are forward biased and D_1 and D_3 are reverse biased.



(c) Different Types of Junction Diode

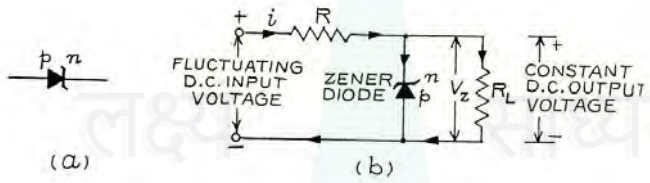
The junction diodes are of many types. The important types are Zener diode, photodiode, light-emitting diode (LED) and solar cell.

(i) Zener Diode: It is a voltage-regulating device based upon the phenomenon of avalanche breakdown in a junction diode.

When the reverse-bias applied to a junction diode is increased, there is an abrupt rise in the (reverse) current when the bias reverse reaches a certain value, known as 'breakdown voltage' or 'Zener voltage'.

Thus, in this region of the reverse characteristic curve, the voltage across the diode remains almost constant for a large range of currents. Hence the diode may be used to stabilize voltage at a pre-determined value. It is then known as 'Zener diode'. It can be designed, by properly controlled doping of the diode, to stabilize voltage at any desired value between 4 –100 volt. .

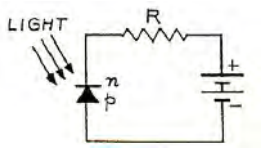
Fig. (a) shows the symbol of a Zener diode and Fig. (b) shows a simple circuit for stabilizing voltage across a load R_L. The circuit consists of a series voltage-dropping resistance R and a Zener diode in



parallel with the load R_L. The Zener diode is selected with a Zener voltage V_Z equal to the voltage desired across the load. The fluctuating d.c. input voltage may be the d.c. output of a rectifier. Whenever the input voltage increases, the excess voltage is dropped across the resistance R . This causes an increase in the input current i. This increase is conducted by the Zener diode, while the current through the load and hence the voltage across it remains constant at V_Z. Likewise, a decrease in the input voltage causes a decrease in the input current i. The current through the diode decreases correspondingly, again maintaining the current through the load constant.

Since the resistance R absorbs the input voltage fluctuations to give a constant output voltage V_Z, the circuit cannot work if the input voltage falls below V_Z. .

(ii) Photodiode : A photodiode is a reverse-biased p-n junction made from a photosensitive semiconductor. The junction is embedded in clear plastic. The upper surface across the junction is open to light, while the remaining sides of the plastic are painted black or enclosed in a metallic case. The entire unit is extremely small, of the order of a 0·1 inch size.

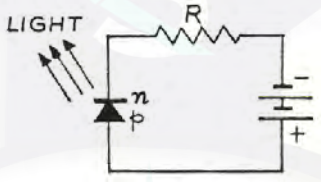


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When no light is falling on the junction and the reverse-bias is of the order of a few tenths of a volt, an almost constant small current ($\approx \mu A$) is obtained. This "dark" current is the reverse saturation current due to the thermally-generated minority-carriers (electrons in p -region and holes in n -region). When light of appropriate frequency is made incident on the junction, additional electron-hole pairs are created near the junction (due to breaking of covalent bonds). These light-generated minority-carriers cross the· (reverse-biased) junction and contribute to the (reverse) current due to thermally-generated carriers. Therefore, the current in the circuit increases (a fraction of a mA). This, so-called 'photoconductive' current varies almost linearly with the incident light flux.

The p--n photodiodes can operate at frequencies of the order of 1 MHz. Hence they are used in high-speed reading of computer punched cards, light-detection systems, light-operated switches, electronic counters etc.

(iii) Light-Emitting Diode (LED) : When a p-n junction diode is forward-biased. both the electron and the holes move towards the junction. As they cross the junction, the electrons fall into the holes (recombine). Hence, energy is released at the junction (because the electrons fall from a higher to a lower energy level). In case of Ge and Si diodes, the energy released is infra-red radiation. If, however, the diode is made of gallium arsenide or indium phosphide, the energy released is visible light. The diode is then called a 'light-emitting diode' (LED).



LEDs have replaced incandescent lamps in many applications because of their low input power, long life and fast on-off switching.

They are extensively used in fancy electronic devices like calculators, etc.

Ex. A zener diode of voltage V_Z (= 6 Volt) is used to maintain a constant voltage across a load resistance R_L (=1000Ω) by using a series resistance R_S (=100Ω). If the e.m.f. or source is E (= 9V), calcualte the value of current through series resistance, Zener diode and load resistance. What is the power being dissipated in Zener diode.

Sol. Here, E = 9V; V_Z = 6; R_L = 1000Ω and R_s = 100Ω,

Potential drop across series resistor $V = E - V_Z = 9 - 6 = 3$ V

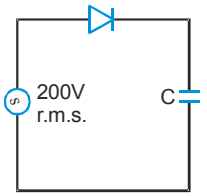
Current through series resistance R_S is $I = \frac{V}{R} = \frac{3}{100} = 0.03A$

Current through load resistance R_L is $I_L = \frac{V_Z}{R_L} = \frac{6}{1000} = 0.006A$

Current through Zener diode is $I_Z = I - I_L = 0.03 - 0.006 = 0.024$ A

Power dissipated in Zener diode is $P_Z = V_Z I_Z = 6 \times 0.024 = 0.144$ Watt

Ex. In the figure, an A.C. of rms voltage 200 volt is applied to the circuit containing diode and the capacitor and it is being rectified. The potential across the capacitor C in volt will be-

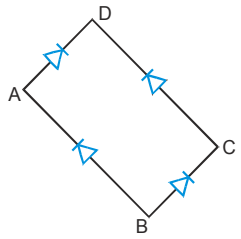


(1) 500 **(2)** 200 **(3)** 283 **(4)** 141

Ans. (3)

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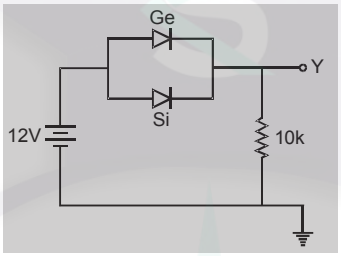
Ex. In the figure, input is applied across A and C and output is taken across B and D, then the output is-



(1) Zero **(2)** Same as input **(3)** Full wave rectified **(4)** Half wave rectified

Ans. (3)

Ex. Two junction diodes one of germanium (Ge) and other of silicon (Si) are connected as shown in figure to a battery of emf 12 V and a load resistance 10 kΩ. The germanium diode conducts at 0.3 V and silicon diode at 0.7 V. When a current flows in the circuit, the potential of terminal Y will be-



(1) 12 V **(2)** 11 V **(3)** 11.3 V **(4)** 11.7 V

Ans. (4)

Ex. Potential barrier developed in a junction diode opposes-

(1) Minority carriers in both regions only **(2)** Majority carriers

(3) Electrons in N-region **(4)** Holes in P-region

Ans. (2)

Ex. Avalanche breakdown in a semiconductor diode occurs when-

(1) Forward current exceeds a certain value **(2)** Reverse bias exceeds a certain value

(3) Forward bias exceeds a certain value **(4)** The potential barrier is reduced to zero

Ans. (2)

Ex. A potential barrier of 0.50 V exists across a p-n junction.

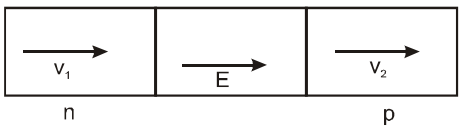
(a) If the depletion region is 5.0×10^{-7} m wide, what is the intensity of the electric field in this region ?

(b) An electron with speed 5.0×10^{5} m/s approaches the p-n junction from the n-side. With what speed will it enter the p-side ?

Sol. : **(a)** The electric field is E = V/d

$$= \frac{0.50\,V}{5.0 \times 10^{-7}\,m} = 1.0 \times 10^{6}\,V/m.$$

(b)



Suppose the electron has a speed v_1 when it enters the depletion layer and v_2 when it comes out of it (figure). As the potential energy increases by e × 0.50 V, from the principle of conservation of energy,

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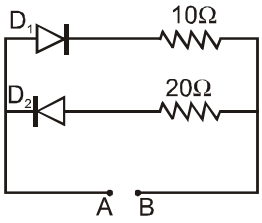
$\frac{1}{2}mv_1^2 = e \times 0.50\ V + \frac{1}{2}mv_2^2$ or,

$\frac{1}{2} \times (9.1 \times 10^{-31}\ kg) \times (5.0 \times 10^5\ m/s)^2 = 1.6 \times 10^{-19} \times 0.5\ J + \frac{1}{2}(9.1 \times 10^{-31}\ kg)\ v_2^2$

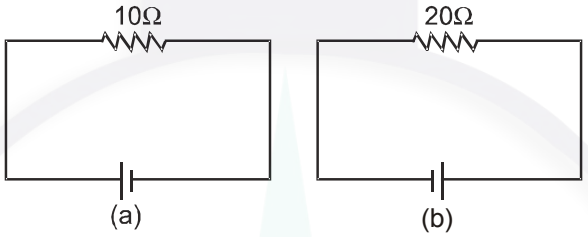
or, $1.13 \times 10^{-19}\ J = 0.8 \times 10^{-19}\ J + (4.55 \times 10^{-31} kg)\ v_2^2$.

Solving this, $v_2 = 2.7 \times 10^5$ m/s

Ex. A 2 V battery may be connected across the points A and B as shown in figure. Assume that the resistance of each diode is zero in forward bias and infinity in reverse bias. Find the current supplied by the battery if the positive terminal of the battery is connected to (a) the point A (B) the point B.

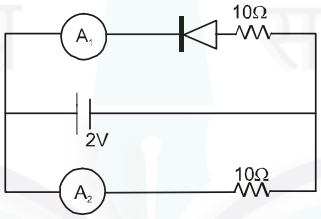


Sol. : **(a)** When the positive terminal of the battery is connected to the point A, the diode D_1 is forward-biased and D_2 is reverse-biased. The resistance of the diode D_1 is zero, and it can be replaced by a resistanceless wire. Similarly, the resistance of the diode D_2 is infinity, and it can be replaced by a broken wire. The equivalent circuit is shown in figure. The current supplied by the battery is 2 V/10 Ω = 0.2 A.



(b) When the positive terminal of the battery is connected to the point B, the diode D_2 is forward-biased and D_1 is reverse biased. The equivalent circuit is shown in figure (b). The current through the battery is 2 V/20 Ω = 0.1 A.

Ex. What are the reading of the ammeters A_1 and A_2 shown in figure. Neglect the resistance of the meters.



Ans. Reading of A_1 is zero, Reading of A_2 is 0.2 A

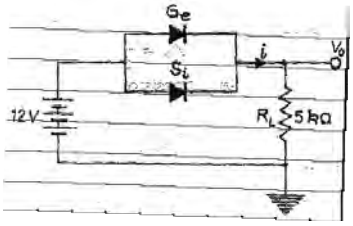
Ex. Calculate the value of V_0, if the Si diode and the Ge diode start conducting at 0.7 V and 0.3 V respectively, in the given circuit. If the Ge diode connection be reversed, what will be the new values of V_0 and I ?

Sol. The effective forward voltage across Ge diode is 12 V – 0.3 = 11.7.

This will appear as the output voltage across the load, that is,

$V_0 = 11.7$ V

The current in the load is



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$$i = \frac{V_0}{R_L} = \frac{11.7}{5K\Omega} = 2.34 \text{ mA}.$$

On reversing the connections of Ge diode, it will be reverse-biased and conduct no current. Only Si diode will conduct. The effective forward voltage across Si diode is 12 V – 0.7V = 11.3 V. This will appear as output, that is

$V_0 = 11.3$ V

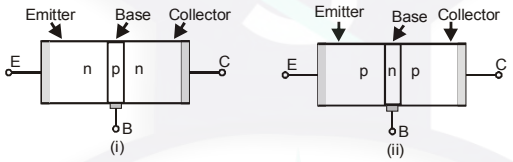
The current in the load is

$$i = \frac{V_0}{R_L} = \frac{11.3}{5k\Omega} = 2.26 \text{ mA}.$$

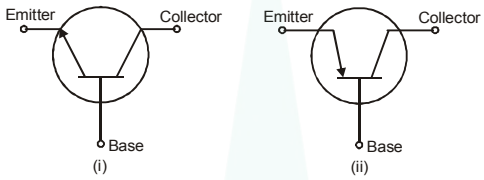
7. Junction Transistor :

Transistor structure and action :

A transistor has three doped regions forming two p–n junctions between them. There are two types of transistors, as shown in figure.



(a) Schematic representations of a n–p–n transistor and p–n–p transistor



(b) Symbols for n–p–n and p–n–p transistors.

(i) n–p–n transistor : Here two segments of n–type semiconductor (emitter and collector) are separated by a segment of p–type semiconductor (base).

(ii) p–n–p transistor : Here two segments of p–type semiconductor (termed as emitter and collector) are separated by a segment of n–type semiconductor (termed as base).

The schematic representations of an n–p–n and a p–n–p configuration are shown in figure. All the three segments of a transistor have different thickness and their doping levels are also different. In the schematic symbols used for representing p–n–p and n–p–n transistors (figure b) the arrowhead shows the direction of conventional current in the transistor. A brief description of the three segments of a transistors is given below:

Emitter : This is the segment on one side of the transistor shown in fig.(a). It is of moderate size and heavily doped. It supplies a large number of majority carriers for the current flow through the transistor.

Base : This is the central segment. It is very thin and lightly doped.

Collector : This segment collects a major portion of the majority carriers supplied by the emitter. The collector side is moderately doped and larger in size as compared to the emitter, so that heat generated during the collection of charge carriers may be easily dissipated into atmosphere

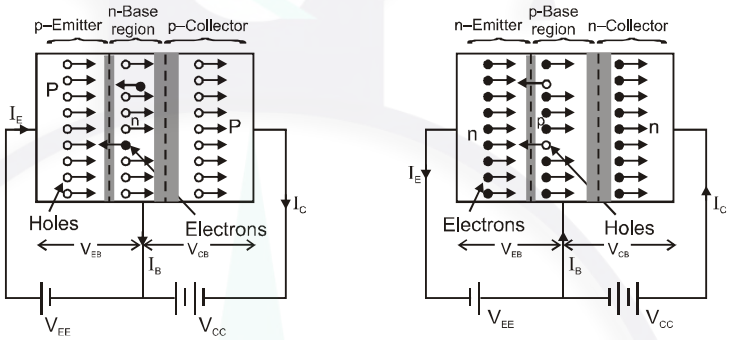
In case of a p–n junction, there is a formation of depletion region across the junction. In case of a transistor, there are two depletion regions are formed respectively at the emitter base–junction and the base collector junction.

The transistor works as an amplifier, with its emitter–base junction forward biased and the base–collector junction

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reverse biased. This situation is shown in figure, where V_{CC} and V_{EE} are used for creating the respective biasing. When the transistor is biased in this way it is said to be in active state. We represent the voltage between emitter and base as V_{EB} and that between the collector and base as V_{CB} . In figure, base is a common terminal for the two power supplies whose other terminals are connected to emitter and collector, respectively. So, the two power supplies are represented as $V_{EE'}$ and $V_{CC'}$ respectively. In circuits, where emitter is the common terminal, the power supply between the base and emitter is represented as V_{BB} and that between collector and emitter as $V_{CC'}$.

The heavily doped emitter has a high concentration of majority carriers, which will be holes in a p–n–p transistor and electrons in an n–p–n transistor. These majority carriers enter the base region in large numbers. The base is thin and lightly doped. So, the majority carriers there would be few. In a p–n–p transistor the majority carries in the base are electrons since base is of n–type semiconductor. The large number of holes entering the base from the emitter swamps the small number of electrons there. As the base collector–junction is reverse biased, these holes, which appear as minority carriers at the junction, can easily cross the junction and enter the collector. The holes in the base could move either towards the base terminal to combine with the electrons entering from outside or cross the junction to enter into the collector and reach the collector terminal. The base is made thin so that most of the holes find themselves near the reverse-biased base-collector junction and so cross the junction instead of moving to the base terminal.



Bias Voltage applied on : (a) p–n–p transistor and (b) n–p–n transistor

Note : Due to forward bias a large current enters the emitter–base junction, but most of it is diverted to adjacent reverse–biased base–collector junction and the current coming out of the base becomes a very small fraction of the current that entered the junction. If we represent the hole current and the electron current crossing the forward biased junction by the sum $I_h + I_e$. We see that the emitter current $I_E = I_h + I_e$ but the base current $I_B << I_h + I_e$, because a major part of I_E goes to collector instead of coming out of the base terminal. The base current is thus a small fraction of the emitter current.

It is obvious from the above description and also from a straight forward application of Kirchoff's law to figure(a) that the emitter current is the sum of collector current and base current :

$$I_E = I_C + I_B$$

We also see that $I_C \approx I_{E'}$

Our description of the direction of motion of the holes is identical with the direction of the conventional current. But the direction of motion of electrons is just opposite to that of the current. Thus in a p–n–p transistor the current enters from emitter into base whereas in a n–p–n transistor it enters from the base into the emitter. The arrowhead in the emitter shows the direction of the conventional current.

We can conclude that in the active state of the transistor the emitter–base junction acts as a low resistance while the base collector acts as a high resistance.

In a transistor, only three terminals are available viz emitter (E), base (B) and collector (C). Therefore in a circuit the input/output connections have to be such that one of these (E,B or C) is common to both the input and the output. Accordingly, the transistor can be connected in either of the following three configurations :

Common Emitter (CE), Common Base (CB), Common Collector (CC).

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Working of Transistor

(1) There are four possible ways of biasing the two P-N junctions (emitter junction and collector junction) of transistor.

(i) Active mode : Also known as linear mode operation.

(ii) Saturation mode : Maximum collector current flows and transistor acts as a closed switch from collector to emitter terminals.

(iii) Cut-off mode : Denotes operation like an open switch where only leakage current flows.

(iv) Inverse mode : The emitter and collector are inter changed.

Different modes of operation of a transistor

Operating mode	Emitter base bias	Collector base bias
Active	Forward	Reverse
Saturation	Forward	Forward
Cut off	Reverse	Reverse
Inverse	Reverse	Forward

(2) A transistor is mostly used in the active region of operation i.e., emitter base junction is forward biased and collector base junction is reverse biased.

(3) From the operation of junction transistor it is found that when the current in emitter circuit changes. There is corresponding change in collector current.

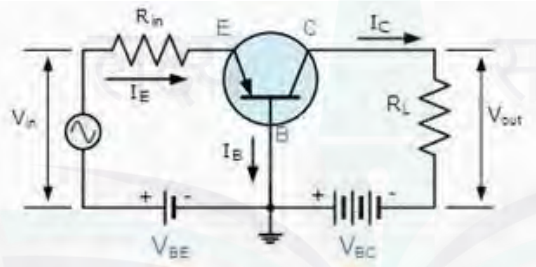
(4) In each state of the transistor there is an input port and an output port. In general each electrical quantity (V or I) obtained at the output is controlled by the input.

Transistor Configurations

A transistor can be connected in a circuit in the following three different configurations.

Common base (CB), Common emitter (CE) and Common collector (CC) configuration.

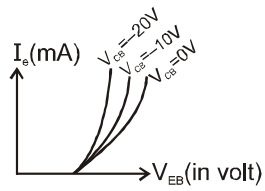
(1) CB configurations : Base is common to both emitter and collector.



(i) Input current = I_e (ii) Input voltage = V_{EB} (iii) Output voltage = V_{CB} (iv) Output current = I_C

With small increase in emitter-base voltage V_{EB}, the emitter current I_e increases rapidly due to small input resistance.

(v) **Input characteristics :** If V_{CB} = constant, curve between I_e and V_{EB} is known as input charactersistics. It is also known as emitter charactersistics :



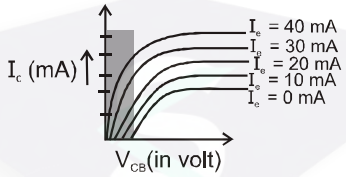
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Input characteristics of NPN transistor are also similar to the above figure but I_e and V_{EB} both are negative and V_{CB} is positive. Dynamic input resistance of a transistor is given by

$$R_i = \left(\frac{\Delta V_{EB}}{\Delta I_e}\right)_{V_{CB}=\text{constant}} \quad \{R_i \text{ is of the order of } 100\Omega\}$$

(vi) Output characteristics : Taking the emitter current i_e constant, the curve drawn between I_C and V_{CB} are known as output charactersistics of CB configuration.

$$\text{Dynamics output resistance } R_0 = \left(\frac{\Delta V_{CB}}{\Delta i_C}\right)_{i_e=\text{constant}}$$



Note: Transistor as CB amplifier

(i) ac current gain $\alpha_c = \dfrac{\text{Small change in collector current } (\Delta i_c)}{\text{Small changeincollectorcurrent } (\Delta i_e)}$

(ii) dc current gain α_{dc} (or α) $= \dfrac{\text{Collector current } (i_c)}{\text{Emitter current } (i_e)}$

value of α_{dc} lies between 0.95 to 0.99

(iii) Voltage gain $A_v = \dfrac{\text{Change in output voltage } (\Delta V_0)}{\text{Change in input voltage } (\Delta V_i)}$

$\Rightarrow A_v = \alpha_{ac} \times$ Resitance gain

(iv) Power gain $= \dfrac{\text{Change in output power } (\Delta P_0)}{\text{Change in input power } (\Delta P_C)}$

$\Rightarrow$ Power gain $= \alpha^2_{ac} \times$ Resistance gain

Common Emitter(CE) :

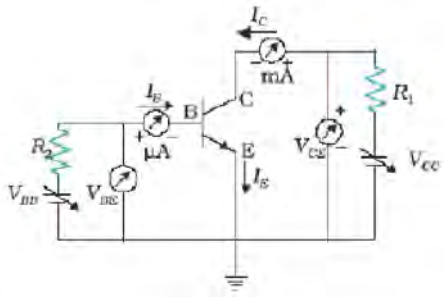
The transistor is most widely used in the CE configuration.

When a transistor is used in CE configuration, the input is between the base and the emitter and the output is between the collector and the emitter. The variation of the base current I_B with the base–emitter voltage V_{BE} is called the input characteristic. The output characteristics are controlled by the input characteristics. This implies that the collector current changes with the base current.

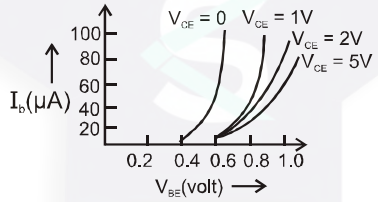
CE configurations : Emitter is common to both base and collector.

The graphs between voltages and currents when emitter of a transistor is common to input and output circuits are known as CE charactersistics of a transistor.

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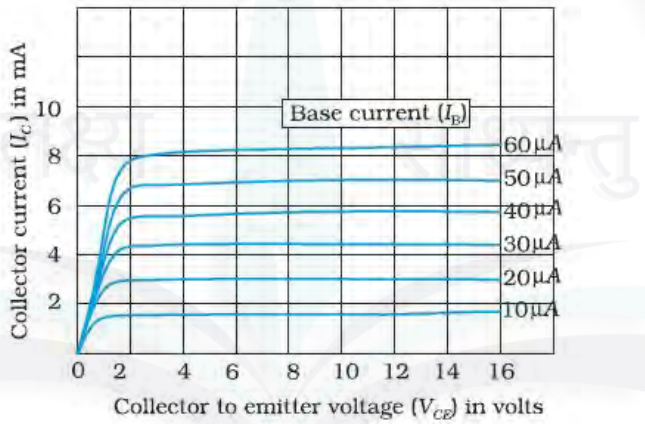


Input characterisitics : Input characterisitics curve is drawn between base current I_b and emitter base voltage V_{EB}, at constant collector emitter voltage V_{CE}.



Dynamic input resistance $R_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE} \to \text{constant}}$

Output characteristics : Variation of collector current I_C with V_{CE} can be noticed for V_{CE} between 0 to 1 V only. The value of V_{CE} up to which the I_C changes with V_{CE} is called knee voltage. The transistor are operated in the region above knee voltage.



Dynamic output resistance $R_0 = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B \to \text{constant}}$

(b) Transistor as a device :

The transistor can be used as a device application depending on the configuration used (namely CB, CC and CE), the biasing of the E-B and B-C junction and the operation region namely cutoff, active region and saturation.

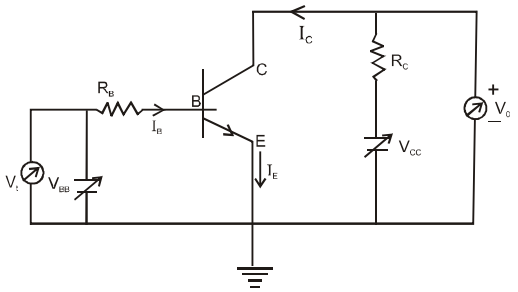
When the transistor is used in the cutoff or saturation state it acts as a switch. On the other hand for using the transistor as an amplifier, it has to operate in the active region.

(i) Transistor as a switch:

We shall try to understand the operation of the transistor as a switch by analysing the behaviour of the base-biased transistor in CE configuration as shown in fig. (a). Applying Kirchhoff's voltage rule to the input and output sides of this circuit, we get

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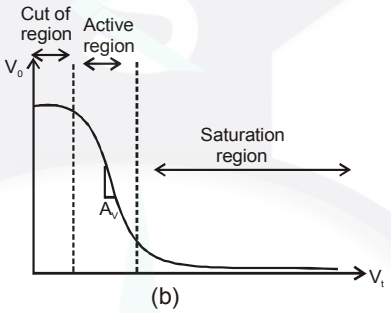
$V_{BB} = I_B R_B + V_{BE}$ and $V_{CE} = V_{CC} - I_C R_C$.



(a)

We shall treat V_{BB} as the dc input voltage V_i and V_{CE} as the dc output voltage V_o. So, we have

$V_i = I_B R_B + V_{BE}$ and $V_0 = V_{CC} - I_C R_C$.



(b)

Let us see how V_0 changes as V_i increases from zero onwards. In the case of Si transistor, as long as input V_i is less than 0.6 V, the transistor will be in cut off state and current I_C will be zero. Hence $V_O = V_{CC}$.

When V_i becomes greater than 0.6 V the transistor is in active state with some current I_C in the output path and the output V_0 decrease as the term $I_C R_C$ increases. With increase of V_i, I_C increases almost linearly and so V_0 decreases linearly till its value becomes less than about 1.0 V.

Beyond this, the change becomes non linear and transistor goes into saturation state. With further increase in V_i the output voltage is found to decrease further towards zero though it may never become zero. If we plot the V_0 vs V_i curve, [also called the transfer characteristics of the base-biased transistor (figure b], we see that between cut off state and active state and also between active state and saturation state there are regions of non-linearity showing that the transition from cutoff state to active state and from active state to saturation state are not sharply defined.

As long as V_i is low and unable to forward-bias the transistor, V_0 is high (at V_{CC}). If V_i is high enough to drive the transistor into saturation very near to zero. When the transistor is not conducting it is said to be switched off and when it is driven into saturation it is said to be switched on. This shows that if we define low and high states as below and above certain voltage levels corresponding to cutoff and saturation of the transistor, then we can say that a low input switches the transistor off and a high input switches it on.

(ii) Transistor as an Amplifier (CE-Configuration) : To operate the transistor as an amplifier it is necessary to fix its operating point somewhere in the middle of its active region. If we fix the value of V_{BB} corresponding to a point in the middle of the linear part of the transfer curve then the dc base current I_B would be constant and corresponding collector current I_C will be constant The dc voltage $V_{CE} = V_{CC} - I_C R_C$ would also remain constant. The operating values of V_{CE} and I_B determine the operating point, of the amplifier. If a small sinusoidal voltage with amplitude v_s is superposed on the dc base bias by connecting the source of that signal in series with the V_{BB} supply, then the base current will have sinusodial variations supperimposed on the value of I_B. As a consequence the collector current also will have sinusoidal variations superimposed on the value of I_C producing in turn corresponding change in the value of V_0. We can measure the ac variations across the input and output terminals by blocking the dc voltages by larger capacitors.

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In the discription of the amplifier given above we have not considered any ac signal. In general, amplifiers are used to amplify alternating signals. Now let us superimpose an ac input signal v_i (to be amplified) on the bias V_{BB} (dc) as shown in Figure. The output is taken between the collector and the ground.

The working of an amplifier can be easily understood, if we first assume that $v_i = 0$. Then applying Kirchhoff's law to the output loop, we get

$$V_{CC} = V_{CE} + I_C R_L$$

Likewise, the input loop gives

$$V_{BB} = V_{BE} + I_B R_B$$

when v_i is not zero, we get

$$V_{BE} + v_i = V_{BE} + I_B R_B + \Delta I_B (R_B + r_i)$$

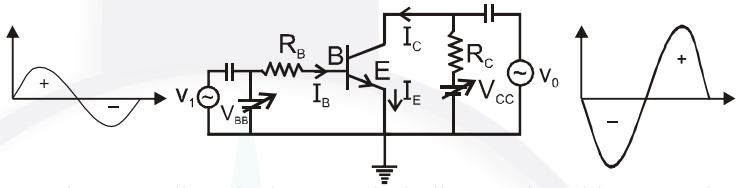
The change in V_{BE} can be related to the input resistance r_i and the change in I_B.

Hence $v_i = \Delta I_B (R_B + r_i)$

$= r\Delta I_B$

The change in I_B causes a change in I_C. We define a parameter β_{ac}, which is similar to the β_{dc} defined in equation as

$$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B} = \frac{i_c}{i_b}$$



which is also known as the ac current gain A_i. Usually β_{ac} is close to β_{dc} in the linear region of the output characterstics.

The change in I_C due to a change in I_B causes a change in V_{CE} and the voltage drop across the resistor R_L because V_{CC} is fixed.

These changes can be given by Eq. as

$\Delta V_{CC} = \Delta V_{CE} + R_L \Delta I_C = 0$

or $\Delta V_{CE} = -R_L \Delta I_C$

The change in V_{CE} is the output voltage v_0. From equation we get

$v_0 = \Delta V_{CE} = -\beta_{ac} R_L \Delta I_B$

The voltage gain of the amplifier is

$$A_v = \frac{v_0}{v_i} = \frac{\Delta V_{CE}}{r\Delta I_B} = -\frac{\beta_{ac} R_L}{r}$$

The negative sign represents that output voltage is opposite with phase with the input voltage.

From the dissusion of the transistor characteristics you have seen that there is a current gain β_{ac} in the CE configuration. Here we have also seen the voltage gain A_v. Therefore the power gain A_p can be expressed as the product of the current gain and voltage gain. Mathematically

$$A_p = \beta_{ac} \times A_v$$

Since β_{ac} and A_v are greater than 1, we get ac power gain. However it should be realised that transistor is not a power generating device. The energy for the higher ac power at the output is supplied by the battery.

Note: Transistor as CE amplifier

(i) ac current gain $\beta_{ac} = \left(\frac{\Delta i_C}{\Delta i_b}\right)_{V_{CE} = \text{constant}}$

(ii) dc current gain $\beta_{dc} = \frac{i_c}{i_b}$

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(iii) Votage gain : $A_v = \frac{\Delta V_0}{\Delta V_i} = \beta_{ac} \times$ Resistance gain

(iv) Power gain = $\frac{\Delta P_0}{\Delta P_i} = \beta^2_{ac} \times$ Resistance

(v) Transconductance (g_m) : The ratio of the change in collector current to the change in emitter base voltage is called trans conductance. i.e. $g_m = \frac{\Delta i_c}{\Delta V_{EB}}$. Also $g_m = \frac{A_v}{R_L}$; R_L = Load resistance.

(3) Relation between α and β : $\beta = \frac{\alpha}{1-\alpha}$ or $\alpha = \frac{\beta}{1+\beta}$

Ex. Let i_E, i_C and i_B represent the emitter current, the collector current and the base current respectively in a transistor. Then

(1) i_C is slightly smaller than i_E. **(2)** i_C is slightly greater than i_E.

(3) i_B is much smaller than i_E. **(4)** i_B is much greater than i_E.

Ans. (1,3)

Ex. In a common base transistor amplifier, the input and the output resistance are 500 Ω and 40kΩ, and the emitter current is 1.0mA. Find the input and the output voltages. Given α = 0.95.

Sol. The input voltage is emitter current multiplied by input resistance, that is,

$V_{in} = i_E \times R_{in} = (1.0 \times 10^{-3}\ A) \times 500\Omega = 0.5\ V$

Similarly, the output voltage is

$V_{out} = i_C \times R_{out} = \alpha\, i_E \times R_{out}$

$= 0.95\ (1.0 \times 10^{-3}\ A) \times (40 \times 10^3\ \Omega) = 38\ V.$

Ex. A P–N–P transistor is used in common–emitter mode in an amplifier circuit. A change of 40μA in the base current brings a change of 2mA in collector current and 0.04 V in base–emitter voltage. Find the: **(i)** input resistance ($R_{inp.}$), and **(ii)** the base current amplification factor (β).

If a load of 6kΩ is used, then also find the voltage gain of the amplifier.

Sol. : Given $\Delta I_B = 40\mu A = 40 \times 10^{-6}\ A$

$\Delta I_C = 2mA = 2 \times 10^{-3}\ A$

$\Delta V_{BE} = 0.04$ volt, $R_L = 6k\Omega = 6 \times 10^3\ \Omega$

(i) Input Resistance, $R_{inp.} = \frac{\Delta V_{BE}}{\Delta I_B} = \frac{0.04}{40 \times 10^{-6}} = 10^3\ \Omega = 1\ k\Omega$

(ii) Current amplification factor, $\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{2 \times 10^{-3}}{40 \times 10^{-6}} = 50$

(iii) Voltage gain in common–emitter configuration,

$A_\upsilon = \beta \frac{R_L}{R_{inp.}} = 50 \times \frac{6 \times 10^3}{1 \times 10^3} = 300.$

Ex. In an N–P–N transistor 10^{10} electrons enter the emitter in 10^{-6} s. 2% of the electrons are lost in the base. Calculate the current transfer ratio and current amplification factor.

Sol. We know that current = charge/time

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The emitter current (I_E) is given by $I_E = \frac{Ne}{t} = \frac{10^{10} \times (1.6 \times 10^{-19})}{10^{-6}} = 1.6$ mA

The base current (I_B) is given by

$I_B = \frac{2}{100} \times 1.6 = 0.032$ mA

In a transistor, $I_E = I_B + I_C$

$I_C = I_E - I_B = 1.6 - 0.032 = 1.568$ mA

Current transfer ratio $= \frac{I_C}{I_E} = \frac{1.568}{1.6} = 0.98$

Current amplification factor $= \frac{I_C}{I_B} = \frac{1.568}{0.032} = 49.$

Ex. When the voltage between emitter and the base V_{EB} of a transistor is changed by 5mV while keeping the collector voltage V_{CE} fixed when then its emitter current changes by 0.15 mA. Calculate the input resistance of the transistor.

Ans. 33.33 ohm

Ex. A transistor is used in common-emitter mode in an amplifier circuit. When a signal of 20 mV is added to the base–emitter voltage, the base current changes by 20μA and the collector current changes by 2 mA. The load resistance is 5 kΩ. Calculate **(a)** the factor β, **(B)** the input resistance R_{BE}, **(C)** the transconductance and **(D)** the voltage gain.

Sol. **(a)** $\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{2\text{mA}}{20\mu\text{A}} = 100$

(b) The input resistance $R_{BE} = \frac{\Delta V_{BE}}{\Delta I_B} = \frac{20\text{mV}}{20\,\mu\text{A}} = 1\text{k}\Omega$

(c) Transconductance $= \frac{\Delta I_c}{\Delta V_{BE}} = \frac{2\text{mA}}{20\text{mV}} = 0.1$ mho.

(d) The change in output voltage is $R_L \Delta I_c$

$= (5\text{ kW})\,(2\text{mA}) = 10\text{V}.$

The applied signal voltage = 20 mV.

Thus, the voltage gain is,

$\frac{10\,\text{V}}{20\text{mV}} = 500.$

Ex. The a-c current gain of a transistor is β= 19. In its common-emitter configuration, what will be the change in the collector-current for a change of 0.4 mA in the base-current ? What will be the change in the emitter current ?

Sol. By definition, the a-c current gain β is given by

$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}$

$\therefore \Delta I_C = \beta \times \Delta I_B = 19 \times 0.4\text{ mA} = 7.6\text{ mA}.$

The emitter - current is the sum of the base- current and the collector-current ($i_E = i_B + i_C$)

$\therefore \Delta I_E = \Delta I_B + \Delta I_C = 0.4\text{ mA} + 7.6\text{ mA} = 80\text{ mA}.$

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Ex. A transistor is connected in common-emitter (C-E) configuration. The collector-supply is 8 V and the voltage drop across a resistor of 800 Ω in the collector circuit is 0.5 V. If the current-gain factor (α) is 0.96, find the base-current.

Sol. The alternating-current gain is

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.96}{1-0.96} = 24$$

The collector - current is

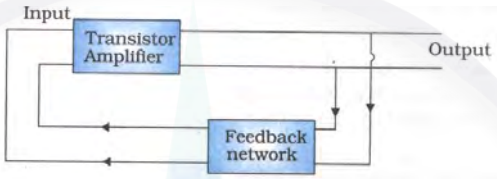
$$i_C = \frac{\text{voltage – drop across collector resistor}}{\text{resistance}} = \frac{0.5\,V}{800\,\Omega} \times 10^{-3}\,A.$$

But $\beta = \frac{i_C}{i_B}$, where i_B is base - current.

$$\therefore\ i_B = \frac{i_C}{\beta} = \frac{0.625 \times 10^{-3}\,A}{24} = 26 \times 10^{-6}\,A = 26\ \mu A.$$

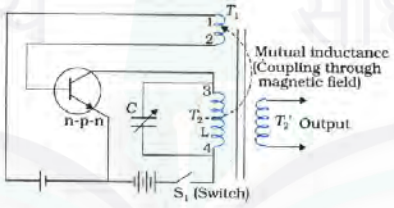
8. Feedback amplifier and transistor oscillator:

In an oscillator, we get ac output without any external input singnal. A portion of the output power is returned back (feedback) to the input in phase with the starting power (this process is termed positive feedback) as shown in figure(a). The feedback can be achieved by inductive coupling (through mutual inductance) or LC or RC networks.



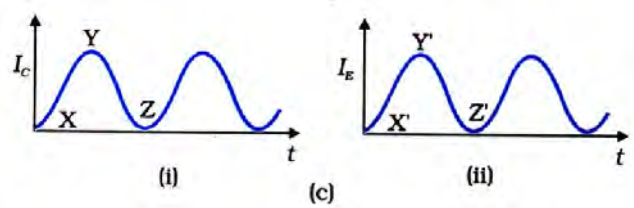
(a)

Suppose switch S_1 is put on to apply proper bias for the first time. Obviously, a surge of collector current flows in the transistor. This current flows through the coil T_2 where terminals are numbered 3 and 4 (Fig. b).



(b)

This current does not reach full amplitude instantaneously but increases from X To Y, as shown in figure(C). The inductive coupling between coil T_2 and coil T_1 now causes a current to flow in the emitter circuit (note that this actually is the 'feedback' from input to output). As a result of this positive feedback, this current (in T_1 emitter current) also increases from X' to Y' Fig. (C) (ii).



(c)

The current in T_2 (collector current), connected in the collector circuit acquires the value Y when the transistor becomes saturated. This means that maximum collector current is flowing and can increase no further. Since there is no further change in collector current, the magnetic field around T_2 ceases to grow. As soon as the field becomes

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static, there will be no further feedback from T_2 to T_1. Without continued feedback, the emitter current begins to fall. Consequently, collector current decreases causes the magnetic field to decay around the coil T_2. Thus, T_1 is now seeing a decaying field in T_2 (opposite from what it saw when the field was growing at the initial start operation). This causes a further decrease in means that both I_E and I_C cease to flow. Therefore, the transistor has reverted back to its original state (when the power was first switched on). The whole process now repeat itself. The transistor is driven to saturation, then to cut-off, and then back to saturation. The time for change from saturation to cut-off and back is determined by the constant of the tank circuit or tuned circuit (inductance L of Coil T_2 and C connected in parallel to it). The resonance frequency **(ν)** of this tuned circuit determines the frequency at which the oscillator will oscillate.

$$\nu = \frac{1}{2\pi\sqrt{LC}}$$

9. Analogue Circuits and Digital Circuits and signal :

There are two types of electronic circuits : analogue circuits and digital circuits :

In analogue circuits, the voltage (or current) varies continuously with time (figure a). Such a voltage (or current) signal is called an 'analogue signal'.Figure shows a typical voltage analogue signal varying sinusoidally between 0 and 5V.

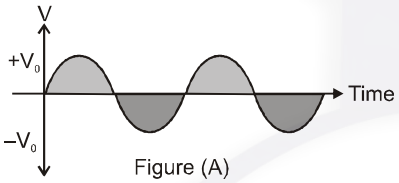


Figure (A)

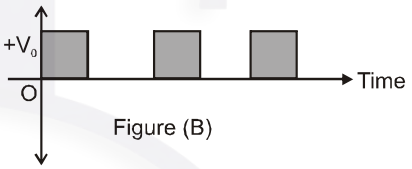


Figure (B)

On the other hand, in digital circuits, the voltage (or current) has only two levels, either zero or some constant value of voltage (figure b). A signal having only two levels of voltage (or current) is called a 'digital signal'. Figure shows a typical digital signal in which the voltage at any time is either 0 or 5V.

In digital circuits, the binary number system is used, according to which the two levels of the (digital) signal are repressented by the digits 0 and 1 only.

The digital circuits are the basis of calculators, computers, etc.

10. Logic Gates :

A logic gate is a digital circuit which works according to some logical relationship between input and output voltages. It either allows a signal to pass through or stops it.

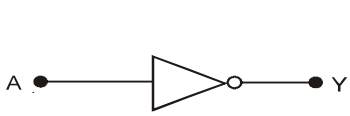
A gate is a digital circuit that follows curtain logical relationship between the input and output voltages. Therefore, they are generally known as logic gates — gates because they control the flow of information. The five common logic gates used are NOT, AND, OR, NAND, NOR. Each logic gate is indicated by a symbol and its function is defined by a truth table that shows all the possible input logic level combinations with their respective output logic levels. Truth tables help understand the behaviour of logic gates. These logic gates can be realised using semiconductor devices.

(a) The NOT Gate :

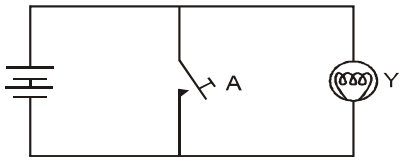
The NOT gate has only one input and one output. It combines the input A with the output Y, according to the Boolean expression $\overline{A} = Y$,

read as 'NOT A equals Y'. It means that Y is negation (or inversion) of A. Since there are only two digits 0 and 1 in the binary system, we have, $Y = 0$, if $A = 1$ and $Y = 1$ if $A = 0$. The logic symbol of the NOT gate is shown in figure.

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(a)



(b)

Truth table

A	$Y = \bar{A}$
0	1
1	0

(c)

The possible combinations of the input A and the output Y of the NOT gate can be known with the help of electric circuit, shown in figure. In this circuit, a switch A (input) is connected in parallel to a battery and a bulb Y(output). The working of the circuit is as follows :

If switch A is open (A = 0), the bulb wil glow (Y = 1).

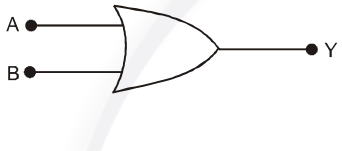
If switch A is closed (A = 1), the bulb will not glow (Y = 0).

These two possible combinations of input A and output Y are tabulated in figure, which is the truth table of the NOT gate.

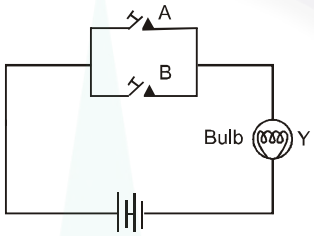
(b)The OR Gate :

The OR gate is a device that has two input variables A and B and one output variable Y, and follows the Boolean expression, A + B = Y,

read as' A OR B equal Y'. Its logic symbol is shown in figure.



(a)



(b)

Truth Table

A	B	Y(= A+ B)
0	0	0
0	1	1
1	0	1
1	1	1

(c)

The possible combinations of the inputs A and B and the output Y of the OR gate can be known with the help of an electrical circuit, shown in figure. In this circuit, two switches A and B (inputs) are connected in parallel with a battery and a bulb Y (output).

(c) The AND Gate :

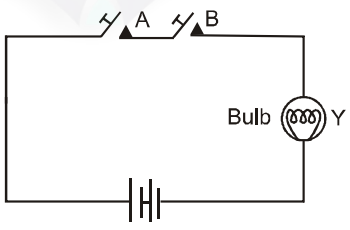
The AND gate is also a two-input and one-output logic gate. It combines the inputs A and B to give the output Y, according to the Boolean expression

A.B = Y

read 'A AND B equals Y'



(a)



(b)

Truth table

A	B	Y(= A. B)
0	0	0
0	1	0
1	0	0
1	1	1

(c)

Combinations of gates :

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Various combinations of the three basic gates, namely, OR, AND and NOT, produce complicated digital circuits, which are also called 'gates'. The commonly used combinations of basic gates are NAND gate, NOR, gate. These are also called universal gates.

(i) The NAND gate :

This gate is a combination of AND and NOT gates. If the output Y' of AND gate is connected to the input of NOT gate, as shown in figure, the gate so obtained is called NAND gate. The logic symbol of NAND gate is shown in figure.



(a) (b)

The Boolean expression for the NAND gate is $\overline{A \cdot B} = Y$

read as 'A AND B negated equals Y'.

The truth table of the NAND gate can be obtained by logically combining the truth tables of AND and NOT gates. In figure, the output Y' of the truth table of AND gate have been negated (NOT operation) to obtain the corresponding outputs Y for the NAND gate. The resulting table is the truth table of the NAND gate.

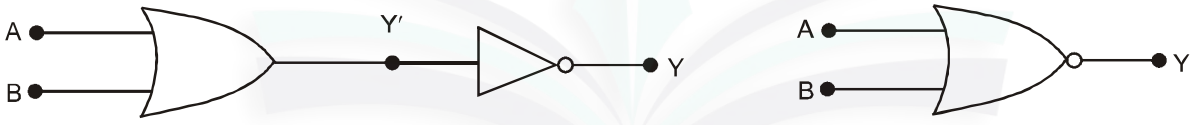
A	B	Y′ (= A. B)	Y (= $\overline{A.B}$) = $\overline{Y'}$
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

$\Rightarrow$

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

(ii) The NOR Gate :

The NOR gate is a combination of OR and NOT gates. If the output Y′ of OR gate is connected to the input of NOT gate, as shown in figure, the gate so obtained is NOR gate.



(a) (b)

The Boolean expression for the NOR gate is

$$\overline{A + B} = Y$$

read as 'A OR B negated equals Y' :

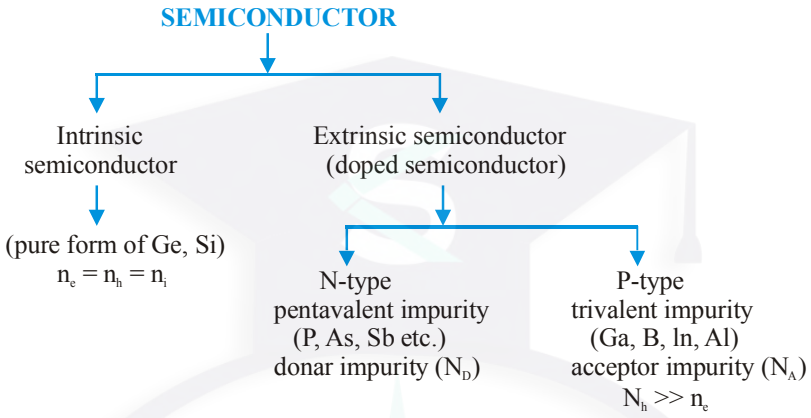
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TIPS& FORMULAS

1. Number of electrons reaching from valence band to conduction band

$$n = AT^{3/2}e^{-\frac{\Delta Eg}{2kT}}$$

2. Classification of Semiconductors :



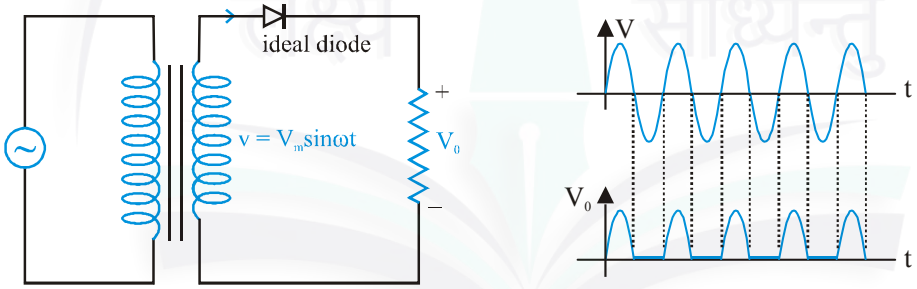
3. Mass-action law $n_i^2 = n_e \times n_h$

(a) For N-type semiconductor $n_e = N_D$

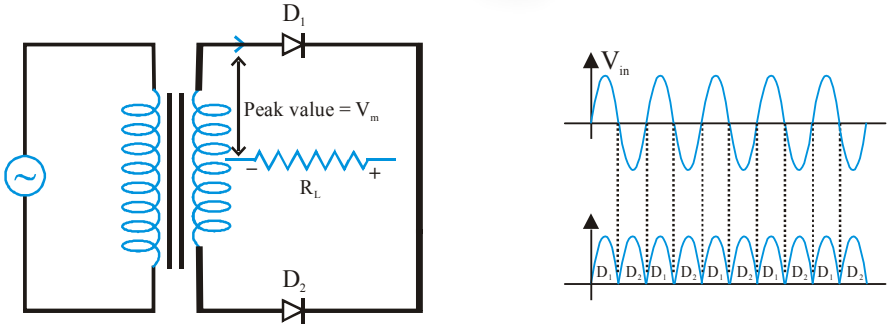
(b) For P-type semiconductor $n_h = N_A$

4. Conductivity $n_i e(\mu_e + \mu_h)$

5. Half wave rectifier

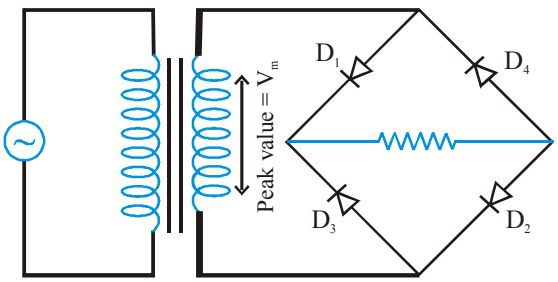


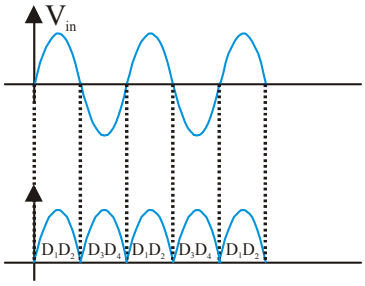
6. Centre – Tap Full wave Rectifier



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7. Full wave Bridge reactifier





8. Form factor $= \frac{I_{rms}}{I_{dc}}$

(a) For HWR (Half wave rectifier) Form factor $= \frac{\pi}{2}$

(b) For FWR (Full wave rectifier) Form factor $= \frac{\pi}{2\sqrt{2}}$

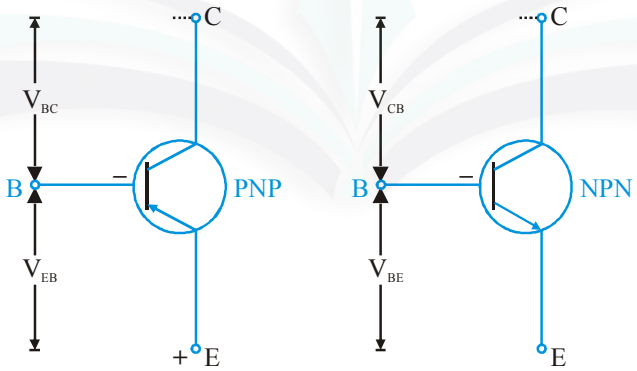
9. Ripple factor $r = \frac{I_{ac}}{I_{dc}}$

(a) For HWR $r = 1.21$ **(b)** For FWR $r = 0.48$

10. Rectifier efficiency $\eta = \frac{P_{dc}}{P_{ac}} = \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_F + R_L)}$

(a) For HWR $\eta\% = \frac{40.6}{1 + \frac{R_F}{R_L}}$ & FWR $\eta\% = \frac{81.2}{1 + \frac{R_F}{R_L}}$

11. For transistor $I_E = I_B + I_C$



(a) **(b)**

Comparative study of transistor configurations

1. Common Base **(CB)** **2.** Common Emitter **(CE)**

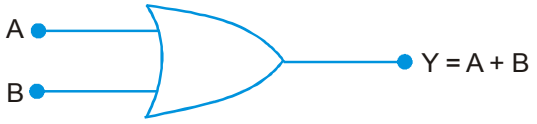
3. Common Collector **(CC)**

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12. **Relation between α, β and γ :** $\beta = \frac{\alpha}{1-\alpha}, \gamma = 1+\beta, \gamma = \frac{1}{1-\alpha}$

13. **Logic gates**

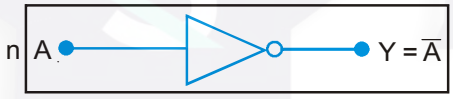
(a) **OR gate**



(b) **AND gate**



(c) **NOT gate**



(d) **NOR gate**



(e) **NAND gate**



(f) **XOR gate**



(e) **XNOR gate**



14. **De Morgan's theorem** $\overline{A+B} = \overline{A} \cdot \overline{B}$, $\overline{A \cdot B} = \overline{A} + \overline{B}$

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SOLVED EXAMPLE

Ex.1 A doped semiconductor has impurity levesl 30 meV below the conduction band. **(a)** Is the material n-type or p-type ? **(b)** In a thermal collision, an amount kT of energy is given to the extra electron loosely bound to the impurity ion and this electron is just able to jump into the conduction band. Calculate the temperature T.

Sol. **(a)** The impurity provides impurity leves close to the conduction band and a number of electrons from the impurity level will populate the conduction band. Thus, the majority carriers are electrons and the material is n-type.

(b) According to the question, kT = 30 meV

or, $$T = \frac{30\,\text{meV}}{k}$$

$$= \frac{0.03\,\text{eV}}{8.62\times10^{-5}\,\text{eVK}^{-1}} = 348\,\text{K}$$

Ex.2 The energy of a photon of sodium light ($\lambda = 589$ nm) equals the band gap of a semiconducting material. (a) Find the minimum energy E required to creat a hole-electron pair. (b) Find the value of E/kT at a temperature of 300 K.

Sol. **(a)** The energy of the photon is $E = \frac{hc}{\lambda}$

$$= \frac{1242\,\text{eVnm}}{589\,\text{nm}} = 2.1\,\text{eV}$$

Thus the band gap is 2.1 eV. This is also the minimum energy E required to push an electron from the valence band into the conduction band. Hence, the minimum energy required to creat a hole-electron pair is 2.1 eV.

(b) At $T = 300\,\text{K}$

$$kT = (8.62\times10^{-5}\,\text{eVK}^{-1})(300\,\text{K})$$

$$= 25.86\times10^{-3}\,\text{eV}.$$

Thus, $$\frac{E}{kT} = \frac{2.1\,\text{eV}}{25.86\times10^{-3}\,\text{eV}} = 81$$

So it is difficult for the thermal energy to create the hole-electron pair but a photon of light can do it easily.

Ex.3 A p-type semiconductor has acceptor levels 57 meV above the valence band. Find the maximum wavelength of light which can create a hole.

Sol. To create a hole, an electron from the valenec band should be given sufficient energy to go into one of the acceptor levels. Since the acceptor levels are 57 meV above the valence band, at least 57 meV is needed to create a hole.

If λ be the wavelength of light, its photon will have an energy hc/λ. To create a hole,

$$\frac{hc}{\lambda} \geq 57\,\text{meV}$$

or, $$\lambda \leq \frac{hc}{57\,\text{meV}}$$

$$= \frac{1242\,\text{eV nm}}{57\times10^{-3}\,\text{eV}} = 2.18\times10^{-5}\,\text{m}$$

Ex.4 The band gap in germanium is $\Delta E = 0.68$ eV. Assuming that the number of hole-electron pairs is proportional to $e^{-\Delta E/2kT}$, find the percentage increase in the number of charge carriers inpure germanium as the temperature is increased from 300 K to 320 K.

Sol. The number of charge carriers in an intrinsic semiconductor is double the number of hole-electron pairs. If N_1 be the number of charge carriers at temperature T_1 and N_2 at T_2, we have

$$N_1 = N_0 e^{-\Delta E/2kT_1}$$

and $$N_2 = N_0 e^{-\Delta E/2kT_2}$$

The percentage increase as the temperature is raised from T_1 to T_2 is

$$f = \frac{N_2 - N_1}{N_1}\times100 = \left(\frac{N_2}{N_1} - 1\right)\times100$$

$$= 100\left[e^{\frac{\Delta E}{2k}\left(\frac{1}{T_1}-\frac{1}{T_2}\right)} - 1\right]$$

Now $$\frac{\Delta E}{2k}\left(\frac{1}{T_1}-\frac{1}{T_2}\right)$$

$$= \frac{0.68\,\text{eV}}{2\times8.62\times10^{-5}\,\text{eV K}^{-1}}\left(\frac{1}{300\,\text{K}} - \frac{1}{320\,\text{K}}\right)$$

$= 0.82.$

Thus, $f = 100 \times [e^{0.82} - 1] \approx 127.$

Thus, the number of charge carriers increases by about 127%.

Ex.5 The concentration of hol-electron pairs in pure silicon at T = 300 K is 7×10^{15} per cubic metre. Antimony is doped into silicon in a proportion of 1 atom in 10^7 atoms. Assuming that half of the impurity atoms contribute electrons in the conduction band, calculate the factor by which the number of charge carriers increases due to doping. The number of silicon atoms per cubic metre is 5×10^{28}.

Sol. The number of charge cariers before doping is equal to the number of holes plus the number of conduction electrosn. Thus, the number of charge carriers per cubic metre before doping

$$= 2 \times 7 \times 10^{15} = 14 \times 10^{15}.$$

Since antimony is doped in a proportion of 1 in 10^7, the number of antimony atoms per cubic metre is $10^{-7} \times 5 \times 10^{28} = 5 \times 10^{21}$. As half of these atoms contribute electrons to the conduction band, the number of extra conduction electrons produced is 2.5×10^{21} per cubic metre. Thus, the number of charge carriers per cubic metre after the doping is

$$2.5 \times 10^{21} + 14 \times 10^{15}$$

$$\approx 2.5 \times^{21}.$$

The factor by which the number of charge carriers is increased

$$= \frac{2.5 \times 10^{21}}{14 \times 10^{15}} = 1.8 \times 10^5.$$

In fact, as the n-type impurity is doped, the number of holes will decrease. This is because the product of the concentrations of holes and conduction electrons remains almost the same. However, this does not affect our result as the number of holes is anyway too small as compared to the number of conduction electrons.

Ex.6 A potential barrier of 0.50 V exists across a p-n junction.

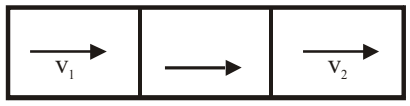
(a) If the depletion regions 5.0×10^{-7} m wide, what is the intensity of the electric field in this region?

(b) An electron with speed $5.0 \times 10\,5$ ms^{-1} approaches the p-n junction from the n-side. With what speed will it enter the p-side?

Sol. **(a)** The electric field is E = V/d

$$= \frac{0.50\,V}{5.0 \times 10^{-7}\,m} = 1.0 \times 10^6\,Vm^{-1}$$

(b)



Suppose the electron has a speed v_1 when it enters the depletion layer and v_2 when it comes out of it. As the potential energy increases by $e \times 0.50$ V, from the principle of conservation of energy,

$$\frac{1}{2}mv_1^2 = e \times 0.50\,V + \frac{1}{2}mv_2^2$$

or, $\frac{1}{2} \times (9.1 \times 10^{-31}\,kg) \times (5.0 \times 10^5\,ms^{-2})^2$

$$= 1.6 \times 10^{-19} \times 0.5\,J + \frac{1}{2}(9.1 \times 10^{-31}\,kg)\,v_2^2$$

or, $1.13 \times 10^{-19}\,J = 0.8 \times 10^{-19}\,J + (4.55 \times 10^{-31}\,kg)\,v_2^2.$

Solving this, $v_2 = 2.7 \times 10^5\,ms^{-1}.$

Ex.7 The reverse-biased current of a particular p-n junction diode increases when it is exposed to light of wavelength less than or equal to 600 nm. Assume that the increase in carriers concentration takes place due to the creation of new hole-electron pairs by the light. Find the band gap.

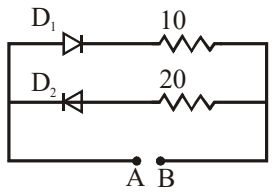
Sol. The reverse-biased current is caused mainly due to the drift current. The drift current in a p-n junction is caused by the formation of new hole-electron pairs and their subsequent motions in the depletion layer. When the junction is exposed to light, it may absorb energy from the light photons. If this energy supplied by a photon is greater than (or equal to) the band gap, a hole-electron pair may be formed. Thus, the reverse-biased current will increase if the light photons have energy greater than (or equal to) the band gap.

Hence the band gap is equal to the energy of a photon of 600 nm light which is

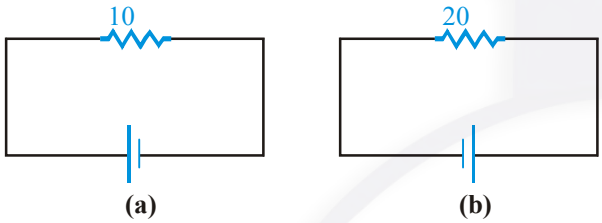
$$\frac{hc}{\lambda} = \frac{1242\,eVnm}{600\,nm} = 2.07\,eV$$

Ex.8 A 2 V battery may be connected across the points A and B as shown in figure. Assume that the resistance of each diode is zero in forward bias and infinity in reverse bias. Find the current supplied by the battery if the positive terminal of the battery is connected to (a) the point A (b) the point B.

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Sol. **(a)** When the positive terminal of the battery is connected to the point A, the diode D_1 is forward-biased and D_2 is reverse-biased. the resistance of the diode D_1 is zero, and it can be replaced by a resistanceless wire. Similarly, the resistance of the diode D_2 is infinity, and it can be replaced by a broken wire. The equivalent circuit is shown if figure. The current supplied by the battery is 2 V/10 Ω = 0.2 A.



(b) When the positive terminal of the battery is connected to the point B, the diode D_2 is forward-biased and D_1 is reverse biased. the equivalent circuit is shown in figure. The current through the battery is 2 V/20 Ω = 0.1 A.

Ex.9 A change of 8.0 mA in the emitter current brings a change of 7.9 mA in the collector current. How much change in the base current is required to have the same change 7.9 mA in the collector current? Find the values of α and β.

Sol. We have,

$$I_E = I_B + I_C$$

or, $$\Delta I_E = \Delta I_B + \Delta I_C.$$

From the question, when $\Delta I_E = 8.0$ mA, $\Delta I_C = 7.9$ mA.

Thus,

$$\Delta I_B = 8.0\,\text{mA} - 7.9\,\text{mA} = 0.1\,\text{mA}.$$

So a change of 0.1 mA in the base current is required to have a change of 7.9 mA in the collector current.

$$\alpha = \frac{I_C}{I_E} = \frac{\Delta I_C}{\Delta I_E}$$

$$= \frac{7.9\,\text{mA}}{8.0\,\text{mA}} \approx 0.99.$$

$$\beta = \frac{I_C}{I_B} = \frac{\Delta I_C}{\Delta I_B}$$

$$= \frac{7.9\,\text{mA}}{0.1\,\text{mA}} = 79.$$

Check if these values of α and β satisfy the equation

$$\beta = \frac{\alpha}{1-\alpha}.$$

Ex.10 A transistor is used in common-emitter mode in an amplifier circuit. When a signal of 20 mV is added to the base-emitter voltage, the base current changes by 20 μA and the collector current changes by 2 mA. The load resistance is 5 kΩ. Calculate **(a)** the factor β, **(b)** the input resistance R_{BE}, **(c)** the transconductance and **(d)** the voltage gain.

Sol. **(a)** $\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{2\,\text{mA}}{20\,\mu\text{A}} = 100.$

(b) The input resistance $R_{BE} = \frac{\Delta V_{BE}}{\Delta I_B}$

$$= \frac{20\,\text{mV}}{20\,\mu\text{A}} = 1\,\text{k}\Omega$$

(c) Transconductance $= \frac{\Delta I_C}{\Delta V_{BE}}$

$$= \frac{2\,\text{mA}}{20\,\text{mV}} = 0.1\ \text{mho}.$$

(d) The change in output voltage is $R_L \Delta I_C$

$$= (5\,\text{k}\Omega)\,(2\,\text{mA}) = 10\,\text{V}.$$

The applied signal voltage = 20 mV.

Thus, the voltage gain is,

$$\frac{10\,\text{V}}{20\,\text{mV}} = 500.$$

Ex.11 Construct the truth table for the function X of A and B represented by figure.

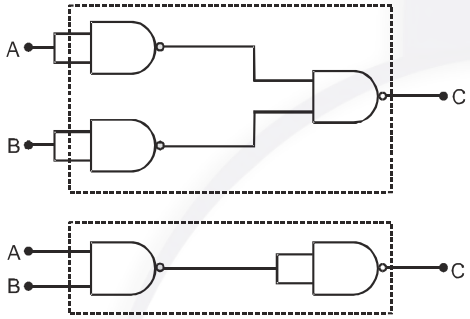


Sol. Here an AND gate and an OR gate are used. Let the

output of the OR gate be Y. Clearly, Y = A + B. The AND gate receives A and A + B as input. The output of this gate is X. So X = (A + B). The following table evaluates X for all combinations of A and B. The last three columns give the truth table.

A	B	Y=A+B	X=A(A+B)	A	B	X
0	0	0	0	0	0	0
0	1	1	0	0	1	0
1	0	1	1	1	0	1
1	1	1	1	1	1	1

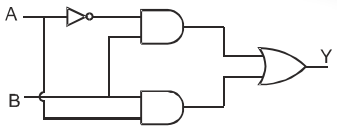
Ex.12 The combination of 'NAND' gates shown here under are equivalent to -



(1) An OR gate and an AND gate respectively
(2) An AND gate and a NOT gate respectively
(3) An AND gate and an OR gate respectively
(4) An OR gate and a NOT gate respectively

Ans. **(1)**

Ex.13 Truth table for the following is-



(1)

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

(2)

A	B	Y
0	0	0
0	1	1
1	0	0
1	1	1

(3)

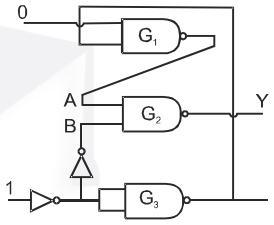
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

(4)

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

Ans. **(2)**

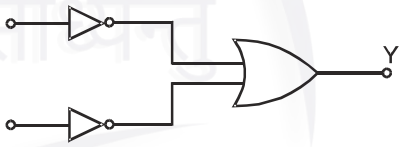
Ex.14 In circuit in following figure the value of Y is -



(1) zero
(2) 1
(3) fluctuates between 0 and 1
(4) indeterminate as the circuit cannot be realized

Ans. **(1)**

Ex.15 The output Y for the following logic gate circuit will be-



(1) AB **(2)** $\overline{A} \cdot \overline{B}$

(3) $\overline{A + B}$ **(4)** $\overline{A \cdot B}$

Ans. **(4)**

Ex.16 The following truth-table belongs to which one of the four gates-

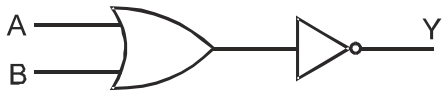
A	B	X
1	1	0
0	1	0
1	0	0
0	0	1

(1) OR
(2) NAND
(3) XOR
(4) NOR

Ans. **(4)**

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Ex.17 The given circuit is for the gate-

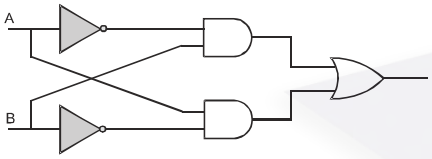


(1) NOR **(2)** NAND

(3) NOT **(4)** XOR

Ans. **(1)**

Ex.18 The truth table of the logic circuit shown-



(1)

A	B	Y
0	0	0
1	0	1
1	0	1
1	1	1

(2)

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

(3)

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

(4)

A	B	Y
0	0	0
1	0	0
0	1	0
1	1	1

Ans. **(2)**

Sol. It is also called XOR gate the Boolean expression for XOR gate is

$$Y = A \cdot \overline{B} + \overline{A} \cdot B$$

Exercise # 1 SINGLE OBJECTIVE NEET LEVEL

1. The nature of binding for a crystal with alternate and evenly spaced positive and negative ions is
(A) Covalent (B) Metallic
(C) Dipolar (D) Ionic

2. For a crystal system, $a = b = c$, $\alpha = \beta = \gamma \neq 90^{\circ}$, the system is
(A) Tetragonal system
(B) Cubic system
(C) Orthorhombic system
(D) Rhombohedral system

3. Biaxial crystal among the following is
(A) Calcite (B) Quartz
(C) Selenite (D) Tourmaline

4. The temperature coefficient of resistance of a conductor is
(A) Positive always (B) Negative always
(C) Zero (D) Infinite

5. Potassium has a *bcc* structure with nearest neighbour distance 4.525 $\AA$. Its molecular weight is 39. Its density in kg/m^3 is
(A) 900 (B) 494
(C) 602 (D) 802

6. The expected energy of the electrons at absolute zero is called
(A) Fermi energy (B) Emission energy
(C) Work function (D) Potential energy

7. In a triclinic crystal system
(A) $a \neq b \neq c$, $\alpha \neq \beta \neq \gamma$
(B) $a = b = c$, $\alpha \neq \beta \neq \gamma$
(C) $a \neq b \neq c$, $\alpha \neq \beta = \gamma$
(D) $a = b \neq c$, $\alpha = \beta = \gamma$

8. Metallic solids are always opaque because
(A) Solids effect the incident light
(B) Incident light is readily absorbed by the free electron in a metal
(C) Incident light is scattered by solid molecules
(D) Energy band traps the incident light

9. In which of the following ionic bond is present
(A) *NaCl* (B) *Ar*
(C) *Si* (D) *Ge*

10. Which of the following materials is non crystalline
(A) Copper (B) Sodium chloride
(C) Wood (D) Diamond

11. The majority charge carriers in *P*-type semiconductor are
(A) Electrons (B) Protons
(C) Holes (D) Neutrons

12. A *P*-type semiconductor can be obtained by adding
(A) Arsenic to pure silicon
(B) Gallium to pure silicon
(C) Antimony to pure germanium
(D) Phosphorous to pure germanium

13. The valence of an impurity added to germanium crystal in order to convert it into a *P*-type semi conductor is
(A) 6 (B) 5
(C) 4 (D) 3

14. In a semiconductor, the concentration of electrons is $8 \times 10^{14}/cm^3$ and that of the holes is $5 \times 10^{12} cm^3$. The semiconductor is
(A) *P*-type (B) *N*-type
(C) Intrinsic (D) *PNP*-type

15. In *P*-type semiconductor, there is
(A) An excess of one electron
(B) Absence of one electron
(C) A missing atom
(D) A donar level

16. The valence of the impurity atom that is to be added to germanium crystal so as to make it a *N*-type semiconductor, is
(A) 6 (B) 5
(C) 4 (D) 3

17. Silicon is a semiconductor. If a small amount of *As* is added to it, then its electrical conductivity
(A) Decreases (B) Increases
(C) Remains unchanged (D) Becomes zero

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18. When the electrical conductivity of a semi-conductor is due to the breaking of its covalent bonds, then the semiconductor is said to be

(A) Donar **(B)** Acceptor

(C) Intrinsic **(D)** Extrinsic

19. A piece of copper and the other of germanium are cooled from the room temperature to 80 K, then which of the following would be a correct statement

(A) Resistance of each increases

(B) Resistance of each decreases

(C) Resistance of copper increases while that of germanium decreases

(D) Resistance of copper decreases while that of germanium increases

20. To obtain *P*-type Si semiconductor, we need to dope pure with

(A) Aluminium **(B)** Phosphorous

(C) Oxygen **(D)** Germanium

21. In the forward bias arrangement of a *PN*-junction diode

(A) The *N*-end is connected to the positive terminal of the battery

(B) The *P*-end is connected to the positive terminal of the battery

(C) The direction of current is from *N*-end to *P*-end in the diode

(D) The *P*-end is connected to the negative terminal of battery

22. In a *PN*-junction diode

(A) The current in the reverse biased condition is generally very small

(B) The current in the reverse biased condition is small but the forward biased current is independent of the bias voltage

(C) The reverse biased current is strongly dependent on the applied bias voltage

(D) The forward biased current is very small in comparison to reverse biased current

23. The cut-in voltage for silicon diode is approximately

(A) 0.2 V **(B)** 0.6 V

(C) 1.1 V **(D)** 1.4 V

24. The electrical circuit used to get smooth dc output from a rectifier circuit is called

(A) Oscillator **(B)** Filter

(C) Amplifier **(D)** Logic gates

25. *PN*-junction diode works as a insulator, if connected

(A) To A.C. **(B)** In forward bias

(C) In reverse bias **(D)** None of these

26. The reverse biasing in a *PN* junction diode

(A) Decreases the potential barrier

(B) Increases the potential barrier

(C) Increases the number of minority charge carriers

(D) Increases the number of majority charge carriers

27. The electrical resistance of depletion layer is large because

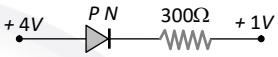
(A) It has no charge carriers

(B) It has a large number of charge carriers

(C) It contains electrons as charge carriers

(D) It has holes as charge carriers

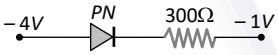
28. In the circuit given below, the value of the current is



(A) 0 *amp* **(B)** 10^{-2} *amp*

(C) 10^{2} *amp* **(D)** 10^{-3} *amp*

29. What is the current in the circuit shown below



(A) 0 *amp* **(B)** *amp*

(C) 1 *amp* **(D)** 0.10 *amp*

30. If the forward voltage in a semiconductor diode is doubled, the width of the depletion layer will

(A) Become half **(B)** Become one-fourth

(C) Remain unchanged **(D)** Become double

31. When *NPN* transistor is used as an amplifier

(A) Electrons move from base to collector

(B) Holes move from emitter to base

(C) Electrons move from collector to base

(D) Holes move from base to emitter

32. The phase difference between input and output voltages of a CE circuit is

(A) 0° **(B)** 90°

(C) 180° **(D)** 270°

33. An oscillator is nothing but an amplifier with

(A) Positive feed back **(B)** Large gain

(C) No feedback **(D)** Negative feedback

34. The emitter-base junction of a transistor is ..... biased while the collector-base junction is ..... biased

(A) Reverse, forward **(B)** Reverse, reverse

(C) Forward, forward **(D)** Forward, reverse

35. In an *NPN* transistor the collector current is 24 *mA*. If 80% of electrons reach collector its base current in *mA* is

(A) 36 **(B)** 26

(C) 16 **(D)** 6

36. A *NPN* transistor conducts when

(A) Both collector and emitter are positive with respect to the base

(B) Collector is positive and emitter is negative with respect to the base

(C) Collector is positive and emitter is at same potential as the base

(D) Both collector and emitter are negative with respect to the base

37. In the case of constants α and β of a transistor

(A) $\alpha = \beta$ **(B)** $\beta < 1 \quad \alpha > 1$

(C) $\alpha\beta = 1$ **(D)** $\beta > 1 \quad \alpha < 1$

38. Which of the following is true

(A) Common base transistor is commonly used because current gain is maximum

(B) Common emitter is commonly used because current gain is maximum

(C) Common collector is commonly used because current gain is maximum

(D) Common emitter is the least used transistor

39. If $\alpha = 0.98$ and current through emitter $i_e = 20\ mA$, the value of β is

(A) 4.9 **(B)** 49

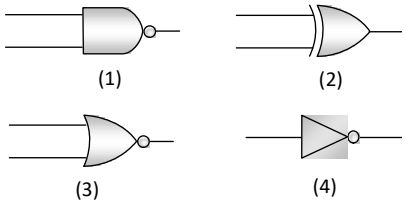
(C) 96 **(D)** 9.6

40. For a common base configuration of *PNP* transistor $\frac{I_C}{I_E} = 0.98$ then maximum current gain in common emitter configuration will be

(A) 12 **(B)** 24

(C) 6 **(D)** 5

41. Given below are symbols for some logic gates

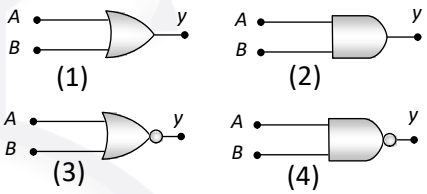


The XOR gate and NOR gate respectively are

(A) 1 and 2 **(B)** 2 and 3

(C) 3 and 4 **(D)** 1 and 4

42. Given below are four logic gate symbol (figure). Those for OR, NOR and NAND are respectively



(A) 1, 4, 3 **(B)** 4, 1, 2

(C) 1, 3, 4 **(D)** 4, 2, 1

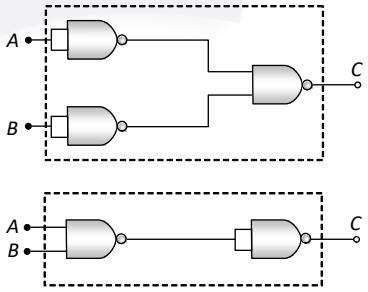
43. The following truth table corresponds to the logic gate

A	0	0	1	1
B	0	1	0	1
X	0	1	1	1

(A) NAND **(B)** OR

(C) AND **(D)** XOR

44. The combination of 'NAND' gates shown here under (figure) are equivalent to



(A) An OR gate and an AND gate respectively

(B) An AND gate and a NOT gate respectively

(C) An AND gate and an OR gate respectively

(D) An OR gate and a NOT gate respectively.

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45. A truth table is given below. Which of the following has this type of truth table

A	0	1	0	1
B	0	0	1	1
y	1	0	0	0

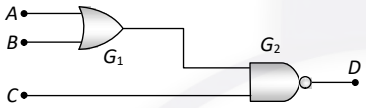
(A) XOR gate **(B)** NOR gate
(C) AND gate **(D)** OR gate

46. The truth table shown in figure is for

A	0	0	1	1
B	0	1	0	1
Y	1	0	0	1

(A) XOR **(B)** AND
(C) XNOR **(D)** OR

47. For the given combination of gates, if the logic states of inputs A, B, C are as follows $A = B = C = 0$ and $A = B = 1$, $C = 0$ then the logic states of output D are



(A) 0, 0
(B) 0, 1
(C) 1, 0
(D) 1, 1

48. Boolean algebra is essentially based on
(A) Truth **(B)** Logic
(C) Symbol **(D)** Numbers

49. The logic behind 'NOR' gate is that it gives
(A) High output when both the inputs are low
(B) Low output when both the inputs are low
(C) High output when both the inputs are high
(D) None of these

50. A logic gate is an electronic circuit which
(A) Makes logic decisions
(B) Allows electrons flow only in one direction
(C) Works binary algebra
(D) Alternates between 0 and 1 values

51. Thermionic emission from a heated filament varies with its temperature T as
(A) T^{-1} **(B)** T
(C) T^2 **(D)** $T^{3/2}$

52. Number of secondary electrons emitted per number of primary electrons depends on
(A) Material of target
(B) Frequency of primary electrons
(C) Intensity
(D) None of the above

53. Due to S.C.R in vacuum tube
(A) $I_p \rightarrow$ Decrease **(B)** I_p – Increase
(C) V_p = Increase **(D)** V_g = Increase

54. In diode, when there is saturation current, the plate resistance (r_p) is
(A) Zero **(B)** Infinite
(C) Some finite quantity **(D)** Data is insufficient

55. The grid voltage of any triode valve is changed from –1 volt to – 3 *volt* and the mutual conductance is 3×10^{-4} *mho*. The change in plate circuit current will be
(A) 0.8 *mA* **(B)** 0.6 *mA*
(C) 0.4 *mA* **(D)** 1 *mA*

56. In a triode, $g_m = 2 \times 10^{-3} ohm^{-1}; \mu = 42$, resistance load, $R = 50$ kilo ohm. The voltage amplification obtained from this triode will be
(A) 30.42 **(B)** 29.57
(C) 28.18 **(D)** 27.15

57. In an amplifier the load resistance R_L is equal to the plate resistance (r_p). The voltage amplification is equal to
(A) μ **(B)** 2μ
(C) $\mu / 2$ **(D)** $\mu / 4$

58. For a given plate-voltage, the plate current in a triode is maximum when the potential of
(A) The grid is positive and plate is negative
(B) The grid is positive and plate is positive
(C) The grid is zero and plate is positive
(D) The grid is negative and plate is positive

59. If $R_p = 7K\Omega, g_m = 2.5$ *millimho*, then on increasing plate voltage by $50\,V$, how much the grid voltage is changed so that plate current remains the same
(A) $-2.86\,V$ **(B)** $-4\,V$
(C) $+4\,V$ **(D)** $+2\,V$

60. The amplification factor of a triode is 20 and trans-conductance is 3 *milli mho* and load resistance $3 \times 10^4 \Omega$, then the voltage gain is
(A) 16.36 **(B)** 28
(C) 78 **(D)** 108

Exercise # 2 SINGLE OBJECTIVE AIIMS LEVEL

1. Fermi energy is the-
(A) Minimum energy of electrons in metal at 0 K
(B) Minimum energy of electrons in metal at 0°C
(C) Maximum energy of electrons in metal at 0 K
(D) Maximum energy of electrons in metal at 0°C

2. The forbidden energy band gap in conductors, semiconductors and insulators are EG_1, EG_2 and EG_3 respectively, The relation among them is
(A) $EG_1 = EG_2 = EG_3$ (B) $EG_1 < EG_2 < EG_3$
(C) $EG_1 > EG_2 > EG_3$ (D) $EG_1 < EG_2 > EG_3$

3. Which of the following statements is true-
(A) In insulators the conduction band is completely empty.
(B) In conductor the conduction band is completely empty.
(C) In semiconductor the conduction band is partially empty at low temperature.
(D) In insulators the conduction band is completely filled with electrons.

4. The valence band at 0 K is-
(A) completely filled (B) completely empty
(C) partially filled (D) nothing can be said

5. Which of the following statement is true-
(A) At absolute zero temperature, the semiconductor behave as a conductor
(B) The energy gap in semiconductor is more than that for insulator
(C) The resistance of semiconductor increases with increase in temperature
(D) The resistance of semiconductor decreases with increase in temperature

6. An electric field is applied to a semiconductor. Let the number of charge carries be n and the average drift speed be v. If the temperature is increased,
(A) both n and v will increase
(B) n will increase but v will decrease
(C) v will increases but n will decrease
(D) both n and v will decrease

7. Electric conduction in a semiconductor takes place due to
(A) electrons only
(B) holes only
(C) both electrons and holes
(D) neither electron nor holes

8. The free electron concentration (n) in the conduction band of a semiconductor at a temperature T Kelvin is described in terms of E_g and T as-
(A) $n = ATe^{-Eg/kT}$
(B) $n = AT^2e^{-Eg/kT}$
(C) $n = AT^2e^{-Eg/2kT}$
(D) $n = AT^{3/2}e^{-Eg/2kT}$

9. The mobility of free electron is greater than that of free holes because
(A) They carry negative charge
(B) They are light
(C) They mutually collide less
(D) They require low energy to continue their motion

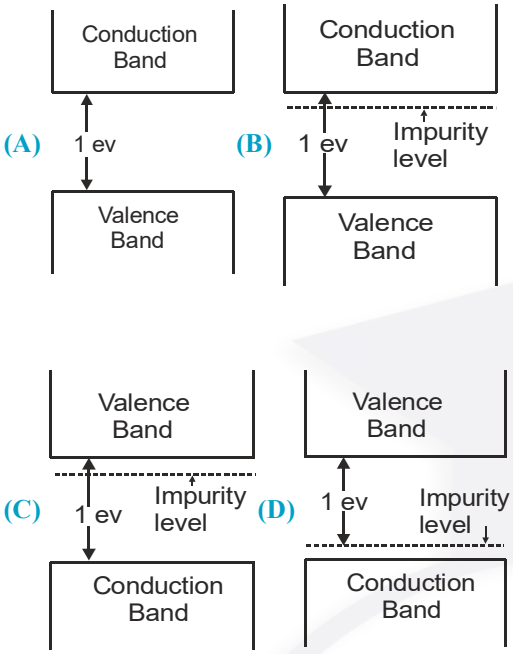
10. Let n_p and n_e be the numbers of holes and conduction electrons in an extrinsic semiconductor
(A) $n_p > n_e$ (B) $n_p = n_e$
(C) $n_p < n_e$ (D) $n_p \neq n_e$

11. The electrical conductivity of pure germanium can be increased by
(A) increassing the temperature
(B) doping acceptor impurities
(C) doping donor impurities
(D) irradiating ultraviolet light on it.

12. A N-type semiconductor is
(A) Negatively charged
(B) Positively charged
(C) Neutral
(D) None of these

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13. Which of the following energy band diagram shows the N-type semiconductor-



14. In a P-type semiconductor, the acceptor level is 57 meV, above the valence band. The maximum wave length of light required to produce a hole will be-

(A) 57 A^o **(B)** 57×10^{-3} A^o

(C) 217100 A^o **(D)** 11.61×10 A^o

15. If N-type semiconductor is heated then-

(A) The number of electrons increases and the number of holes decreases

(B) The number of holes increases and the number of electrons decreases

(C) The number of electrons and holes both remain equal

(D) The number of both electrons and holes increases equally

16. A P-type silicon semiconductor is made by adding one atom of indium per 5×10^7 atoms of silicon is 25×10^{28} atom/$m.^3$. Point the number of acceptor atoms in per cubic cm. of silicon-

(A) 2×10^{30} atom/cm^3

(B) 5×10^{15} atom/cm^3

(C) 1×10^{15} atom/cm^3

(D) 2.5×10^{36} atom/cm^3

17. GaAs is-

(A) an elemental semiconductor

(B) a compound semiconductor

(C) an insulator

(D) a metallic semiconductor

18. Forbidden energy gap of Ge is 0.75 eV, maximum wave length of incident radiation for producing electron-hole pair in germanium semiconductor is-

(A) 4200 A^o **(B)** 16500 A^o

(C) 4700 A^o **(D)** 4000 A^o

19. What will be conductance of pure silicon crystal at 300K temp.? If electron hole pairs per cm^3 is 1.072×10^{10} at this temp., $\mu_n = 1350$ cm^2/volt sec and $\mu_p = 480$ cm^2/volt sec-

(A) 3.14×10^{-6} mho/cm

(B) 3×10^6 mho/cm

(C) 10^{-6} mho/cm

(D) 10^6 mho/cm

20. The intrinsic carrier density in germanium crystal at 300 K is 2.5×10^{13} per cm^3. If the electron density in an N-type germanium crystal at 300 K be 0.5×10^{17} per cm^3, the hole density (per cm^3) in this N-type crystal at 300 K would be expected around-

(A) 2.5×10^{13} **(B)** 5×10^6

(C) 1.25×10^{10} **(D)** 0.2×10^4

21. Mobility of electrron in N-type Ge is 5000 cm^2 / volt sec and conductivity 5 mho/cm. If effect of holes is negligible then impurity concentration will be-

(A) 6.25×10^{15} / cm^3 **(B)** 9.25×10^{14} / cm^3

(C) 6×10^{13} / cm^3 **(D)** 9×10^{13} / cm^3

22. The length of a germanium rod is 0.58 cm and its area of cross-section is $1mm^2$. If for germanium $n_i = 2.5 \times 10^{19}$ m^{-3}, $\mu_h = 0.19$ m^2/ V-s, $\mu_e = 0.39$ m^2/ V-s, then the resistance of the rod will be -

(A) 2.5 KΩ **(B)** 5.0 KΩ

(C) 7.5 KΩ **(D)** 10.0 KΩ

23. Pure Si at 300 K has equal electron (n_e) and hole (n_h) concentrations of 1.5×10^{16} m^{-3}. Doping by indium increases n_h to 4.5×10^{22} m^{-3}. Calculate n_e in the doped Si-

(A) 5.0×10^9 m^{-3} **(B)** 6.0×10^6 m^{-3}

(C) 7.0×10^3 m^{-3} **(D)** 4.0×10^9 m^{-3}

24. The P-N junction is-

(A) an ohmic resistance

(B) an non ohmic resistance

(C) a positive resistance

(D) a negative resistance

25. The contributions in the total current flowing through a semiconductor due to electrons and holes are $\frac{3}{4}$ and $\frac{1}{4}$ respectively. If the drift velocity of electrons is $\frac{5}{2}$ times that of holes at this temperature, then the ratio of the concentrations of electrons and holes is-

(A) 6 : 5 **(B)** 5 : 6

(C) 3 : 2 **(D)** 2 : 3

26. Diffusion current in a p-n junction is greater than the drift current in magnitude

(A) if the junction is forward-biased

(B) if the junction is reverse-biased

(C) if the junction is unbiased

(D) in no case

27. The depletion region of a P-N diode, under open circuit condition contains-

(A) Electrons

(B) Holes

(C) Unmasked immobile impurity ions

(D) Impurity atoms

28. A hole diffuses from the p-side to the n-side in a p-n junction. This means that

(A) a bond is broken on the n-side and the electron freed from the bond jumps to the conduction band

(B) a conduction electron on the p-side jumps to a broken bond to complete it

(C) a bond is broken on the n-side and the electron freed from the bond jumps to a broken bond on the p-side to complete it

(D) a bond is broken on the p-side and the electron freed from the bond jumps to a broken bond on the n-side to complete it.

29. Depletion layer in P-N junction is caused by-

(A) Drift of holes

(B) Diffusion of free charge carriers

(C) Migration of impurity ions

(D) Drift of electrons

30. Which is the wrong statement in following sentence? A device in which P and N type semiconductors are used is more useful then a vacuum tube because-

(A) power is not necesary to heat the filament

(B) it is more stable

(C) very less heat is producted in it

(D) its efficiency is high due to a high voltage drop across the junction

31. What accounts for the flow of charge carriers in forward and reverse biasing of silicon P-N diode-

(A) Drift in both reverse and forward bias

(B) Drift in forward bias and diffusion in reverse bias

(C) Drift in reverse bias and diffusion in forward bias

(D) Diffusion in both forward and reverse bias

32. The contact potential at the junction site in a P-N junction is-

(A) positive on P side and negative on N side

(B) negative on P side and positive on N side

(C) zero

(D) infinite

33. When value of current increase in P-N junction, then the value of contact potential-

(A) decrease

(B) increase

(C) remain unchanged

(D) depends on temperature

34. The diffusion current in a P-N junction flows-

(A) from the N-side to the P-side

(B) from the P-side to the N-side

(C) from the N-side to the P-side if the junction is forward-biased and in the opposite direction if it is reverse baised

(D) from the P-side to the N-side if the junction is forward-biased and in the opposite direction if it is reverse biased

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35. The barrier potential in a P-N junction is maximum in-

(A) the reverse bias condition

(B) the forward bias condition

(C) the condition when the junction diode is used as rectifier

(D) zero bias condition

36. For a reverse bias P-N junction-

(A) P region is positive and current is due to electrons

(B) P region is positive and the current is due to holes

(C) P region is negative and the current is due to electrons

(D) P region is negative and current is due to both electrons and holes

37. The drift current in a P-N junction flows -

(A) from the N-side to the P-side

(B) from the P-side to the N-side

(C) from the N-side to the P-side if the junction is forward-biased and in the oposite direction if it is reverse biased.

(D) from the P-side to the N-side if the junction is forward-baised and in the opposite direction if it is reverse baised.

38. The value of barrier potential of P-N junction in Ge is-

(A) 0.03 volt in the direction of forward current

(B) 0.3 volt in the direction opposite of the forward current

(C) 25 volt in the direction opposite to the forward current

(D) 25 volt in the direction of the forward current

39. During P-N junction formation when the electron and holes stops moving from P to N and N to P, then

(A) There is increase in number of +ve and –ve ions at junction

(B) There is increase in number of electrons at junction

(C) There is increase in number of holes at junction

(D) There is increase in number of holes and electrons at junction

40. A device whose one end is connected to –ve terminal and other end connected to +ve terminal. If both ends are interchanged with supply then current is not flowing then device will be-

(A) P-N junction **(B)** Transistor

(C) Zener diode **(D)** Triode

41. Region which have no free electron and holes in a P-N juction is-

(A) P-region **(B)** N-region

(C) junction **(D)** depletion region

42. The P-N junction diode works as insulator, if connected-

(A) To a.c. **(B)** In forward bias

(C) In reverse bias **(D)** None of these

43. Potential barrier developed in a junction diode opposes-

(A) Minority carriers in both regions only

(B) Majority carriers

(C) Electrons in N-region

(D) Holes in P-region

44. The resistance of a reverse baised P-N junction diode is about-

(A) 1 ohm **(B)** 10^2 ohm

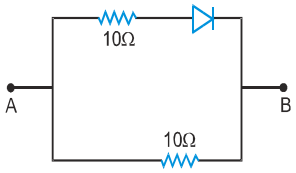
(C) 10^3 ohm **(D)** 10^6 ohm

45. If the forward voltage in a diode is increased, the width of the depletion region-

(A) Decreases **(B)** Increases

(C) Fluctuates **(D)** does not change

46. If V_A and V_B denote the potentials of A and B, then the equivalent resistance between A and B in the adjoint electric circuit is -



(A) 10 ohm if $V_A > V_B$

(B) 5 ohm if $V_A < V_B$

(C) 5 ohm if $V_A > V_B$

(D) 20 ohm if $V_A > V_B$

47. In which case is the juction diode is not reverse bias-

(A) 

(B) 

(C) 

(D) 

48. If the two ends of a P-N junction are joined by a wire-

(A) There will not be a steady current in the circuit

(B) There will be a steady current from the N-side to the P-side

(C) There will a steady current from the P-side to the N-side

(D) There may or may not be a current depending upon the resistance of the connecting wire.

49. The avalanche breakdown in P-N junction is due to-

(A) Shift of Fermi level

(B) Cumulative effect of conduction band electron collision

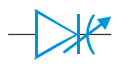
(C) Widening of forbidden gap

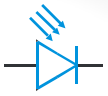
(D) Low impurity concentration

50. Symbol of zener diode-

(A) 

(B) 

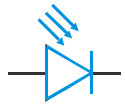
(C) 

(D) 

51. Symbolic representation of photodiode is-

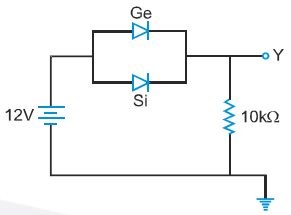
(A) 

(B) 

(C) 

(D) 

52. Two junction diodes one of germanium (Ge) and other of silicon (Si) are connected as shown in figure to a battery of emf 12 V and a load resistance 10 kΩ. The germanium diode conducts at 0.3 V and silicon diode at 0.7 V. When a current flows in the circuit, the potential of terminal Y will be



(A) 12 V **(B)** 11 V

(C) 11.3 V **(D)** 11.7 V

53. Consider the following statements 1 and 2 and identify the correct answer-

[1] A zener diode is always connected in reverse bias.

[2] The potential barrier of a P-N junction lies between 0.1 to 0.3 V approximately.

(A) [1] and [2] are correct

(B) [1] and [2] are wrong

(C) [1] is correct, but [2] is wrong

(D) [1] is wrong, but [2] is correct

54. If the forward voltage in a semiconductor diode is changed form 0.5V to 2V, then the forward current changes by 1.5 mA. The forward resistance of diode will be-

(A) 1KΩ **(B)** 2KΩ

(C) 4KΩ **(D)** 8KΩ

55. When light falls on a photo diode, its conductivity increases. Experimentally it is found that the conductivity changes only when the wavelength of the incident light is less than 620 nm. The band gap of the diode is-

(A) 0.75 eV **(B)** 1.1 eV

(C) 1.5 eV **(D)** 2.0 eV

56. If the frequency of input alternating potential is n, then the ripple frequency of output potential of full wave rectifier will be-

(A) 2n **(B)** n

(C) $\frac{n}{2}$ **(D)** $\frac{n}{4}$

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57. When the reverse potential in a semiconductor diode are 10V and 20V, then the corresponding reverse currents are 25μA and 50μA respectively. The reverse resistance of junction diode will be-

(A) 40Ω **(B)** 4×10^{5} Ω

(C) 40KΩ **(D)** 4×10^{-5} Ω

58. Function of rectifier is

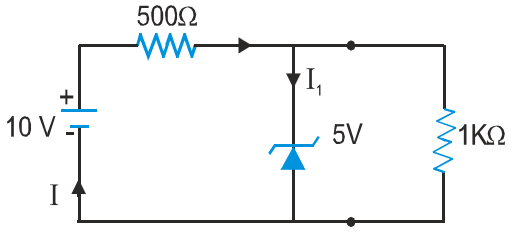
(A) To convert ac into dc

(B) To convert dc into ac

(C) Both (A) and (B)

(D) None of these

59. The current flowing through the zener diode in fig. is-



(A) 20 mA **(B)** 25 mA

(C) 15 mA **(D)** 5 mA

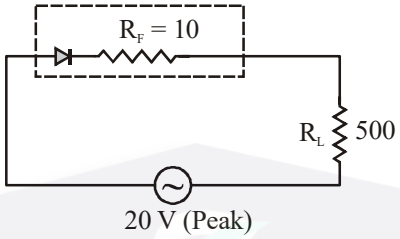
60. The electrical circuits used to get smooth d.c. output from a rectified circuit is called

(A) oscillator **(B)** full wave rectifier

(C) amplifier **(D)** filter

Exercise # 3 PART - 1 MATRIX MATCH COLUMN

1. In the circuit shown the barrier voltasge of diode is 0.7 V. Match the physical quantities given in column-I to the results given in column-II



Column I	Column II
(A) Peak current (in mA) in diode	**(p)** 37.8
(B) Peak voltage (in volts) at the ends of load	**(q)** 40.0
(C) Peak current (in mA) if diode is ideal	**(r)** 20.0
(D) Peak voltage (in volts) at the ends of load if diode is ideal	**(t)** Zero

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Exercise # 3 PART - 2 ASSERTION & REASONING

These questions contains, Statement I (assertion) and Statement II (reason).

(A) If both assertion and reason are true and the reason is the correct explanation of the assertion.

(B) If both assertion and reason are true but reason is not the correct explanation of the assertion.

(C) If assertion is true but reason is false.

(D) If assertion is false but reason is true.

(E) If the assertion and reason both are false.

1. **Assertion :** The logic gate NOT can be built using diode.
   Reason : The output voltage and the input voltate of the diode have 180 phase difference

2. **Assertion :** The number of electrons in a P-type silicon semiconductor is less than the number of electrons ina pure silicon semiconductor at room temperature.
   Reason : It is due to law of mass action.

3. **Assertion :** In a common emitter transistor amplifier the input current is much less than the output current.
   Reason : The common emitter transistor amplifier has very high input impedance.

4. **Assertion :** A transistor amplifier in common emitter configuration has a low input impedence.
   Reason : The base to emitter region is forward biased.

5. **Assertion :** The resistivity of a semiconductor increases with temperature.
   Reason : The atoms of a semiconductor vibrate with larger amplitude at higher temperature there by increasing it's resistivity.

6. **Assertion :** If the temperature of a semiconductor is increased then it's resistance decreases.
   Reason : The energy gap between conduction band and valence band is very small.

7. **Assertion :** The temperature coefficient of resistance is positive for metals and negative for P-type semiconductor.
   Reason : The effective charge carriers in metals are negatively charged whereas in P-type semiconductor they are positively charged.

8. **Assertion :** Electron has higher mobility than hole in a semiconductor.
   Reason : Mass of electron is less than the mass of hole.

9. **Assertion :** An N-type semiconductor has a larger number of electrons but still it is electrically neutral.
   Reason : An N-type semiconductor is obtained by doping an intrinsic semiconductor with a pentavalent impurity.

10. **Assertion :** The crystalline solids have a sharp melting point.
    Reason : All the bonds between the atoms or molecules of a crystalline solids are equally strong, that they get broken at the same temperature.

Exercise # 4 PART - 1 PREVIOUS YEAR (NEET/AIPMT)

1. If α and β are current gains in common - base and common - emitter configurations of a transistor, then β equal to [CBSE AIPMT-2000]

(A) $\frac{1}{\alpha}$ **(B)** $\frac{\alpha}{1+\alpha}$

(C) $\frac{\alpha}{1-\alpha}$ **(D)** $\alpha - \frac{1}{\alpha}$

2. The truth table given below [CBSE AIPMT-2000]

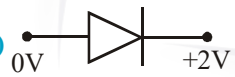
Input		Output
A	B	Y
0	0	0
1	0	0
0	1	0
1	1	1

represents

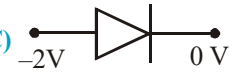
(A) AND gate **(B)** NOR gate

(C) OR gate **(D)** NAND gate

3. In which of the following figures, junction diode is forwared biased ? [CBSE AIPMT-2000]

(A) 

(B) 

(C) 

(D) 5 V

4. Si and Cu are cooled to a temperature of 300 K, then resistivity [CBSE AIPMT-2001]

(A) for Si increases and for Cu decreases

(B) for Cu increases and for Si decreases

(C) decreases for both Si and Cu

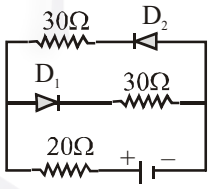
(D) increases for both Si and CU

5. In a common - base configuration of a transisitor $\frac{\Delta i_c}{\Delta i_e} = 0.98$, then current gain in common emitter configuration of transisitor will be [CBSE AIPMT-2001]

(A) 49 **(B)** 98

(C) 4.9 **(D)** 24.5

6. If internal resistance of cell is negligible, then current flowing through the circuit is [CBSE AIPMT-2001]



(A) $\frac{3}{50}$A **(B)** $\frac{5}{50}$A

(C) $\frac{4}{50}$A **(D)** $\frac{2}{50}$A

7. In bcc structure of lattice constant a, the minimum distance between atoms is [CBSE AIPMT-2001]

(A) $\frac{\sqrt{3}}{2}$a **(B)** $\sqrt{2}$a

(C) $\frac{a}{\sqrt{2}}$ **(D)** $\frac{a}{2}$

8. The number of atoms per unit cell in bcc lattice is [CBSE AIPMT-2002]

(A) 1 **(B)** 2

(C) 4 **(D)** 9

9. For a transistor $\frac{i_c}{i_e} = 0.96$, the current gain in common-emitter configuration is [CBSE AIPMT-2002]

(A) 6 **(B)** 12

(C) 24 **(D)** 48

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10. For conduction in a p-n junction the biasing is [CBSE AIPMT-2002]

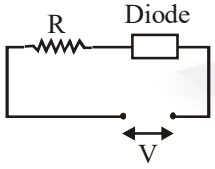
(A) hingh potential on n-side and low potential on p-side

(B) high potential on p -side and low potential on n-side

(C) same potential on both p and n-sides

(D) undetermined

11. For a given circuit of ideal p-n junction diode, which of the following is correct? [CBSE AIPMT-2002]



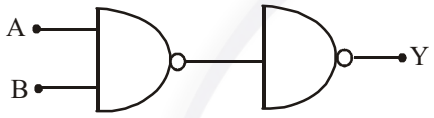
(A) In forward biasing the voltage across R is V

(B) In reverse biasing the voltage across R is V

(C) In forward biasing the voltage across R is 2V

(D) In reverse biasing the voltage across R is 2V

12. Following diagram performs the logic function of [CBSE AIPMT-2003]



(A) OR gate **(B)** AND gate

(C) XOR gate **(D)** NAND gate

13. Barrier potential of a p-n junction diode does not depend on [CBSE AIPMT-2003]

(A) forward bias **(B)** doping density

(C) diode design **(D)** temperature

14. If a full wave rectifier circuit is operating from 50 Hz mains, the fundamental frequency in the ripple will be : [CBSE AIPMT-2003]

(A) 70.7 Hz **(B)** 100 Hz

(C) 25 Hz **(D)** 59 Hz

15. A n-p-n transistor conducts when [CBSE AIPMT-2003]

(A) collector is positive and emitter is at same potential as the base

(B) both collector and emitter are negative with respect to the base

(C) both collector and emitter are positive with respect to the base

(D) collector is positive and emitter is negative with respect to the base

16. In semiconductors at a room temperature [CBSE AIPMT-2004]

(A) the valence band is partially empty and the conduction band is partially filled

(B) the valence band is completely filled and the conduction band is partially filled

(C) the valence band is completely filled

(D) the conduction band is completely empty

17. The peak voltage in the output of a half wave diode rectifier fed with a sinusoidal signal without filter is 10V. The d. c. component of the output voltage is :- [CBSE AIPMT-2004]

(A) $\frac{10}{\sqrt{2}}$ V **(B)** $\frac{10}{\pi}$ V

(C) 10 V **(D)** $\frac{20}{\pi}$ V

18. The output of OR gate is 1 [CBSE AIPMT-2004]

(A) only if both inputs are zero

(B) if either or both inputs are 1

(C) the frequency of the light falling on the cell

(D) if either input is zero

19. In a p–n junction photo cell, the value of the photo electromotive force produced by monochromatic light is proportional to: - [CBSE AIPMT-2004]

(A) The barrier voltage at the p–n junction

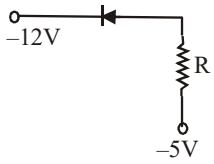
(B) The intensity of the light falling on the cell

(C) The frequency of the light falling on the cell

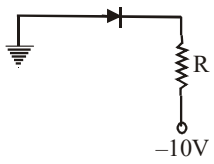
(D) The voltage applied at the p–n junction

20. Of the diodes shown in the following diagrams, which one is revese biased ? [CBSE AIPMT-2004]

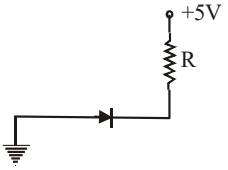
(A)



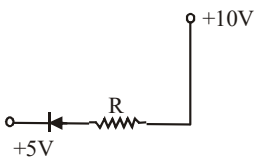
(B)



(C)



(D)



21. Application of a forward bias to a p-n junction [CBSE AIPMT-2005]

(A) ncreases the number of donors on the n - side

(B) Increases the electric field in the depletion zone

(C) Increases the potential difference across the depletion zone

(D) Widens the depletion zone

22. Zener diode is used for [CBSE AIPMT-2005]

(A) producing oscillations in an oscillator

(B) amplification

(C) stabilisation

(D) rectification

23. Carbon, Silicon and Germanium atoms have four valence electrons each. Their valence and conduction bands are separated by energy band gaps represented by $(E_g)C$, $(E_g)_{Si}$ and $(E_g)Ge$ respectively. Which one of the following relationships is true in their case [CBSE AIPMT-2005]

(A) $(E_g)_C > (E_g)_{Si}$ **(B)** $(E_g)_C = (E_g)_{Si}$

(C) $(E_g)_C < (E_g)_{Ge}$ **(D)** $(E_g)_C < (E_g)_{Si}$

24. Choose only false statement trom the following [CBSE AIPMT-2005]

(A) Substances with energy gap of the order of 10eV are insulators

(B) The conductivity of a semiconductor increases with increases in temperature.

(C) In conductors the valence and conduction bands may over lap

(D) The resistivity of a semiconductor increases with increase in temperature

25. Copper has face centered cubic (fcc) lattice with interatomic spacing equal to 2.54Å. The value of lattice constant for this lattice is- [CBSE AIPMT-2005]

(A) 1.27 Å **(B)** 5.08 Å

(C) 2.54 Å **(D)** 3.59 Å

26. A transistor-oscillator using a resonant circuit with an inductor L (of negligible resistance) and a capacitor C in series produce oscillations of frequency f. If L is doubled and C is changed to 4C, the frequency will be:- [CBSE AIPMT-2006]

(A) $\frac{f}{4}$ **(B)** 8 f

(C) $\frac{f}{2\sqrt{2}}$ **(D)** $\frac{f}{2}$

27. A transistor is operated in common emitter configuration at constant collector voltage. $V_c = 1.5$ V such that a change in the base current from 100 µA to 150µA produces a change in the collector current from 5 mA to 10 mA. The current gain (â) is:- [CBSE AIPMT-2006]

(A) 67 **(B)** 75

(C) 100 **(D)** 50

28. A forward biased diode is [CBSE AIPMT-2006]

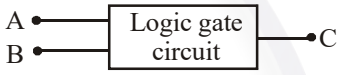
(A) 

(B) 

(C) 

(D) 

29. The following figure shows a logic gate circuit with two inputs A and B and the output C. The voltage waveforms of A, B and C are as shown below-









The logic circuit gate is [CBSE AIPMT-2006]

(A) AND gate

(B) NAND gate

(C) NOR gate

(D) OR gate

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30. In the following circuit, the output Y for all possible inputs A and B is expressed by the truth table

[CBSE AIPMT-2007]

(A)

A	B	Y
0	1	0
0	0	0
1	0	0
1	0	0

(B)

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

(C)

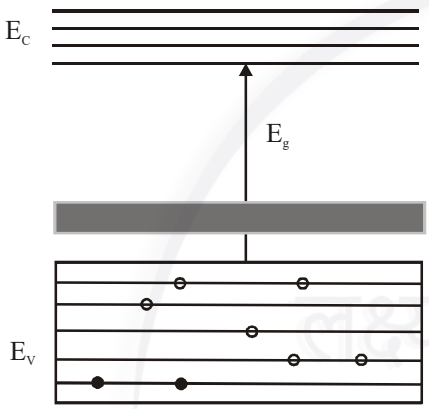
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

(D)

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

31. In the nergy band diagram of a material shown belew, the open circles and filled circles denote holes and electrons respectively. The material is a/ an

[CBSE AIPMT-2007]



(A) p-type semiconductor **(B)** insulator
(C) metal **(D)** n-type semiconductor

32. For a cubic crystal structure which one of the following relations indicating the cell characteristics is correct? [CBSE AIPMT-2007]

(A) $a \neq b \neq c$ and $\alpha \neq \beta$ and $\gamma \neq 90^\circ$

(B) $a \neq b \neq c$ and $\alpha \neq \beta = \gamma = 90^\circ$

(C) $a = b = c$ and $\alpha \neq \beta \neq \gamma = 90^\circ$

(D) $a = b = c$ and $\alpha = \beta = \gamma = 90^\circ$

33. If the lattice parameter for a crystalline structure is 3.6 Å, then the atomic radius in fcc crystal is

[CBSE AIPMT-2008]

(A) 1.81 Å **(B)** 2.10 Å
(C) 2.92 Å **(D)** 1.27 Å

34. The voltage gain of an amplifier with 9 % negative feedback is 10. The voltage gain without feedback will be - [CBSE AIPMT-2008]

(A) 90 **(B)** 10
(C) 1.25 **(D)** 100

35. A p-n photodiode is made of a material with a band gap of 2.0 eV. The minimum frequency of the radiation that can be absorbed by the aterial is nearly

[CBSE AIPMT-2008]

(A) 10×10^{14} Hz **(B)** 5×10^{14} Hz
(C) 1×10^{14} Hz **(D)** 20×10^{14} Hz

36. The circuit is equivalent to [CBSE AIPMT-2008]



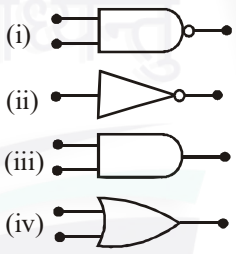
(A) AND gate **(B)** NAND gate
(C) NOR gate **(D)** OR gate

37. A p-n photodiode is fabricated from a semiconductor with a band gap of 2.5 eV. It can detect a signal of wavelength [CBSE AIPMT-2009]

(A) 6000 Å **(B)** 4000 nm
(C) 6000 nm **(D)** 4000 Å

38. The symbolic representation of four logic gates

[CBSE AIPMT-2009]



The logic symbols for OR, NOT and NAND gates are respectively

(A) (iii), (iv), (ii) **(B)** (iv), (i), (iii)
(C) (iv), (ii), (i) **(D)** (i), (iii), (iv)

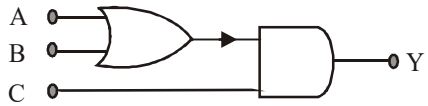
39. A transistor is operated in common-emitter configuration at $V_C = 2V$ such that a change in the base current from 100 μA to 200 μA produces a change in the collector current from 5 mA to 10 mA. The current gain is : [CBSE AIPMT-2009]

(A) 75 **(B)** 100
(C) 150 **(D)** 50

40. Sodium has body centred packing. Distance between two nearest atoms is 3.7Å. The lattice parameter is **[CBSE AIPMT- 2009]**

(A) 6.8 Å **(B)** 4.3 Å
(C) 3.0Å **(D)** 8.6 Å

41. To get an output Y = 1 from the circuit shown below, the input must be **[CBSE AIPMT-2010]**



	A	B	C
(A)	0	1	0
(B)	0	0	1
(C)	1	0	1
(D)	1	0	0

42. A common emitter amplifier has a voltage gain of 50, an input impedance of 100 Ω and an output impedance of 200 Ω. The power gain of the amplifier is **[CBSE AIPMT-2007,10]**

(A) 500 **(B)** 1000
(C) 1250 **(D)** 50

43. The device that can act as a complete electronic circuit is **[CBSE AIPMT-2010]**

(A) Junction diode **(B)** Intergrated circuit
(C) Junction transistor **(D)** Zener diode

44. Which one of the following statement is false ? **[CBSE AIPMT-2010]**

(A) Pure Si doped with trivalent impurities gives a p-type semiconductor
(B) Majority carriers in a n-type semiconductor are holes
(C) Minority carriers in a p-type semiconductor are electrons
(D) The resistance of intrinsic semiconductor decreases with increase of temperature

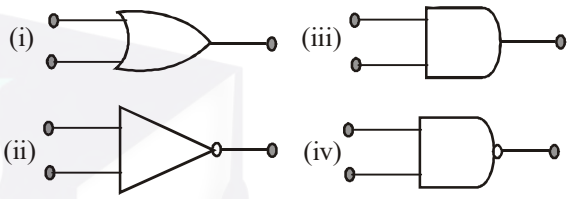
45. In forward biasing of the p-n junction **[CBSE AIPMT-2011]**

(A) the positive terminal of the battery is connected to n-side and the depletion region becomes thin
(B) the positive terminal of the battery is connected to n-side and the depletion region becomes thick
(C) the positive terminal of the battery is connected to p-side and the deplection region become thin
(D) the positive terminal of the battery is connected to p-side and the depletion region becomes thick

46. If a small amount of antimony is added to germanium crystal **[CBSE AIPMT-2011]**

(A) the antimony becomes an acceptor atom
(B) there will be more free electrons than holes in the semiconductor
(C) its resistance is increased
(D) it becomes a p-type semiconductor

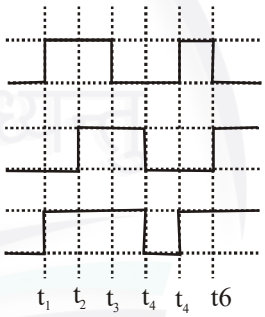
47. Symbolic representation of four logic gates are shown as **[CBSE AIPMT-2011]**



Pick out which ones are for NAD, NAND, and NOT gates, respectively

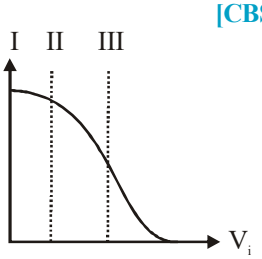
(A) (iii), (ii) and (i) **(B)** (iii), (ii) and (iv)
(C) (ii), (iv) and (iii) **(D)** (ii), (iii) and (iv)

48. The figure shows a logic circuit with two inputs A and B and the output C The voltage wave forms acrossA, B, and C are as given. The logic circuit gate is **[CBSE AIPMT-2012]**



(A) OR gate **(B)** NOR gate
(C) AND gate **(D)** NAND gate

49. Transfer characteristic [output voltage (V_0) vs input voltage (V_i) for a base biased transistor in CE configuration is as shown in the figure. For using transistor as a switch it is used] **[CBSE AIPMT-2012]**



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(A) in region III

(B) both in region (I) and (III)

(C) in region II

(D) in region I

50. C and Si both have same lattice structure having 4 bonding electrons in each. However, C is insulator whereas Si is intrinsic semiconductor. This is because **[CBSE AIPMT-2012]**

(A) in case of C, the valence bond is not completely filled at absolute zero temperature

(B) in case of C, the conduction band is partly filled even at absolute zero temperature

(C) the four bonding electrons in the case of C lie in the second orbit, whereas in the case of Si they lie in the third

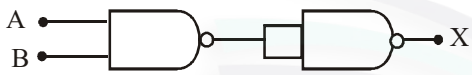
. (D) the four bonding electrons in the case of C lie in the third orbit, whereas for Sithey lie in the fourth orbit

51. In a CE transistor amplifier, the audio signal voltage across the collector resistance of 2kΩ is 2V. If the base resistance is 1 kΩ and the current amplification of the transistor is 100, the input signal voltage is **[CBSE AIPMT 2012]**

(A) 0.1 V (B) 1.0 V

(C) 1 mV (D) 10 mV

52. Tlne output (X) of the logic circuit shown in figure will be **[CBSE AIPMT-2013]**



(A) p (B) 1

(C) i (D) n

53. In a common emitter (CE) amplifier having a voltage gain G, the transistor used has transconductance 0.03 mho and current gain 25. If the above transistor is replaced with mho and current gain 20, the voltage gain will **[CBSE AIPMT-2013]**

(A) $\frac{2}{3}$G (B) 1.5 G

(C) $\frac{1}{3}$G (D) $\frac{5}{4}$G

54. In a n-type semiconductor, which of the following statement is true? **[CBSE AIPMT-2013]**

(A) Electrons are majority carriers and trivalent atoms ate dopants

(B) Electrons are minority carriers and pentavalent atoms are dopants

(C) Holes are minority carriers and pentavalent atoms are dopants

(D) Holes are majority carriers and trivalent atoms are dopants

55. The barrier potential of a p_njunctiondepends on **[CBSE AIPMT-2014]**

[i) type of semiconductor material

(ii) amount of doping

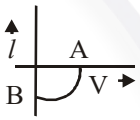
(iii) temperature

Which one of the following is correct?

(A) (i) and (ii) onty (B) (ii) onty

(C) (ii) and (iii) onty (D) iii, (ii) lnd (ii)

56. The given graph represents V-I characteristic foJ a semiconductor device. Which of the following statement is correct? **[CBSE AIPMT-2014]**



(A) It is V-I characteristic for solar cell where pointA represents open circuit voltage and point B hort circuit current

(B) It is for a solar cell and points A and B represent open circuit voltage and current, respectively

(C) It is for a photodiode and points A and B represent open circuit voltage and current, respectively

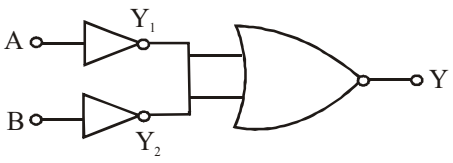
(D) It is for a LED and points A andg represent open circuit voltage and short circuiicurrent respectively

57. The input signal given to a CE amplifier having a voltage gain of 150 is $V_i = 2\cos\left(15t+\frac{\pi}{3}\right)$. The corresponding output singal will be **[CBSE AIPMT-2015]**

(A) $300\cos\left(15t+\frac{\pi}{3}\right)$ (B) $75\cos\left(15t+\frac{2\pi}{3}\right)$

(C) $2\cos\left(15t+\frac{5\pi}{3}\right)$ (D) $300\cos\left(15t+\frac{4\pi}{3}\right)$

58. Which logic gate is represented by the following combination of logic gates? **[CBSE AIPMT-2000]**



(A) OR **(B)** NAND
(C) AND **(D)** NOR

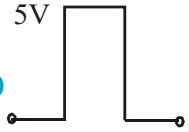
59. If in p-n junction, a square input signal of 10V is apoplied as shown **[CBSE AIPMT-2015]**



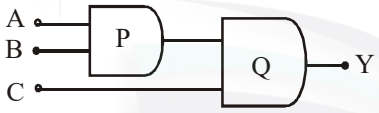
(A)


(B)


(C)


(D)


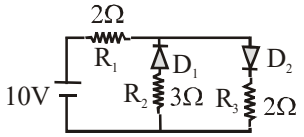
60. What is the output Y in the following circuit, when all the three inputs A, B, C are first 0 and then 1? **[CBSE AIPMT-2015]**



(A) 0, 1 **(B)** 0, 0
(C) 1, 0 **(D)** 1, 1

61. The given circuit has two ideal diodes connected as shown in the figure below. The current flowing through the resistance R_1 will be **[CBSE AIPMT-2000]**

(A) 2.5 A
(B) 10.0 A
(C) 1.43 A
(D) 3.13 A



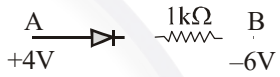
62. For CE transistor amplifier, the audio signal voltage across the collector resistance of 2 kΩ is 4V. If the current amplicication factor of the transistor is 100 and the base resistance is 1 kΩ, then the input signal voltage is **[CBSE AIPMT-2016]**

(A) 10 mV **(B)** 20 mV
(C) 30 mV **(D)** 15 mV

63. A n-p-n transistor is connected in common emitter configuration in a given amplifier. A Ioad resistance of 800 Ω) is connected in the collector circuit and the voltage dtop across it is 0.8V. If the current amplification factor is 0.96 and the input resistance of the circuits is 192 Ω), the voltage gain and the power gain of the amplifier will respectively be **[NEET-2016]**

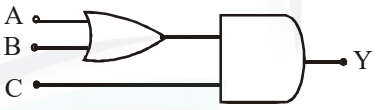
(A) 3,69,384 **(B)** 4, 4
(C) 4, 3.69 **(D)** 4,3.84

64. Consider the junction diode as ideal. The value of current flowing through '48 is **[CBSE AIPMT-2016]**



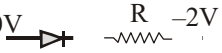
(A) 10^{-2} A **(B)** 10^{-1} A
(C) 10^{-3} A **(D)** 0 A

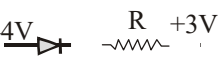
65. To get output 1 for the following circuit the correct choice for the input is **[NEET-2016]**

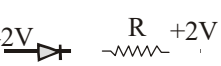


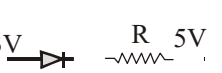
(A) A = 1, B = 0, C = 0 **(B)** A = 1, B = 1, C = 0
(C) A = 1, B = 0, C = 1 **(D)** A = 0, B = 1, C = 0

66. Which one fo the following represents forward bias diode? **[NEET-2017]**

(A)


(B)


(C)


(D)


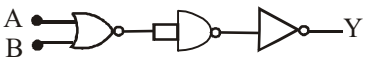
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67. In a common emitter transistor amplifier, the audio signal voltage across the collector is 3 V. The resistance of collector is 3 kΩ. If current gain is 100 and the base resistance is 2 kΩ), the voltage and power gain of the amplifier is **[CBSE AIPMT-2000]**

(A) 200 and 1000 **(B)** 15 and 200

(C) 150 and 15000 **(D)** 20 and 2000

68. The given electrical network is equivalent to **[CBSE AIPMT-2017]**



(A) AND gate **(B)** OR gate

(C) NOR gate **(D)** NOT gate

Exercise # 4 PART - 2 PREVIOUS YEAR (AIIMS)

1. What accounts for the flow of charge carriers in forward and reverse biasing of silicon p - n diode ?

(A) Drift in forward bias and diffusion in reverse bias

(B) Drift in reverse bias and diffusion in forward bias

(C) Drift in both reverse and forward bias

(D) Diffusion in both forward and reverse bias.

2. At 0 K temperature, a p-type semiconductor

(A) does not have any charge carriers

(B) has few holes but no free electrons

(C) has few holes and few free electrons

(D) has equal number of holes and free electrons.

3. The potential barrier, in the depletion layer, is due to

(A) ions **(B)** electrons

(C) holes **(D)** forbidden band

4. To a germanium sample, traces of gallium are added as a impurity. The resultant sample would behave like

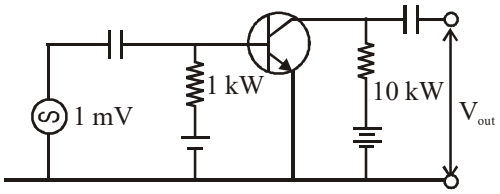
(A) a conductor

(B) a p-type semiconductor

(C) an n-type semiconductor

(D) an insulator

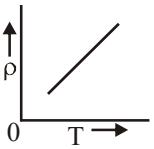
5. In the following common emitter configuration an npn transistor with current gain $\beta = 100$ is used. The output voltage of the amplifier will be

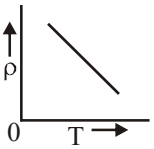


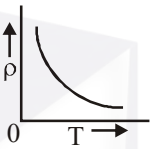
(A) 10 mV **(B)** 0.1 V

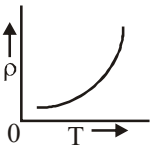
(C) 1.0 V **(D)** 10 V.

6. The temperature (T) dependence of resistivity (ρ) of a semiconductor is represented by

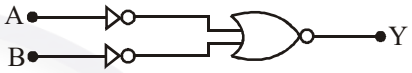
(A)


(B)


(C)


(D)


7. Which logic gate is represented by the following combination of logic gates ?



(A) OR **(B)** NAND

(C) AND **(D)** NOR

8. A Ge specimen is doped with Al. The concentration of acceptor atoms is ~ 10^{21} atoms/m^3. Given that the intrinsic concentration of electron-hole pairs is ~ $10^{19/3}$, the concentration of electrons in the specimen is

(A) $10^{17}/m^3$ **(B)** $10^{15}/m^3$

(C) $10^{4}/m^3$ **(D)** $10^{2}/m^3$

9. Which of the following logic gates is an universal gate ?

(A) OR **(B)** NOT

(C) AND **(D)** NAND

10. Consider an n-p-n transistor amplifier in common-emitter configuration. The current gain of the transistor is 100. If the collector current changes by 1 mA, what will be the change in emitter current ?

(A) 1.1 mA **(B)** 1.01 mA

(C) 0.01 mA **(D)** 10 mA

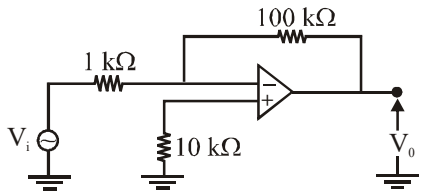
11. In a semiconducting material the mobilities of electrons and holes are μ_e and μ_n respectively. Which of the following is true ?

(A) $\mu_e > \mu_n$ **(B)** $\mu_e < \mu_n$

(C) $\mu_e = \mu_n$ **(D)** $\mu_e < 0 ; \mu_n > 0$

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12. The voltage gain of the following amplifier is



(A) 10 **(B)** 100
(C) 1000 **(D)** 9.9

13. When a p-n diode is reverse biased, then
(A) no current flows
(B) the depletion region is increased
(C) the depletion region is reduced
(D) the height of the potential barrier is reduced

14. The circuit given below represents which of logic operations ?



(A) AND **(B)** NOT
(C) OR **(D)** NOR

15. An amplifier has a voltage gain A_V = 1000. The voltage gain in dB is
(A) 30 dB **(B)** 60 dB
(C) 3 dB **(D)** 20 dB

16. A light emitting diode (LED) has a voltage drop of 2 volt across it and passes a current of 10 mA when it operates with a 6 volt battery through a limiting resistor R. The value of R is
(A) 40 kΩ **(B)** 4 kΩ
(C) 200 Ω **(D)** 400 Ω

17. The minimum potential difference between the base and emitter required to switch a silicon transistor ON is approximately
(A) 1 V **(B)** 3 V
(C) 5 V **(D)** 4.2 V

18. If collector current is 120 mA and base current is 2 mA and resistance gain is 3, what is power gain ?
(A) 180 **(B)** 10800
(C) 1.8 **(D)** 18

19. Zener diode acts as a/an
(A) oscillator **(B)** regulator
(C) rectifier **(D)** filter

20. In the half wave rectifier circuit operating from 50 Hz mains frequency, the fundamental frequency in the ripple would be
(A) 25 Hz **(B)** 50 Hz
(C) 70.7 Hz **(D)** 100 Hz

21. A transistor is a/an
(A) chip **(B)** insulator
(C) semiconductor **(D)** metal

22. The number 0 (zero) is required for
(A) transistor **(B)** abacus
(C) computer **(D)** calculator

23. A Ge specimen is doped with Al. The concentration of acceptor atoms is ~ 10^{21} atoms/m^3. Given that the intrinsic concentration of electron hole pairs is 10^{19}/m^3, the concentration of electrons in the specimen is
(A) $10^{17}/m^3$ **(B)** $10^{15}/m^3$
(C) $10^{4}/m^3$ **(D)** $10^{2}/m^3$

24. The forbidden gap in the energy bands of silicon is
(A) 2.6 eV **(B)** 1.1 eV
(C) 0.1 eV **(D)** 6 eV

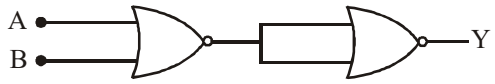
25. Which of the following gates correspond to the truth table given below ?

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

(A) NAND **(B)** OR
(C) XOR **(D)** NOR

26. When the inputs of a two input logic gate are 0 and 0, the output is 1. When the inputs are 1 and 0, the output is zero. The type of logic gate is
(A) XOR **(B)** NAND
(C) NOR **(D)** OR

27. The logic gate represented in following figure is

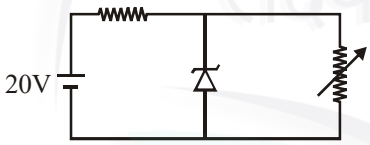


(A) OR Gate **(B)** NOT Gate
(C) NAND Gate **(D)** XOR Gate

28. Direction of electric field in P-N junction diode is
(A) from P-side to N-side
(B) from N-side to P-side
(C) randomly oriented
(D) electric field does not exist

29. Which of the following current must be zero in an unbiased PN junction diode ?
(A) Current due to majority charge carriers (both electrons and holes)
(B) Current due to minority charge carriers (both electrons and holes)
(C) Current due to majority and minority charge carriers
(D) Current due to majority and minority charge carriers (only holes)

30. In the given circuit, the voltage across the load is maintained at 12 V. The current in the zener diode varies from 0-50 mA. What is the maximum wattage of the diode ?



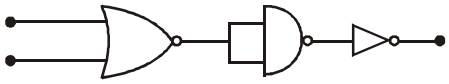
(A) 12 W **(B)** 6 W
(C) 0.6 W **(D)** 1.2 W

31. For a common-emitter transistor, input current is 5μA, $\beta = 100$ circuit is operated at load resistance of 10 kΩ, then voltage across collector emitter will be
(A) 5 V **(B)** 10 V
(C) 12.5 V **(D)** 7.5 V

32. In an intrinsic semiconductor band gap is 1.2 eV then ratio of number of charge carriers at 600 K and 300 K is
(A) 10^4 **(B)** 10^7
(C) 10^5 **(D)** 10^3

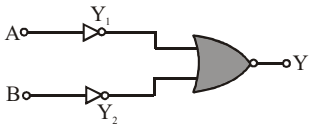
33. Given that the mobility of electrons is Ge is 0.4 $m^2 V^{-1} s^{-1}$ and electronic charge is 1.6×10^{-19}C. The number of donor atom (per m^3) semiconductor of conductivity 500 mho/m is
(A) 8×10^{21} **(B)** 8×10^{15}
(C) 5×10^{21} **(D)** 8×10^{16}

34. The circuit as shown in figure is equivalent to



(A) NOR gate **(B)** OR gate
(C) AND gate **(D)** NAND gate

35. Which logic gate is represented by the following combination of logic gates in figure ?
(A) OR
(B) NAND
(C) AND
(D) NOR



36. Which of the given statements about transistor is not true ?
(A) emitter is heavily doped
(B) Base is thin
(C) Base is lightly doped
(D) Collector region is smaller comparative to emitter in size

37. If the plate resistance of triode valve is 13×10^6 Ω and amplification factor is 21. The mutual conductance will be
(A) 1.6×10^{-6} mho **(B)** 1.6×10^6 mho
(C) 2.6×10^{-5} mho **(D)** 2.6×10^5 mho

38. The current gain for a transistor working as common-base amplifier is 0.96. If the emitter current is 7.2 mA, then base current is
(A) 0.35 mA **(B)** 0.29 mZ
(C) 0.39 mA **(D)** 0.43 mA

39. A zener diode is specified as having a breakdown voltage of 9.1 V, with a maximum power dissipation of 364 mW. What is the maximum current the diode can handle ?
(A) 40 mA **(B)** 60 Ma
(C) 50 mA **(D)** 45 mA

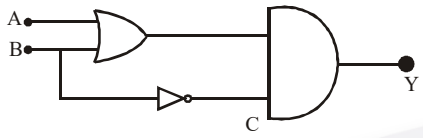
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40. A transistor connected at common emitter mode contains load resistance of 5 kΩ and an input resistance of 1 kW. If the input peak voltage is 5 mV and the current gain is 50, find the voltage gain.

(A) 250 **(B)** 500

(C) 125 **(D)** 50

41. The output for the given, circuit is



(A) $(A+B)\cdot\overline{B}$ **(B)** $(A\cdot B)\cdot\overline{B}$

(C) $(A+B)\cdot B$ **(D)** $(A\cdot B)+B$

ASSERTION AND REASON

42. **Assertion :** During reverse biasing a diode doesn't conduct current.

Reason : It narrows the depletion layer.

43. **Assertion :** The resistivity of a semiconductor increases with temperature.

Reason : The atoms of a semiconductor vibrate with larger amplitude at higher temperatures thereby increasing its resistivity.

44. **Assertion :** In a transistor the base is made thin.

Reason : A thin base makes the transistor stable.

45. **Assertion :** A transistor amplifier in common emitter configuration has a low input impedence.

Reason : The base to emitter region is forward biased.

46. **Assertion :** A diode lasers are used as optical sources in optical communication.

Reason : Diode lasers consume less energy.

47. **Assertion :** The logic gate NOT can be built using diode.

Reason : The output voltage and the input voltage of the diode have 180° phase difference.

48. **Assertion :** The number of electrons in a p-type silicon semiconductor is less than the number of electrons in a pure silicon semiconductor at room temperature.

Reason : It is due to law of mass action.

49. **Assertion :** In a common emitter transistor amplifier the input current is much less than the output current.

Reason : The common emitter transistor amplifier has very high input impedance.

50. **Assertion :** In common base configuration, the current gain of the transistor is less than unity.

Reason : The collector terminal is reverse biased for amplification.

51. **Assertion :** A p-n junction with reverse bias can be used as a photo-diode to measure light intensity.

Reason : In a reverse bias condition the current is small but is more sensitive to changes in incident light intensity.

52. **Assertion :** NAND is a universal gate.

Reason : It can be used to describe all other logic gates.

53. **Assertion :** Diode lasers are used as optical sources in optical communication.

Reason : Diode lasers consume less energy.

54. **Assertion :** A photocell is called an electric eye.

Reason : When light is incident on some semiconductor its electrical resistance is reduced.

55. **Assertion :** In a common-emitter amplifier the load resistance of the output circuit is 1000 times the load resistance of the input circuit. If $\alpha = 0.98$, then voltage gain is 49×10^3.

Reason : $\alpha = \frac{\beta}{1-\beta}$ (symbols have their usual meaning).

56. **Assertion :** Most amplifiers use common emitter circuit configuration.

Reason : Its input resistance is comparatively higher.

57. **Assertion :** A pure semiconductor has negative temperature coefficient of resistance.

Reason : On raising the temperature, more charge carriers are released, conductance increases and resistance decreases.

58. **Assertion :** At a fixed temperature, silicon will have a minimum conductivity when it has a smaller acceptor doping.

Reason : The conductivity of an intrinisic semiconductor is slightly higher than that of a lightly doped p-type

59. **Assertion :** Photodiode and photovoltaic cell are based on the same principle.

Reason : Both use same method of operations to work

60. **Assertion :** Transistor can be used as a switch.

Reason : Both linear and non-linear voltage bias dependance occurs in it.

61. **Assertion :** The resistance of a junction of a spoiled transistor is low when forward biased or reverse biased.

Reason : The resistance of a junction of a transistor in working order is high always.

62. **Assertion :** A p-n junction with reverse bias can be used as a photo-diode to measure light intensity.

Reason : In a reverse bias condition the current is small but it is more sensitive to change in intensity of incident light.

63. **Assertion :** The output voltage and the input voltage of the NOT gate have 180° phase difference.

Reason : The logic NOT can be built using diode.

64. **Assertion :** In a common emitter transistor amplifier, the input current is much less than the output current than output impedance.

Reason : The common emitter transistor amplifier has higher input impedance than output impedance.

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MOCK TEST

STRAIGHT OBJECTIVE TYPE

1. A silicon speciman is made into a *P*-type semi-conductor by dopping, on an average, one Indium atom per 5×10^{7} silicon atoms. If the number density of atoms in the silicon specimen is 5×10^{28} atoms $/m^3$ then the number of acceptor atoms in silicon per cubic centimetre will be

(A) $2.5\times10^{30}\ atoms\ /\ cm^3$ **(B)** $1.0\times10^{13}\ atoms\ /\ cm^3$ **(C)** $1.0\times10^{15}\ atoms\ /\ cm^3$ **(D)** $2.5\times10^{36}\ atoms\ /\ cm^3$

2. The probability of electrons to be found in the conduction band of an intrinsic semiconductor at a finite temperature

(A) Decreases exponentially with increasing band gap

(B) Increases exponentially with increasing band gap

(C) decreases with increasing temperature

(D) Is independent of the temperature and the band gap

3. The typical ionisation energy of a donor in silicon is

(A) $10.0\,eV$ **(B)** $1.0\,eV$ **(C)** $0.1\,eV$ **(D)** $0.001\,eV$

4. In *PN*-junction diode the reverse saturation current is $10^{-5}\ amp$ at $27°C$. The forward current for a voltage of $0.2volt$ is

(A) $2037.6\times10^{-3}\,amp$ **(B)** $203.76\times10^{-3}\,amp$ **(C)** $20.376\times10^{-3}\,amp$ **(D)** $2.0376\times10^{3}\,amp$

$[\exp(7.62)=2038.6, K=1.4\times10^{-23}\,J/K]$

5. When a potential difference is applied across, the current passing through

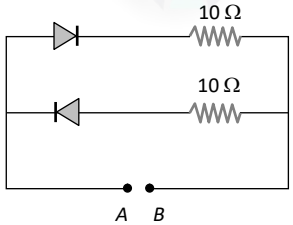
(A) An insulator at $0K$ is zero

(B) A semiconductor at 0 K is zero

(C) A *P-N* diode at 300 K is finite, if it is reverse biased

(D) All options are correct

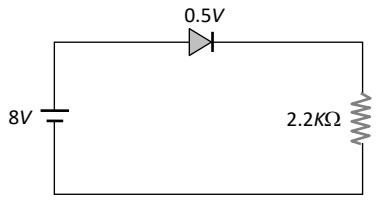
6. A $2V$ battery is connected across the points A and B as shown in the figure given below. Assuming that the resistance of each diode is zero in forward bias and infinity in reverse bias, the current supplied by the battery when its positive terminal is connected to A is



(A) $0.2\,A$ **(B)** $0.4\,A$ **(C)** Zero **(D)** $0.1\,A$

7. In the circuit, if the forward voltage drop for the diode is $0.5V$, the current will be

(A) $3.4\,mA$
(B) $2\,mA$
(C) $2.5\,mA$
(D) $3\,mA$

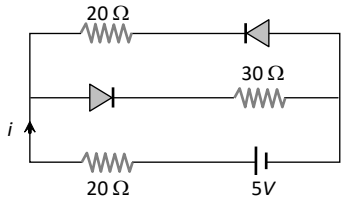


8. A P-type semiconductor has acceptor levels 57 meV above the valence band. The maximum wavelength of light required to create a hole is (Planck's constant $h = 6.6\times10^{-34}\,J\text{-}s$)

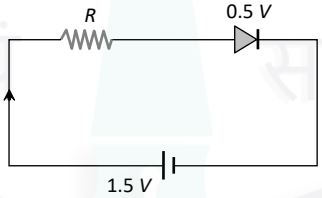
(A) $57\,\mathring{A}$ **(B)** 57×10^{-3} Å **(C)** $217100\,\mathring{A}$ **(D)** 11.61×10^{-33} Å

9. Current in the circuit will be

(A) $\frac{5}{40}$A
(B) $\frac{5}{50}$A
(C) $\frac{5}{10}$A
(D) $\frac{5}{20}$A



10. The diode used in the circuit shown in the figure has a constant voltage drop of 0.5 V at all currents and a maximum power rating of 100 *milliwatts*. What should be the value of the resistor R, connected in series with the diode for obtaining maximum current

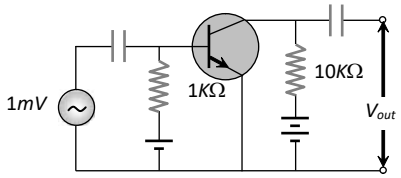


(A) 1.5 Ω **(B)** 5 Ω **(C)** 6.67 Ω **(D)** 200 Ω

11. For a transistor amplifier in common emitter configuration for load impedance of 1 $k\Omega$ ($h_{fe} = 50$ and $h_{oe} = 25\ \mu A/V$) the current gain is

(A) – 5.2 **(B)** – 15.7 **(C)** – 24.8 **(D)** – 48.78

12. In the following common emitter configuration an NPN transistor with current gain $\beta = 100$ is used. The output voltage of the amplifier will be



(A) $10\,mV$ **(B)** $0.1\ V$ **(C)** $1.0\ V$ **(D)** $10\ V$

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13. In semiconductor the concentrations of electrons and holes are $8 \times 10^{18}/m^3$ and $5 \times 10^{18}/m$ respectively. If the mobilities of electrons and hole are 2.3 $m^2/volt\text{-}sec$ and 0.01 $m^2/volt\text{-}sec$ respectively, then semiconductor is

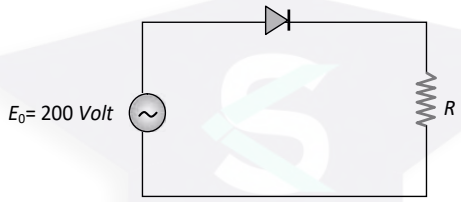
(A) *N*-type and its resistivity is 0.34 *ohm-metre*

(B) *P*-type and its resistivity is 0.034 *ohm-metre*

(C) *N*-type and its resistivity is 0.034 *ohm-metre*

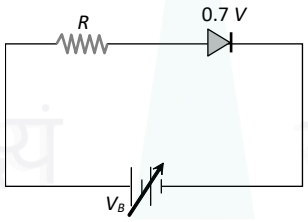
(D) *P*-type and its resistivity is 3.40 *ohm-metre*

14. A sinusoidal voltage of peak value 200 *volt* is connected to a diode and resistor *R* in the circuit shown so that half wave rectification occurs. If the forward resistance of the diode is negligible compared to *R* the *rms* voltage (in *volt*) across *R* is approximately



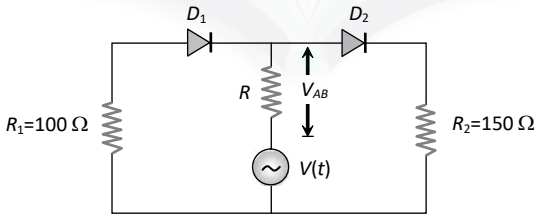
(A) 200 **(B)** 100 **(C)** $\frac{200}{\sqrt{2}}$ **(D)** 280

15. The junction diode in the following circuit requires a minimum current of 1 *mA* to be above the knee point (0.7 *V*) of its I-V characteristic curve. The voltage across the diode is independent of current above the knee point. If V_B = 5 *V*, then the maximum value of *R* so that the voltage is above the knee point, will be



(A) 4.3 *k*Ω **(B)** 860 *k*Ω **(C)** 4.3 Ω **(D)** 860 Ω

16. In the circuit given below, $V(t)$ is the sinusoidal voltage source, voltage drop $V_{AB}(t)$ across the resistance *R* is



(A) Is half wave rectified

(B) Is full wave rectified

(C) Has the same peak value in the positive and negative half cycles

(D) Has different peak values during positive and negative half cycle

17. The peak voltage in the output of a half-wave diode rectifier fed with a sinusoidal signal without filter is 10 V. The dc component of the output voltage is

(A) $10/\sqrt{2}$ V **(B)** $10/\pi V$ **(C)** 10 V **(D)** $20/\pi V$

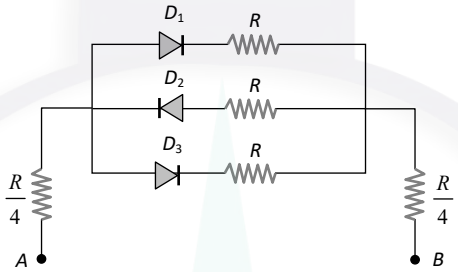
18. A transistor is used as an amplifier in CB mode with a load resistance of 5 $k\,\Omega$ the current gain of amplifier is 0.98 and the input resistance is 70 Ω, the voltage gain and power gain respectively are

(A) 70, 68.6 **(B)** 80, 75.6 **(C)** 60, 66.6 **(D)** 90, 96.6

19. The Bohr radius of the fifth electron of phosphorus (atomic number = 15) acting as dopant in silicon (relative dielectric constant = 12) is

(A) 10.6 Å **(B)** 0.53 Å **(C)** 21.2 Å **(D)** None of these

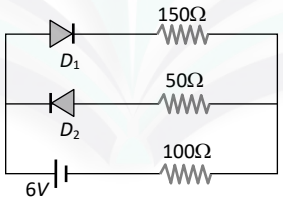
20. In the following circuits PN-junction diodes D_1, D_2 and D_3 are ideal for the following potential of A and B, the correct increasing order of resistance between A and B will be



(i) $-10\,V, -5V$ (ii) $-5V, -10\,V$ (iii) $-4V, -12V$

(A) (i) < (ii) < (iii) **(B)** (iii) < (ii) < (i) **(C)** (ii) = (iii) < (i) **(D)** (i) = (iii) < (ii)

21. The circuit shown in following figure contains two diode D_1 and D_2 each with a forward resistance of 50 *ohms* and with infinite backward resistance. If the battery voltage is 6 V, the current through the 100 *ohm* resistance (in *amperes*) is



(A) Zero **(B)** 0.02 **(C)** 0.03 **(D)** 0.036

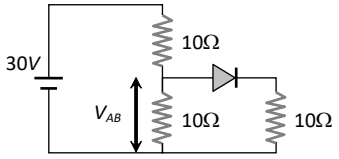
22. Find V_{AB}

(A) 10 V

(B) 20 V

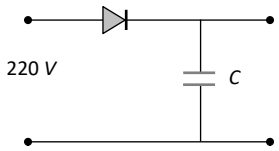
(C) 30 V

(D) None of these



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23. A diode is connected to 220 V (rms) ac in series with a capacitor as shown in figure. The voltage across the capacitor is



(A) 220 V

(B) 110 V

(C) 311.1 V

(D) $\frac{220}{\sqrt{2}}$ V

24. A potential difference of $2V$ is applied between the opposite faces of a Ge crystal plate of area 1 cm^2 and thickness 0.5 mm. If the concentration of electrons in Ge is $2 \times 10^{19}/m^3$ and mobilities of electrons and holes are $0.36 \frac{m^2}{volt - sec}$ and $0.14 \frac{m^2}{volt - sec}$ respectively, then the current flowing through the plate will be

(A) 0.25 A **(B)** 0.45 A **(C)** 0.56 A **(D)** 0.64 A

ASSERTION AND REASON TYPE

These questions contains, Statement 1 (assertion) and Statement II (reason).

(A) Statement-1 is True, Statement-2 is True; Statement-2 **is** a correct explanation for Statement-1

(B) Statement-1 is True, Statement-2 is True; Statement-2 **is NOT** a correct explanation for Statement-1

(C) Statement-1 is True, Statement-2 is False

(D) Statement-1 is False, Statement-2 is True.

25. **Assertion :** The logic gate NOT can be built using diode.

Reason : The output voltage and the input voltage of the diode have 180° phase difference.

26. **Assertion :** The number of electrons in a P-type silicon semiconductor is less than the number of electrons in a pure silicon semiconductor at room temperature.

Reason : It is due to law of mass action.

27. **Assertion :** In a common emitter transistor amplifier the input current is much less than the output current.

Reason : The common emitter transistor amplifier has very high input impedance.

28. **Assertion :** A transistor amplifier in common emitter configuration has a low input impedence.

Reason : The base to emitter region is forward biased.

29. **Assertion :** The resistivity of a semiconductor increases with temperature.

Reason : The atoms of a semiconductor vibrate with larger amplitude at higher temperature there by increasing it's resistivity.

30. **Assertion :** If the temperature of a semiconductor is increased then it's resistance decreases.

Reason : The energy gap between conduction band and valence band is very small

ANSWER KEY

EXERCISE - 1

1	D	**2**	D	**3**	D	**4**	A	**5**	A	**6**	A	**7**	A	**8**	B	**9**	A	**10**	C	**11**	C	**12**	B	**13**	D
14	B	**15**	B	**16**	B	**17**	B	**18**	C	**19**	D	**20**	A	**21**	B	**22**	A	**23**	B	**24**	B	**25**	C	**26**	B
27	A	**28**	B	**29**	A	**30**	A	**31**	A	**32**	C	**33**	A	**34**	D	**35**	D	**36**	B	**37**	D	**38**	B	**39**	B
40	B	**41**	B	**42**	C	**43**	B	**44**	A	**45**	B	**46**	C	**47**	D	**48**	B	**49**	A	**50**	A	**51**	C	**52**	C
53	A	**54**	B	**55**	B	**56**	B	**57**	C	**58**	B	**59**	A	**60**	A										

EXERCISE - 2

1.	C	**2.**	B	**3.**	A	**4.**	A	**5.**	D	**6.**	B	**7.**	C	**8.**	D	**9.**	D	**10.**	D	**11.**	B	**12.**	C	**13.**	B
14.	C	**15.**	D	**16.**	B	**17.**	B	**18.**	B	**19.**	A	**20.**	C	**21.**	A	**22.**	A	**23.**	A	**24.**	B	**25.**	A	**26.**	A
27.	C	**28.**	C	**29.**	B	**30.**	D	**31.**	C	**32.**	B	**33.**	A	**34.**	B	**35.**	A	**36.**	D	**37.**	A	**38.**	B	**39.**	A
40.	A	**41.**	D	**42.**	C	**43.**	B	**44.**	D	**45.**	A	**46.**	C	**47.**	B	**48.**	A	**49.**	B	**50.**	A	**51.**	C	**52.**	D
53.	C	**54.**	A	**55.**	D	**56.**	A	**57.**	B	**58.**	A	**59.**	D	**60.**	D										

EXERCISE - 3 : PART # 1

1. .A → p; B → s; C → q; D → r

PART # 2

1.	D	**2.**	A	**3.**	C	**4.**	A	**5.**	D	**6.**	A	**7.**	B	**8.**	A	**9.**	B	**10.**	A						

EXERCISE - 4 : PART # 1

1.	C	**2.**	A	**3.**	B	**4.**	A	**5.**	A	**6.**	B	**7.**	A	**8.**	B	**9.**	C	**10.**	B	**11.**	A	**12.**	B	**13.**	C
14.	B	**15.**	D	**16.**	A	**17.**	B	**18.**	B	**19.**	B	**20.**	C	**21.**	A	**22.**	C	**23.**	A	**24.**	D	**25.**	D	**26.**	C
27.	C	**28.**	D	**29.**	A	**30.**	D	**31.**	A	**32.**	D	**33.**	D	**34.**	D	**35.**	B	**36.**	C	**37.**	D	**38.**	C	**39.**	D
40.	B	**41.**	C	**42.**	C	**43.**	B	**44.**	B	**45.**	C	**46.**	B	**47.**	C	**48.**	A	**49.**	B	**50.**	C	**51.**	D	**52.**	C
53.	A	**54.**	C	**55.**	D	**56.**	A	**57.**	D	**58.**	C	**59.**	D	**60.**	C	**61.**	A	**62.**	B	**63.**	D	**64.**	A	**65.**	C
66.	A	**67.**	C	**68.**	C																				

PART # 2

1.	B	**2.**	B	**3.**	A	**4.**	B	**5.**	C	**6.**	C	**7.**	C	**8.**	A	**9.**	D	**10.**	B	**11.**	A	**12.**	B	**13.**	B
14.	A	**15.**	B	**16.**	D	**17.**	A	**18.**	B	**19.**	B	**20.**	B	**21.**	C	**22.**	C	**23.**	A	**24.**	B	**25.**	D	**26.**	C
27.	A	**28.**	B	**29.**	B	**30.**	C	**31.**	A	**32.**	C	**33.**	A	**34.**	A	**35.**	C	**36.**	D	**37.**	A	**38.**	B	**39.**	A
40.	A	**41.**	A	**42.**	C	**43.**	D	**44.**	C	**45.**	B	**46.**	A	**47.**	D	**48.**	A	**49.**	C	**50.**	C	**51.**	A	**52.**	A
53.	B	**54.**	B	**55.**	C	**56.**	A	**57.**	A	**58.**	C	**59.**	A	**60.**	B	**61.**	C	**62.**	A	**63.**	C	**64.**	C		

MOCK TEST

1	C	**2**	A	**3**	C	**4**	C	**5**	D	**6**	A	**7**	A	**8**	C	**9**	B	**10**	B	**11**	D	**12**	C	**13**	A
14	B	**15**	A	**16**	D	**17**	B	**18**	A	**19**	A	**20**	C	**21**	B	**22**	A	**23**	D	**24**	D	**25**	D	**26**	A
27	C	**28**	A	**29**	D	**30**	A																		

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HINTS & SOLUTIONS

EXERCISE - 1
NEET LEVEL

1. (D) Ionic bonds cone into being when atoms that have low ionization energies, and hence lose electrons rapidly, interact with other atoms that and to acquire excess electrons. The former atoms give up electrons to the latter and they there upon become positive and negative ions respectively.

2. (D) For tetragonal, cubic and orthorhombic system $\alpha = \beta = \gamma = 90°$.

3. (D) Tourmaline crystal is biaxial.

4. (A) The temperature co-efficient of resistance of conductor is positive.

5. (A) Density $\rho = \frac{nA}{N(a)^3}$

where $n = 2$ for bcc structure , $A = 39 \times 10^{-3}\ kg$,

$N = 6.02 \times 10^{23}$, $a = \frac{2}{\sqrt{3}}d = \frac{2}{\sqrt{3}} \times (4.525 \times 10^{-10})m$

(d = nearest neighbour distance = distance between centres of two neighbouring atoms $= \frac{a}{\sqrt{2}}$)

On putting the values we get $\rho = 907$

6. (A) The highest energy level which an electron can occupy in the valence band at 0 *K*, is called Fermi energy level.

7. (A) In a triclinic crystal $a \neq b \neq c$ and $\alpha \neq \beta \neq \gamma \neq 90°$

8. (B) Metallic solids are opaque because incident light is absorbed by the free electrons in a metal.

9. (A) In ionic bonding electrons are transferred from one type of atoms to the other type creating positive and negative ions. For example in *NaCl*, *Na* loses one electrons and *Cl* gains one so that Na^+ and Cl^- ions have a stable shell structure.

10. (C) Wood is non-crystalline.

11. (C) In *P*-type semiconductors, holes are the majority charge carriers

12. (B) *Ga* has a valancy of 3.

13. (D) Ge + Trivalent impurity $\Rightarrow$ P-type semiconductor

14. (B) Since $n_e > n_h$; the semiconductor is *N*-type.

15. (B) Absence of one electron, creates the positive charge of magnitude equal to that of electronic charge.

16. (B) Ge + Pantavalent impurity $\Rightarrow$ N-type semiconductor

17. (B) Impurity increases the conductivity.

18. (C) Intrinsic semiconductor $\Rightarrow$ Conductivity is due to the breaking of covalent bond

Extrinsic semiconductor $\Rightarrow$ Conductivity is due to the breaking of covalent bond and excess of charge carriers due to impurity.

19. (D) Resistance of conductors (*Cu*) decreases with decrease in temperature while that of semi-conductors (*Ge*) increases with decrease in temperature.

20. (A) Aluminum is trivalent impurity.

21. (B)

22. (A) In forward biased *PN*-junction, external voltage decreases the potential barrier, so current is maximum. While in reversed biased *PN*-junction, external voltage increases the potential barrier, so the current is very small.

23. (B)

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24. (B) Filter circuits are used to get smooth *dc* π-filter is the best filter.

25. (C) In reverse bias no current flows.

26. (B) In reverse biasing, width of depletion layer increases.

27. (A) Depletion layer consist of mainly stationary ions.

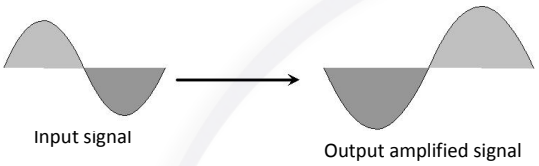
28. (B) Current flow is possible and $i = \frac{V}{R} = \frac{(4-1)}{300} = 10^{-2} A$

29. (A) The potential of *P*-side is more negative that of *N*-side, hence diode is in reverse biasing. In reverse biasing it acts as open circuit, hence no current flows.

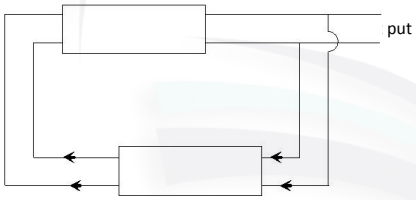
30. (A)

31. (A) When *NPN* transistor is used as an amplifier, majority charge carrier electrons of *N*-type emitter move from emitter to base and than base to collector.

32. (C)



33. (A) In oscillator, a portion of the output power is returned back (feed back) to the input in phase with the starting power. This process is termed as positive feedback.

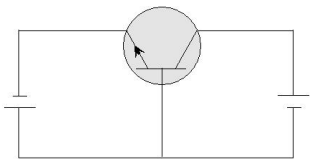


34. (D) The emitter base junction is forward biased while collector base junction is reversed biased.

35. (D) Given $i_c = \frac{80}{100} \times i_e \Rightarrow 24 = \frac{80}{100} \times i_e \Rightarrow i_e = 30\,mA$

By using $i_e = i_b + i_c \Rightarrow i_b = 30 - 24 = 6\,mA$.

36. (B)



37. (D) α is the ratio of collector current and emitter current while β is the ratio of collector current and base current.

38. (B)

39. (B) $\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = 49.$

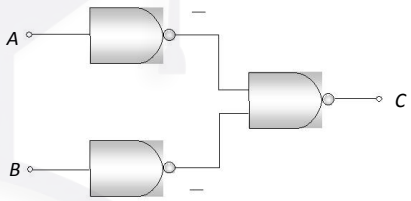
40. (B) $\beta = \frac{\alpha}{1-\alpha} = \frac{0.96}{1-0.96} = 24.$

41. (B) **42. (C)**

43. (B) For 'OR' gate $X = A + B$

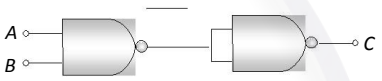
i.e. $0+0=0,\ 0+1=1,\ 1+0=1,\ 1+1=1$

44. (A)



$C = \overline{\overline{A}.\overline{B}} = \overline{\overline{A} + \overline{B}} = A + B$ (De morgan's theorem)

Hence output *C* is equivalent to OR gate.



$C = \overline{A\overline{B}}.\overline{A\overline{B}} = \overline{A\overline{B}} + \overline{A\overline{B}} = AB + AB = AB$

In this case output *C* is equivalent to AND gate.

45. (B) In 'NOR' gate $Y = \overline{A + B}$

i.e. $\overline{0+0} = \overline{0} = 1,\ \overline{1+0} = \overline{1} = 0$

$\overline{0+1} = \overline{1} = 0,\ \overline{1+1} = \overline{1} = 0$

46. (C) For 'XNOR' gate $Y = \overline{A}\,\overline{B} + AB$

i.e. $\overline{0}.\overline{0} + 0.0 = 1.1 + 0.0 = 1 + 0 = 1$

$\overline{0}.\overline{1} + 0.1 = 1.0 + 0.1 = 0 + 0 = 0$

$\overline{1}.\overline{0} + 1.0 = 0.1 + 1.0 = 0 + 0 = 0$

$\overline{1}.\overline{1} + 1.1 = 0.0 + 1.1 = 0 + 1 = 1$

47. (D) The output *D* for the given combination

$D = \overline{(A+B).C} = \overline{(A+B)} + \overline{C}$

If $A = B = C = 0$ then $D = \overline{(0+0)} + \overline{0} = \overline{0} + \overline{0} = 1 + 1 = 1$

If $A = B = 1, C = 0$ then $D = \overline{(1+1)} + \overline{0} = \overline{1} + \overline{0} = 0 + 1 = 1$

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48. (B)

49. (A) The Boolean expression for 'NOR' gate is $Y = \overline{A+B}$

i.e. if $A = B = 0$ (Low), $Y = \overline{0+0} = \overline{0} = 1$ (High)

50. (A)

51. (C) According to Richardson-Dushman equation, number of thermions emitted per sec per unit area $J = AT^2 e^{-W_0/kT} \Rightarrow J \propto T^2$

52. (C) Intensity $\propto$ Number of electrons

53. (A) In SCR (Space charge region) electrons collect around the plate, this cloud decreases the emission of electrons from the cathode, hence plate current decreases.

54. (B)

55. (B) By using $g_m = \frac{\Delta i_p}{\Delta v_g} \Rightarrow 3\times10^{-4} = \frac{\Delta i_p}{-1-(-3)}$

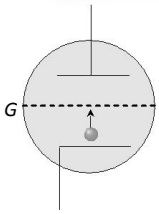
$\Rightarrow \Delta i_p = 6\times10^{-4} A = 0.6\,mA$

56. (B) Voltage gain $A_v = \frac{\mu}{1+\frac{r_p}{R_L}}$ and $\mu = r_p \times g_m$

$\Rightarrow r_p = \frac{42}{2\times10^{-3}} = 21000\Omega \Rightarrow A_v = \frac{42}{1+\frac{21000}{50\times10^3}} = 29.57$

57. (C) Voltage gain $A_v = \frac{\mu}{1+\frac{r_p}{R_L}}$, for $r_p = R_L \Rightarrow A_v = \frac{\mu}{2}$

58. (B) When grid is given positive potential more electrons will cross the grid to reach the positive plate *P*. Hence current increases.



59. (A) By using $\mu = -\frac{\Delta V_p}{\Delta V_g} = r_p \times g_m$

$\Rightarrow 7\times10^3 \times 2.5\times10^{-3} = -\frac{50}{\Delta V_g} \Rightarrow \Delta V_g = -2.86\,V$

60. (A) Using voltage gain $A_v = \frac{\mu}{1+\frac{r_p}{R_L}}$ also $\mu = r_p \times g_m$

$\Rightarrow r_p = \frac{\mu}{g_m} = \frac{20}{3\times10^{-3}}$

$\therefore A_v = \frac{20}{1+\frac{20}{3\times10^{-3}\times3\times10^4}} = \frac{180}{11} = 16.36$

EXERCISE - 2

AIIMS LEVEL

1. C

2. In insulators, the forbidden energy gap is very large, in case of semiconductor it is moderate and in conductors.

3. A **4.** A **5.** D **6.** B **7.** C **8.** D
9. D **10.** D **11.** B

12. N-type semiconductors are neutral because neutral atoms are added during doping.

13. B **14.** C **15.** D **16.** B **17.** B **18.** B
19. A **20.** C **21.** A **22.** A **23.** A **24.** B
25. A **26.** A **27.** C **28.** C **29.** B **30.** D
31. C **32.** B **33.** A **34.** B **35.** A **36.** D
37. A **38.** B **39.** A **40.** A **41.** D **42.** C
43. B **44.** D **45.** A **46.** C **47.** B **48.** A
49. B **50.** A **51.** C **52.** D **53.** C **54.** A
55. D **56.** A **57.** B **58.** A **59.** D **60.** D

EXERCISE - 3

P-1 (Matrix Match)

1. A → p; B → s; C → q; D → r

Diode gets forwardly biased during positive half cycle of alternating source and current flows. Let the barrier voltage of diode is V_B and its forward resistance is R_F, load resistance if R_L. Then peak voltage of aplied signal is

$V_0 = V_B + i_0(R_F + R_L)$

$\therefore \quad i_0 = \frac{V_0 - V_B}{R_F + R_L} = \frac{20-0.7}{10+500} = 37.8\times10^{-3}\,A$

$= 37.8\,mA$

Peak voltage at the ends of the load R_L,

$V_L = i_0 \times R_L = 37.8 \times 10^{-3} \times 500 = 18.9\,V$

For ideal diode, $V_B = 0$ and $R_F = 0$

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$$\therefore \quad i_0 = \frac{V_0}{R_L} = \frac{20}{500} = 0.04A = 40\,mA$$

and $V_L = i_0 R_L = 0.04 \times 500 = 20\,V$

EXERCISE - 3

P-2 (Assertion & Reason)

1. **(D)** In diode the output is in same phase with the input therefore it cannot be used to built NOT gate.

2. **(A)** According to law of mass action, $n_i^2 = n_e n_h$. In intrinsic semiconductors $n_i = n_e = n_h$ and for P-type semiconductor n_e would be less than n_i, since n_h is necessarily more than n_i.

3. **(C)** In common emitter transistor amplifier current gain $\beta > 1$, so output current > Input current, hence assertion is correct. Also, input circuit has low resistance due to forward biasing to emitter base junction, hence reason is false.

4. **(A)** Input impedance of common emitter configuration = $\left.\frac{V_{BE}}{i_B}\right|_{V_{CE}=\text{constant}}$ where ΔV_{BE} = voltage across base and emitter (base emitter region is forward biased) Δi_B = base current which is order of few microampere. Thus input impedance of common emitter is low.

5. **(D)** Resistivity of semiconductor decreases with temperature. The atoms of a semiconductor vibrate with larger amplitudes at higher temperatures there by increasing it's conductivity not resistivity.

6. **(A)** In semiconductors the energy gap between conductin band and valence band is small (>> 1 eV). Due to temperature rise, electron in the valence band gained thermal energy and may jump across the small energy gap, goes in to the conduction badn. Thus conductivity increases and hence resistance decreases.

7. **(B)**

8. **(A)** The ratio of the velocity to the applied field is called the mobility. Since electron is lighter than holes, they move faster in applied field than holes.

9. **(B)**

Intrinsic semiconduct (Neutral)	+	Pentalvalen impurity (Neutral)	$\Longrightarrow$	N-type (Neutral)

10. **(A)** At a particular temperature all the bonds of crystalline solids breaks and show sharp melting point.

EXERCISE - 4

P-1 (NEET/AIPMT)

1. **(C)** Current gain in common - base configuration is,

$$\alpha = \left(\frac{\Delta i_c}{\Delta i_e}\right)_{V_{cc}} \begin{bmatrix}\text{at constant voltage across}\\ \text{collector base junction}\end{bmatrix}$$

Current gain in common eemitter configuration is ,

$$\beta = \left(\frac{\Delta i_c}{\Delta i_b}\right)_{V_{cc}} \begin{bmatrix}\text{at constant voltage across}\\ \text{Collector emitter junction}\end{bmatrix}$$

Also $i_b = i_e - i_c$

or $\Delta i_b = \Delta i_e - \Delta i_c$

As $\beta = \frac{\Delta i_c}{\Delta i_b} = \frac{\Delta i_c}{\Delta i_e} \times \frac{\Delta i_e}{\Delta i_b}$

or $\beta = \alpha \times \frac{\Delta i_c}{\Delta i_e - \Delta i_c}$

or $\beta = \alpha \times \frac{1}{1 - \frac{\Delta i_c}{\Delta i_c}}$ or $\beta = \frac{\alpha}{1-\alpha}$

Altrernative

As we know that relation between current gain in common base and common emitter configuration is given by

$$\alpha = \frac{\beta}{1+\beta}$$

$\Rightarrow \alpha + \alpha\beta = \beta$

$\Rightarrow \beta - \alpha\beta = \alpha$

$\Rightarrow \beta(1-\alpha) = \alpha$

$\Rightarrow \beta = \frac{\alpha}{1-\alpha}$

Note : β is always greater than α. Also $\alpha < 1$ and $\beta > 1$

2. **(A)** We can see from the truth table that output is 1 only when its both inputs are 1.

This is possible only for AND gate. The boolean expression for AND gate is.

$Y = A.B$

Which satisfies the truth table as below

$0.0 = 0$

$1.0 = 0$

$0.1 = 0$

$1.1 = 1$

Here symbol (.) represents AND operation.

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3. **(B)** For forward biasing of p-n junction, p-side should be at higher potential than n-side. Now we apply this rule to the four options.

(A) Here, p-side is at lower optential (0 V) and n-side at higher potential (2 V). So, this diode is not forward biased.

(B) Here, p-side is at higher potential (0 V) and n-side at lower potential (–2 V). So. this diode is forward biased.

(C) Here, p - side is at lower potential (–2 V) and n-side at higher potential (0 V). So, this diode is not forward biased.

(D) Here p -side is at lower potential (2 V) and n-side at higher potential (5 V). So, this is not forward biased.

Hence, choice **(B)** is correct.

4. **(A)** Resistivity of a metal is directlyproportional to temperature because its temperature cofficient is positive and resistivity of semiconductor is inversely proportional to temperature. due to its negative temperatwe coefftcient. Ttris irnplies that with decrease in temperature, resistivity of metal decreases while that of semiconductor increases. Here, Si is a semiconductor and Cu is a metal. So, resistivity of Si increases but that of Cu decreases.

5. **(A)** The current gain **(A)** common -base configurtion is

$$\alpha = \frac{\Delta i_c}{R_{eq}}\left[\begin{array}{l}\text{at constant voltage across}\\ \text{collector base junction}\end{array}\right]$$

$= 0.98$

The current gain in common emitter configuration

$$\beta = \frac{\alpha}{1-\alpha} = \frac{098}{1-0.98} = \frac{0.98}{0.02} = 49$$

6. **(B)** In the circuit diode D_1 is forward biased and diode D_2 is reverse biased. Therefore , on current flows in the arm containing D_2 and all of the current flows through arm containing D_1. Thus current flowing through the circuit is given by

$$I = \frac{V}{R_{eq}} = \frac{5}{20+30} = \frac{5}{50}A \quad [\because Req = 20\Omega + 30\Omega]$$

7. **(A)** in a bcc structure, the position vectors of the nearest neighbours of the origin are

$$\left(\pm\frac{a}{2}\hat{i} \pm \frac{a}{2}\hat{j} \pm \frac{a}{2}\hat{k}\right)$$

The distance between any two nearest neighbours is given but the resultant of above position vector is

$$\sqrt{\left(\frac{a}{2}\right)^2 + \left(\frac{a}{2}\right)^2 + \left(\frac{a}{2}\right)^2} = \sqrt{\frac{3a^2}{4}}$$

$$= \frac{\sqrt{3}}{2}a$$

8. **(B)** Number of atoms per unit cell is given by

$$N = N_b + \frac{N_f}{2} + \frac{N_c}{8}$$

where N_b = number of atoms centred in the body

N_f = number of atoms centred in the face

N_c = number of atoms centred at the corners

For bcc structure

$$N_b = 1, N_f = 0$$

and $N_c = 8$

$$\therefore \quad N = 1 + \frac{0}{2} + \frac{8}{8} = 2$$

9. **(C)** Given that the current gain in common base emitter is $\frac{i_c}{i_e}$ = Current gain **(A)** = 0.96

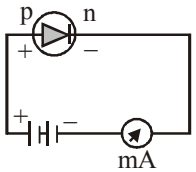
So, current gain in common emitter configuration is

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.96}{1-0.96} = \frac{0.96}{0.04} = 24$$

Note :

The current gain β in common emitter mode is very large as compared to the current gain α in common base mode. This is why a transistor is always used as an amplifier in the CE mode.

10. **(B)** For conduction in a p-n junction, it should be forward biased because it offers minimum resistance to the flow of cunent. For this p-side must be connected to positive terminal (higher potential) and n-side must be connected to negative terminal (lower potential). Fignrre below shows the p-n junction in a conducting state (forward biased condition)



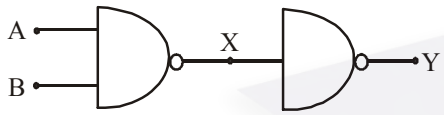
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11. **(A)** In forward biasing, the diode conducts. For ideal junction diode, the forward resistance is zero. Therefore, entire applied voltage occures across resistance R

While in reverse biasing, the diode does not conduct, so it has infinite resistance. Thus, voltage across R is zero in reverse biasing

12. **(B)** For our convenience, the output of first NAND gate is chosen as X as shown

Using De Morgan's theorem



$$\overline{A.B} = \overline{A} + \overline{B}$$

So, $X = \overline{A} + \overline{B}$

Now, output of 2nd NAND gate,

$$Y = \overline{X} = \overline{\overline{A} + \overline{B}}$$

Again $\overline{\overline{A} + \overline{B}} = \overline{\overline{A}}.\overline{\overline{B}} = A.B \qquad [\because \overline{\overline{A}} = A]$

Hence, $Y = A.B$

This is the logic function of AND gate.

13. **(C)** Bafier potential does not depend on diode design while it depends on temperature, doping density and forward biasing.

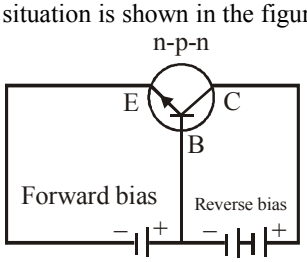
14. **(B)** For full wave rectifier,

Ripple frequency = 2 × input frequency

= 2 × 50

= Collector

15. **(D)** For amplifying action of a transistor, emitter base junction is always forward biased while base collector junction is reverse biased. For forward biasing of emitter base junction in n-p-n transistor, left n-side i.e. emitter should be connected to negative terminal and p-side (base) should be connected to positive terminal of the battery. On the other hand, in right side, n-side (collector) should be connected to positive terminal of the battery to make base collector junction reverse biased. The whole situation is shown in the figure for n-p-n transistor.



E → Emitter

B → Base

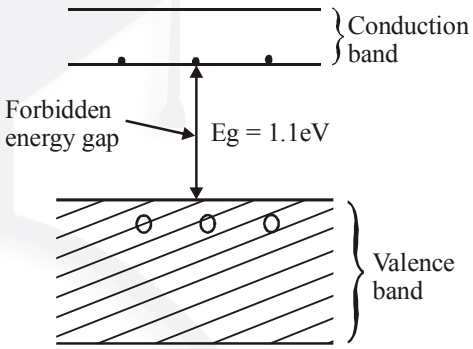
C → Collector

16. **(A)** The energy band scheme of semiconductors is shown here.

In semiconductors, valence band and conduction band are separated by an energy gap called the forbidden energy gap. It is very small. At room temperature some electrons in valence band acquire thermal energy.

This energy is more than forbidden energy gap E_g, thus they jump into the conduction band and leave their vacancy in the valence band which act as holes.

Hence, at room temperature valence band is partially empty and conduction band is partially filled.



17. **(B)** The output DC component of half wave rectifier is given by

$$V_{output} = \frac{\text{peak voltage}}{\pi} = \frac{10}{\pi} V$$

18. **(B)** OR gate has two inputs A and B and output Y. It follow a logic operation represented by '+' Thus, its boolean expression is

$A + B = Y$

The truth table of OR gate is

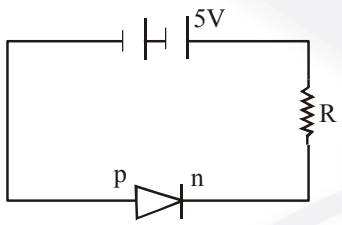
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

Thus, after observing its Boolean expression and its truth table, it is obvious that output of OR gate is 1 if either or both inputs are 1.

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19. **(B)** In aphotoconductive cell, when monochromatic light is incident on the transparent metallic film, a force produced called the photo electromotive force, stimulates the emission of an electric curent where photovoitaic action creates a potential difference between two points. Ttre magnitude of this'current depends upon the intensity of incident light Hence, photo electromotive force produced by monochromatic light is proporbional to the intensity of light falling on the cell.

20. **(C)** When a battery is connected to junction diode withp-side connected to negative terminal or Iower potential and n-side to the positive terminal or higher potential, the junction diode is reverse biased.



The circuit shown in fignrre can be redrawn as

In the option **(C)**; the p-end of the diode is connected to negative terminal of the battery, so the diode has been reverse biased.

21. **(A)** On applylng forward bias to a p-njunction diode, it increases number of donor on the n-side and decreases potential barrier. It also decreases electric field of depletion layer.

22. **(C)** Zener diode is a silicon crystal diode having an unusual reverse cunent characteristic which is particularly suitable for voltage regnriating purposes or voltage stabilisation purposes.

23. **(A)** Carbon, silicaon and germanium are semiconductors

$(E_g)_C = 52\ eV$

$(E_g)_{Si} = 121\ eV$

$(Eg)_{Ge} = 0.75\ eV$

Thus, $(E_g)C > (E_g)_{Si}$ and $(E_g)_C > (E_g)_{Ge}$

24. **(D)** In insulators, energy gap is of the order of 5 to 10 eV and it is practically impossible to impart this much amount of energy to the electrons in valence band so as to jump to conduction band. So,choice **(A)** is correct.

(B) In semiconductors, with the rise in temperature more electrons from valence band jump to conduction band and this results in increase in conductivity. So, choice **(B)** is conect.

(C) In conductors, the conduction band is either partially filled or the conduction band overlaps on the valence band. So, choice **(C)** is correct'

(D) In semiconductor, resistivity decreases with increase in temPerature. So,choice **(D)** is wrong.

25. **(D)** Interatomic spacing for a fcc lattice is given by

$$r = \left[\left(\frac{a}{2}\right)^2 + \left(\frac{a}{2}\right)^2 + (0)^2\right]^{1/2} = \frac{a}{\sqrt{2}}$$

where, a being lattice constant.

$$\therefore \quad a = \sqrt{2}r = \sqrt{2} \times 2.54 = 359\text{Å}$$

Note :

interatomic spacing is just the nearest neighbours distance

26. **(C)** In a series LC circuit, frequency of LC-oscillations is given by

$$f = \frac{1}{2\pi\sqrt{LC}} \text{ or } f \propto \frac{1}{\sqrt{LC}}$$

Considering two cases of L and C,

$$\frac{f_1}{f_2} = \sqrt{\frac{L_2C_2}{L_1C_1}}$$

Given, $L_1 = L, C_1 = C, L_2 = C_2 = 4C, f_1 = f$

$$\therefore \quad \frac{f}{f_2} = \sqrt{\frac{2L \times 4C}{LC}} = 8 \Rightarrow f_2 = \frac{a}{\sqrt{2}}$$

27. **(C)** AC current gain β defined as the ratio of the collector to the base current at constant collector voltage,

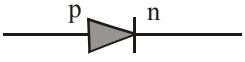
$$\beta = \left(\frac{\Delta i_c}{\Delta i_b}\right)_{V_C}$$

Given, $\Delta i_c = 10\ \mu A - 5\ \mu A = 5\ \mu A$

$\Delta ib = 150\ \mu A - 100 \mu A = 50\ \mu A$

$$\therefore \quad \beta = \frac{5mA}{50 \times 10^{-3}\ mA} = 100$$

28. **(D)** The p-n junction diode can be shown as



If p-side of p-n junction diode is given more positive potential or positive terminal of the battery and n-side is connected to less potential or one terminal of battery, then it is forward biased.

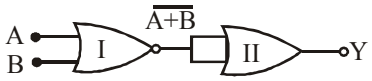
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In option **(D)**, side is at 0V and n-side at –2V, so p is at higher potential. hence, it is forward biased.

Note : p-n junction diode is mainly used as a rectifier.

29. (A) The Boolean expression which satisfies the output of this logic gate is C = A.B, which is for AND gate.

30. (D) We can simplify the gate circuit as



Here, gates -I and II are NOR gates. The output $(\overline{A+B})$ gates -I will appear as input of gate -II. The final output is

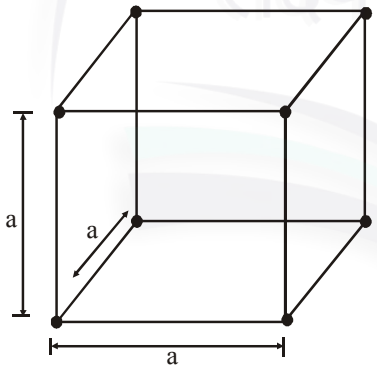
$$Y = \overline{A+B} = A+B$$

This is the Boolean expression of OR gate whose truth table is given below

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

31. (A) Since in the given diagram. we see that there are more number of holes so it is 'p' type semiconductor.

32. (D) In cubic crystals, the crystal axes are perpendicular to one another ($\alpha = \beta = \gamma = 90^\circ$) and the repetitive interval is the same along the three axes (a = b = c)



33. (D) For 'fcc' structure, $I = \frac{a}{2\sqrt{2}}$

where r = radius of the atom in the packing

a = edge length of the cube

Here, a = 3.6Å

$$\therefore \quad r = \frac{3.6}{2\times1.4} = 1.27\text{Å}$$

34. (D) Voltage gain $= \frac{A_V}{1+\beta A_V}$

$$10 = 100 = \frac{A_V}{1+\frac{9}{100}A_V}$$

$$A_V = \frac{10}{0.1} = 100$$

35. (B) Let the energy of radiation falling on the p-n photodiode be E = hv

The minimum energy required = 2eV

$$\therefore \quad 2eV = hv$$

$$\therefore \quad v = \frac{2eV}{h}$$

$$= \frac{2\times1.6\times10^{-19}}{6.6\times10^{14}}$$

$$= 5\times10^{14}\,\text{Hz}$$

36. (C) The gate circuit can be solved by giving two inputs A and B

Output of NOR gate, $Y_1 = \overline{A+B}$

Output of NAND gate, $Y_2 = \overline{Y_1 + Y_2}$

$$= \overline{\overline{A+B}.\overline{A+B}}$$

$$= \overline{\overline{A+B}} + \overline{\overline{A+B}}$$

$$= A+B+AB$$

$$= A+B$$

Output of NOT gate, $Y = \overline{Y}_2 = \overline{A+B}$

which is the output of NOR gate.

37. (D) Energy, $E = hv = h\frac{C}{\lambda}$

$$\Rightarrow \quad \lambda = \frac{hC}{E}$$

Substituting the values of h, c and E in the above equation

$$\lambda = \frac{6.6\times10^{-34}\times3\times10^{8}}{2.5\times1.6\times10^{-19}} = 5000\text{Å}$$

As $4000\,\text{Å} < 5000\,\text{Å}$

Signal of wavelength 4000 Å can be detected by the photodiode

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38. **(C)** The symbols given in problem are
(i) NAND (ii) NOT (iii) AND (iv) OR

39. **(D)** For a transistor

$I_E = I_B + I_C$

where I_E = emitter current
I_B = base current
I_C = collector current

and current gain $\beta = \frac{\Delta I_C}{\Delta I_B}$

Here, $\Delta I_C = 10 \times 10^{-3} - 5 \times 10^{-3}$
$= 5 \times 10^{-3} A$
$\Delta I_B = 200 \times 10^{-6} - 100 \times 10^{-6}$
$= 100 \times 10^{-6} A$

$\therefore \quad \beta = \frac{5}{100} \times 1000 = 50$

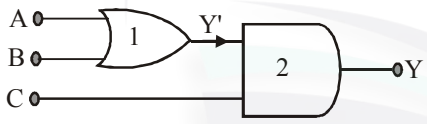
40. **(B)** Neighbour distance of a body centred cuvbic cell

$d = \frac{\sqrt{3}}{2} a$, where a is the lattice parameter

$\Rightarrow \quad 3.7 \frac{\sqrt{3a}}{2}$

or $\quad a = \frac{2 \times 3.7}{\sqrt{3}} = 4.3 Å$

41. **(C)** Gate i is Or gate, $Y' = A + B$



Gate II is AND gate, $Y = Y' . C$
$\therefore \quad A = 1, B = 0\ C = 1$ will give $Y = 1$

42. **(C)** Concept AC power gain

$= \frac{\text{change inoutput power}}{\text{Change in power}}$

$= \frac{\Delta V_C \times \Delta i_C}{\Delta V_i \times \Delta i_b}$

$= \left(\frac{\Delta V_C}{\Delta V_i}\right) \times \left(\frac{\Delta i_C}{\Delta i_b}\right) = A_V \times \beta_{AC}$

Where , A_V is voltage gain and $(B)_{AC}$ is AC current gain. Also,

$A_V = b_{AC} \times$ resistance gain $\left(= \frac{R_0}{R_i}\right)$

Voltage gain = $\beta \times$ impedance gain

$\Rightarrow \quad 50 = \beta \times \frac{200}{100} \Rightarrow \beta = 25$

Also, power gain = $\beta^2 \times$ impedance gain

$= 25^2 \times \frac{200}{100} = 1250$

43. **(B)** Integrated circuits are miniature electronic circuit produced within a single crystal of a semiconductor such as silicon. They contain a million or so transistors and resistors or capacitors. They are widely used in memory circuits, micro computers, pocket calculators and electronic watches on account of their low cost and bulk, reliability into specific regions of the semiconductor crystals.

44. **(B)** p-type semiconductor are obtained by adding a small amount of trivalent impurity to a pure sample of semiconductor (Ge).
Majority charge carriers-holes
Minority charge carriers---electrons
n-type semiconductor are obtained by adding a small amount of pentavalent impudty to a pure sample of semiconductor (Ge). Majority charge carriers---electrons
The resistance of intrinsic semiconductors decreases with increase of temperature.

45. **(C)** In forward biasing of p-n junction, the positive terminal of the battery is connected to p-side and the deplection region becomes thin.

46. **(B)** When a small amount of antimony js added to germanium crystal, the crystal becomes n-type semiconductor, because antimoney is a pentavalent substrate.

47. **(C)** The symbols given in problem are
(i) OR (ii) AND (iii) NOT (iv) NAND

48. **(A)** From the given eaveforms, the following truth table can be made

Inputs		Output
A	B	C
0	0	0
0	0	1
1	1	1
0	1	1

This truth table obtained is or 'OR' gate. So, logic circuit tgate is OR gate

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49. **(B)** For using transistor as a switch, it is used in cut-off state and saturation state only.

50. **(C)** The four bonding electrons in the case of C lie in the second orbit, whereas in case of Si they lies in the third orbit, So loosely bounded valence elecf,rons are present in Si as compared to C.

51. **(D)** Current amplication factor

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

Collector resistance

$$\Delta I_C = \frac{2V}{2\times10^3\Omega} = 1\times10^{-3}\,A$$

Base current

$$\Delta I_B = \frac{V_B}{R_B} = \frac{V_B}{1\times10^3} = V_B\times10^{-3}$$

Given, $\beta = 100$

Now, $100 = \dfrac{10^{-3}}{V_B\times10^{-3}}$

$$V_B = \frac{1}{100}V = 10mV$$

52. **(C)** **(C)** $X = \overline{AB} = A.B$ (i.e. AND gate)

If the output of NAND gate is connected to the input of NOT gate (made from NAND gate by joining two inputs) from the given figure then we get back an AND gate.

53. **(A)** As $A_V = \beta\dfrac{R_L}{R_i}$ or $G = \left(\dfrac{\beta}{R_i}\right)R_L$

$$\Rightarrow G = g_m R_L \Rightarrow G \propto g_m \qquad \left[\because g_m\frac{\Delta I_C}{\Delta V_B} = \frac{\Delta I_C}{\Delta I_B R_i}\right]$$

$$\left[\because g_m\frac{\beta}{R_i}\right]$$

$$\therefore \quad \frac{G_2}{G_1} = \frac{g_{m_2}}{g_{m_1}} \quad G_2 = \frac{0.02}{0.03}\times G$$

So, voltage gain, $G_2 = \dfrac{2}{3}G$

54. **(C)** The n-type semi conductor can be produced by doping an impurity atom of valency 5 i.e. pentavalent atoms (phosphorus.) Holes are minority carriers in them.

55. **(D)** Barrier potential epends on all the three options given. Barrier potential depends on the material used to make p-n junction diode (whether it is Si or Ge). It also depends on amount of doping due to which the number of majority carriers will change. It also depends on temperture due to which the number of minority carriers will change.

56. **(A)** V-I characteristics of a solar cell is shown. Where, A represents open circuit voltage (i.e. I = 0, V = emf) and B shows short circuit voltage (i.e. I = I, V = 0)

57. **(D)** Input signal of a CE amplifer

$$V_{in} = 2\cos\left(15t + \frac{\pi}{3}\right)$$

Voltage gain $A_V = 150$

As CE amplifier gives phase difference of π between input and output signals.

So, $A_V = \dfrac{V_0}{V_{in}} \Rightarrow V_0 = A_V V_{in}$

$$V_0 = 150\times2\cos\left(15t + \frac{\pi}{3} + \pi\right)$$

$$V = 300\cos\left(15t + \frac{4\pi}{3}\right)$$

58. () The truth table for the given circuit is

A	B	y_1	y_2	$y = y_1 + y_2$
0	0	1	1	0
0	1	1	0	0
1	0	0	1	0
1	1	0	0	1

The truth table shows that both the inputs are high, then we are getting high value of ouptut otherwise zero. hence, the combination represents AND gate.

59. **(D)** As it is forward biased so it takes positive value. Hence, option **(D)** is correct.

60. **(C)** Output of the given circuit is given by

$$y = \overline{(AB)(C)}$$

When $A = B = C = 0$, $Y_1 = \overline{(0)(0)(0)} = \bar{0} = 1$

When $A = B = C = 1$, $Y_2 = \overline{(0)(1)} = 0$

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61. (A) We know that a diode only conducts in forward biased condition. In the given circuit, the diode D_1 will be in reverse bias, so it will block the current and diode D_2 will be in forward bias, so it will pass the current.

$$= \frac{V}{R_1 + R_3} = \frac{10}{2+2} = 2.5A$$

62. (B) Key Idea Voltage amplification is

$$A_V = \beta \frac{R_{out}}{R_{in}} = \frac{(V_{out})_{AC}}{(R_{in})_{AC}}$$

Given collector resistance $= R_{out} = 2k\Omega$

Current amplification factor, $\beta = 100$

Base resistance, $R_{in} = 1\ k\Omega$

Output signal voltage = 4V

Putting all the values in given equation, we get

$$A_V = \beta \frac{R_{out}}{R_{in}} = 100 \times \frac{2k\Omega}{1k\Omega} \Rightarrow A_V = 200$$

Now, $A_V = \frac{(V_{out})_{AC}}{(V_{in})_{AC}} = 200$

$$\Rightarrow \quad (V_{in})_{AC} = \frac{4}{200} = 20mV$$

63. (D) Given resistance across load, $R_L = 800\Omega$

Voltage drop across load, $V_L = 0.8V$

Input resistance of circuit, $R_i = 192\Omega$

Collector current is given by,

$$I_C = \frac{V_L}{R_L} = \frac{0.8}{800} = \frac{8}{8000} = 1mA$$

$\because$ Current amplification $= \frac{\text{Output current}}{\text{InputCurrent}}$

$$= \frac{I_C}{I_B} = 0.96 \Rightarrow I_B = \frac{1mA}{0.96}$$

$\because$ Voltage gain, $A_V = \frac{V_L}{V_{in}} = \frac{V_L}{I_B R_i} = \frac{0.8 \times 0.96}{10^{-3} \times 192} = 4$

$\Rightarrow \quad A_V = 4$

$$A_P = \frac{I_C^2 R_L}{I_B^2 R_i} = \left(\frac{I_C}{I_B}\right)^2 . \frac{R_L}{R_i}$$

$$= (0.96)^2 \times \frac{800}{192}$$

$$A_P = 3.84$$

64. (A) Let us assume that current through the diode is I. From the given condition

$$\because \quad I = \frac{V_A - V_B}{R} = \frac{4-(-6)}{1K\Omega} = \frac{10}{1 \times 10^3} = 10^{-2} A$$

65. (C) Consider the given figure, The resultant boolean expresion of the above logic circuit will be

$$Y = (a + B).C$$

Now, let us try with inputs A, B and C given in the options and lets see, which one of them will give output 1 at Y.

If $A = 0, B = 0\ C = 0$

$\Rightarrow \quad Y = (0+0).0 \Rightarrow Y = 0$

If $A = 1, B = 1, C = 0$

$\Rightarrow \quad Y = (1+1).0$

$\Rightarrow \quad Y = 1.0 \Rightarrow Y = 0$

If $A = 1, B = C = 1$

$\Rightarrow \quad Y = 1.0 \Rightarrow Y = 1.1 \Rightarrow Y = 1$

If $A = 0,\ B = 1, C = 0$

$\Rightarrow \quad Y = (0+1).0$

$\Rightarrow \quad Y = 1.0 \Rightarrow Y = 0$

So, we have seen that among the given options, only option **(C)** is the correct choice , i.e.

Output Y = 1 only when inputs A = 1, B = 0 and C=1.

66. (A) In the forward biasing of P-N junction, p side of junction diode is connected to higher potential and n side of junction diode is connected to lower potential. Hence the option **(A)** is correct answer.

67. (C) Collector current $i_C = \frac{V}{R} = \frac{3}{3 \times 10^3} = 10^{-3} A$

Now base current $i_B = \frac{i_C}{B} = \frac{10^{-3}}{100} = 10^{-5} A$

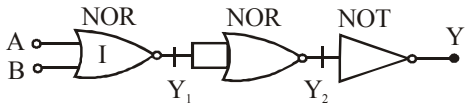
As, voltage $V_{in} = i_B R_B$

$\therefore \quad V_{in} = 10^{-5} \times 2\ 10^3$

$= 2 \times 10^{-2}$ volts

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68. **(C)** Truth table given network is



A	B	Y_1	Y_2	Y
0	0	1	0	1
1	0	0	1	0
0	1	0	1	0
1	1	0	1	0

Output Y network matches with that of NOR gate

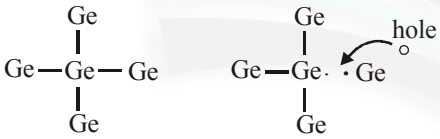
EXERCISE - 4

P-2 (AIIMS)

1. **(B)** **2.** **(B)**

3. **(A)** The depletion layer is the region at the junction of a diode which is devoid of ions. Therefore the potential barrier in the depletion layer is due to ions.

4. **(B)** An intrinsic germanium have four outer electrons which they use to form bonds with four neighbouring Ge atoms. Gallium, being from group III is having three outer electrons. So when we add gallium atoms into germanium, some gallium atoms have a chance to replace some of the germanium atoms. But with gallium, only three neighbouring Ge atoms can make bonds with Ga. The bond with the fourth neighbouring Ge atom is broken as Ga is having a shortage of one outer electron. The broken bond can be filled up by an electron when the electron gets enough energy to jump from the valence bond creating a hole out there. So, we get a p-type semiconductor.



5. **(C)** The output voltage is given by,

$$V_o = V_i \times \beta \times \frac{R_L}{R_{BE}}$$

Here, $V_i = 1$ mV, $\beta = 100$

$R_L = 10\ k\Omega$, $R_{BE} = 1\ k\Omega$

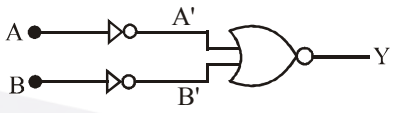
$$\therefore \quad V_o = 1\times10^{-3}\times100\times\frac{10}{1} = 1.0\ V.$$

6. **(C)** The resistivity of semiconductor decreases with increase in temperature and is given by

$$\rho_T = \rho_0 e^{E_g/k_B T}$$

where E_g is the energy gap, k_B is the Boltzmann constant, T is the absolute temperature.

7. **(C)** Truth table



A	B	A'	B'	Y
0	0	1	1	0
0	1	1	0	0
1	0	0	1	0
1	1	0	0	1

Output of this is same as that of AND gate. Alternatively The Boolean expression for the given logic gate is

$$Y = \overline{\bar{A} + \bar{B}}$$

Applying De Morgan's theorem $Y = \bar{\bar{A}} + \bar{\bar{B}} = A \cdot B$ This is the Boolean expression for the AND gate.

8. **(A)** For p-type semiconductor $n_h \approx N_A$

where N_A is the concentration of acceptor atoms. Also

$n_h n_e = n_i^2$, where

n_h = concentration of holes = 10^{21} atoms/m^3

n_i = intrinsic concentration = 10^{19} atoms/m^3

n_2 = concentration of electrons

$$\therefore \quad n_e = \frac{n_i^2}{n_h} = \frac{(10^{19})^2}{10^{21}} = 10^{17} \text{ atoms/m}^3$$

9. **(D)** NAND and NOR gate are used as universal gate.

10. **(B)** Current gain $= \dfrac{\Delta I_C}{\Delta I_B}$

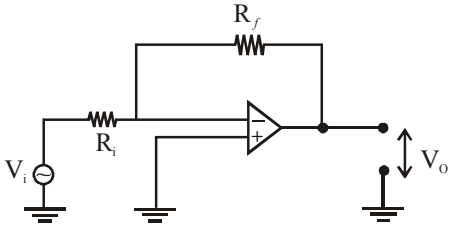
$$\therefore \quad \Delta I_B = \frac{1\,mA}{100} = 10^{-2}\ mA.$$

As $\Delta I_E = \Delta I_B + \Delta I_C = (0.01 + 1)\,mA = 1.01\ mA.$

11. **(A)** $\mu_e > \mu_n$ because electron is lighter than hole.

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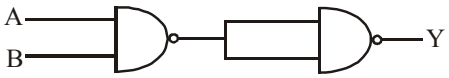
12. **(B)** This is an example of operational amplifier in this voltage gain.



$$A = \frac{V_o}{V_i} = \frac{R_f}{R_i} = \frac{100\,k\Omega}{1k\Omega} = 100.$$

13. **(B)** In reverse biased, the depletion region of p-n diode is increased.

14. **(A)** $Y = \overline{\overline{A \cdot B}} = A \cdot B$



The given circuit is AND gate.

15. **(B)** Voltage gain in dB $= 20 \log_{10} A_V$
$= 20 \log_{10}(1000) = 60$ dB.

16. **(D)** As LED is connected to a battery through a resistance in series.

The current flowing, 10 mA is the same.

The voltage drop across LED = 2 V

$\therefore$ As the battery has 6 V, the potential difference across R = 4 V.

$$\therefore \quad iR = 4\,V \Rightarrow R = \frac{4V}{10 \times 10^{-3} A} = 400\ \Omega.$$

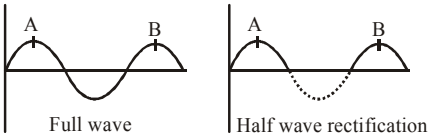
17. **(A)** Base to emitter in Si transistor is 1 V.

18. **(B)** Current gain $\beta = \frac{I_C}{I_B} = \frac{(120\ mA)}{(2\,mA)} = 60$

Power gain = Resistance gain $\times \beta^2 = (3) \times (60)^2 = 10800$

19. **(B)** Zener diode acts as an a voltage regulator.

20. **(B)**



Full wave Half wave rectification

In full wave a.c. or half rectified, the time interval between two peaks are the same. But in half wave rectification, the negative wave part is cut off. But as for frequency or the period, they will be the same as seen from the figures. Therefore, this also will be 50 cycles/second.

21. **(C)** A transistor is a semiconductor.

22. **(C)** A computer is working on a binary system of calculations based on zero and 1.

23. **(A)** $n_h = 10^{21}$ atoms/m^3

$n_i = 10^{19}$ atoms/m^3, $n_e = ?$

$n_e n_h = n_i^2$

$$n_e = \frac{n_i^2}{n_h} = \frac{(10^{19})^2}{10^{21}} = \frac{10^{38}}{10^{21}} = 10^{17}\ \text{atoms/m}^3.$$

24. **(B)** The forbidden gap in the energy band of Si = 1.1 eV.

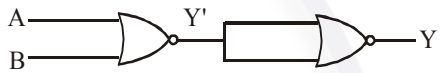
25. **(D)** By truth table, $Y = \overline{A + B}$. Therefore it is a NOR gate operation.

26. **(C)** If we make a truth table for the outputs given in the question. It matches with the truth table of an NOR gate.

$Y = \overline{A + B}$

A	B	Y (output)
1	0	0
0	1	0
0	0	1

27. **(A)**



Truth Table of this gate

A	B	Y'	Y
0	0	1	0
1	0	0	1
0	1	0	1
1	1	0	1

$Y' = A + B = A \cdot B$

and $Y = Y' = A \cdot B = A + B = A + B$

This is the boolean expression for the OR gate.

28. **(B)** The direction of electric field is from N-side to P-side in PN junction diode.

29. **(B)** In an unbiased PN Junction diode current flows due to minority charge carriers (electron in the P-region and holes in the N-region).

30. **(C)** In the circuit, the zener diode is used as power regular therefore,

$P = VI$

$= 12 \times 0.05 = 0.6$ W.

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31. **(A)** Here, $I_B = 5\ \mu A = 5 \times 10^{-6}\ A$

$b = 100$

$R_L = 10\ k\Omega = 10 \times 10^3\ \Omega$

As $\beta = \dfrac{I_C}{I_B}$

or $I_C = (100)(5 \times 10^{-6}\ A) = 5 \times 10^{-4}\ A$

The voltage across collector emitter is

$V_{CE} = R_L I_C = (10 \times 10^3\ \Omega)\,(5 \times 10^{-4}\ A) = 5\ V$

32. **(C)**

33. **(A)** Using, $\sigma = n_e q \mu_e$

Here, $\sigma = 500$ mho/m

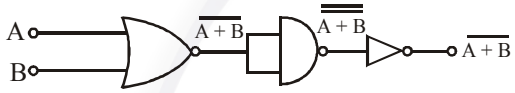
$e = 1.6 \times 10^{-19}\ C$

$\mu_e = 0.4\ m^2\ V^{-1}\ s^{-1}$

$\therefore \quad n_e = \dfrac{500}{1.6 \times 10^{-19} \times 0.4}$

$= 7.8 \times 10^{21} \simeq 8 \times 10^{21}\ m^{-3}$

34. **(C)** From circuit diagram,



Output, $Y = \overline{A + B}$

Thus, circuit behave like NOR gate.

35. **(C)**

A	B	Y_1	Y_2	$Y = \overline{Y_1 + Y_2}$
0	0	1	1	0
0	1	1	0	0
1	0	0	1	0
1	1	0	0	1

According to truth table,

$Y = A \cdot B$, the given combination of logic gates represents AND gate.

36. **(D)**

37. **(A)** For triode valve, amplification factor,

$\mu = r_p \times g_m$

Here, $r_p = 13 \times 10^6\ \Omega$, $\mu = 21$, $g_m = ?$

$\therefore \quad g_m = \dfrac{\mu}{r_p} = \dfrac{21}{13 \times 10^6} = 1.6 \times 10^{-6}$ mho

38. **(B)** $\alpha = \dfrac{I_C}{I_E}$

$\therefore \quad IC = \alpha I_E = 0.96 \times 7.2 = 6.91$ mA

Now, $I_E = I_C + I_B$

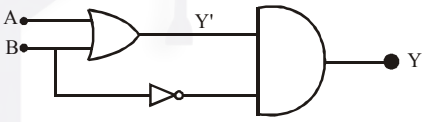
$\therefore \quad I_B = I_E - I_C = 7.2 - 6.91 = 0.29$ mA

39. **(A)** The maximum permissible current is

$I_{Z_{max}} = \dfrac{P}{V_Z} = \dfrac{364 \times 10^{-3}}{9.1} = 40$ mA.

40. **(A)** Voltage gain, $A_V = \beta \times \dfrac{R_o}{R_i} = 50 \times \dfrac{5}{1} = 250$

41. **(A)**



Here $Y' = A + B$

and $Y = Y' \cdot \overline{B} = (A + B) \cdot \overline{B}$

42. **(C)** During reverse biasing, the depletion layer widens, and so there is more resistance for an electron or a hole to cross that layer to conduct current.

43. **(D)** With the increase of temperature, the average energy exchanged in a collision increases and so more valence electrons can cross the energy gap, thereby increasing the electron-hole pairs. As in a semiconductor, conduction occurs mainly through electron-hole pairs, so conductivity increases with increase of temperature. Which in turn implies that the resistivity of a semiconductor decreases with rise in temperature.

44. **(C)** The base is lightly doped and very thin, this constructional feature is key of transistor action due to which only few holes (less than 5%) are able to combine with the electrons in base region. Most of the holes coming from the emitter are able to diffuse through the base region to the collector region.

45. **(B)** Input impedance of common emitter configuration

$= \left.\dfrac{\Delta V_{BE}}{\Delta i_B}\right|_{V_{CE}=\text{constant}}$ where ΔV_{BE} = voltage across base and emitter, DiB = base current which is order of few microampere.

Thus input impedance of common emitter is low.

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46. **(A)** In optical communication, a semiconductor base laser (diode laser) is used to generate analog signals or digital pulses for transmission through optical fibres. The advantages of diode lasers are their small size and low power input.

47. **(D)** In diode the output is in same phase with the input therefore it cannot be used to build NOT gate.

48. **(A)** According to law of mass action, $n_i^2 = n_e n_h$ In p-type semiconductor $n_h > n_e$.

49. **(C)** A good amplifier stage is one which has high input resistance and low output resistance. A transistor is CB configuration has a very low resistance ($\simeq 20\ \Omega$) and a very high output resistance ($\simeq 2\ M\Omega$). It is just the reverse of what is required. The CE configuration is better, its input resistance is about 2 $k\Omega$ and output resistance about 10$k\Omega$. Although input resistance of CE is not very high but it still prefers better amplifier.

50. **(C)** The common base configuration of npn transistor is used for voltage amplification is very small.

The collector is reverse biased for voltage amplification. The reason given has not mentioned that it is voltage amplification.

51. **(A)**

52. **(A)** NAND and NOR gates are treated as universal gates because all other basic gates AND gate OR gate and NOT gate can be constructed using only NAND gate (or NOR gate).

53. **(B)**

54. **(B)** Photo-conductive cell is based on the principle that when light is incident on some semiconductor, its electrical resistance is reduced. Such cells are used in solar batteries.

55. **(C)** We know that

$$\alpha = \frac{\Delta i_C}{\Delta i_E} \text{ and } \beta = \frac{\Delta i_C}{\Delta i_B}$$

$$\text{Also } \beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = 49$$

$$\therefore \quad \text{Voltage gain} = \beta = \frac{R_2}{R_1} = 49 \times 1000 = 49 \times 10^3$$

56. **(A)** Most amplifiers use the common emitter circuit configuration because the cricuit offers both current and voltage gains resulting in much higher power gain that can be obtained by a common-base amplifier. The other consideration for the use of the common-emitter amplifier is that its input resistance is higher and of the order of load resistance.

57. **(A)**

58. **(C)** As conductivity of an intrinsic semiconductor is less than that of a lightly doped p-type

59. **(A)**

60. **(B)** The transistor can be used as a switch, amplifier and oscillator.

61. **(C)** The reason is not true. The junction of a transistor in working order has low resistance, when forward biased and it has high resistance, when reverse biased. The assertion, however is true.

62. **(A)**

63. **(C)** Output of NOT gate is out of phase with its input. The logic NOT cannot be designed using a diode.

64. **(C)** The output impedance is higher than the input impedance in a common emitter transistor amplifier.

MOCK TEST

1. **(C)** Number density of atoms in silicon specimen = $5 \times 10^{28}\ atom/m^3 = 5 \times 10^{22}\ atom/cm^3$

Since one atom of indium is doped in 5×10^7 *Si* atom. So number of indium atoms doped per cm^3 of silicon.

$$n = \frac{5 \times 10^{22}}{5 \times 10^7} = 1 \times 10^{15}\ atom/cm^3.$$

2. **(A)** The probability of electrons to be found in the conduction band of an intrinsic semiconductor

$$P(E) = \frac{1}{1 + e^{\frac{(E-E_F)}{kT}}}$$; where k = Boltzmann's constant

Hence, at a finite temperature, the probability decreases exponentially with increasing band gap.

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3. **(C)** When donor impurity (+5 valence) added to a pure silicon (+4 valence), the +5 valence donor atom sits in the place of + 4 valence silicon atom. So it has a net additional + 1 electronic charge. The four valence electron form covalent bond and get fixed in the lattice. The fifth electron (with net – 1 electronic charge) can be approximated to revolve around + 1 additional charge. The situation is like the hydrogen atom for which energy is given by $E = -\frac{13.6}{n^2} eV$. For the case of hydrogen, the permittivity was taken as ε_0. However, if the medium has a permittivity ε_r, relative to ε_0, then

$$E = -\frac{13.6}{\varepsilon_r^2 n^2} eV$$

For Si, $\varepsilon_r = 12$ and for $n = 1$, $E \simeq 0.1\, eV$

4. **(C)** The forward current

$$i = i_s\,(e^{eV/kT} - 1) = 10^{-5}\left[e^{\frac{1.6\times10^{-19}\times0.2}{1.4\times10^{-23}\times300}} - 1\right]$$

$$= 10^{-5}\,[2038.6 - 1] = 20.376\times10^{-3}\,A$$

5. **(D)** At 0 K, a semiconductor becomes a perfect insulator. Therefore at 0 K, if some potential difference is applied across an insulator or a semiconductor, current is zero. But a conductor will become a superconductor at 0 K. Therefore, current will be infinite. In reverse biasing at 300 K through a P-N junction diode, a small finite current flows due to minority charge carriers.

6. **(A)** Since diode in upper branch is forward biased and in lower branch is reversed biased. So current through circuit $i = \frac{V}{R + r_d}$; here r_d = diode resistance in forward biasing = 0

$$i = \frac{V}{R} = \frac{2}{10} = 0.2A.$$

7. **(A)** The voltage drop across resistance = 8 – 0.5 = 7.5 V

$$\therefore \quad \text{Current } i = \frac{7.5}{2.2\times10^3} = 3.4\,mA$$

8. **(C)** $E = \frac{hc}{\lambda}$

$$\Rightarrow \lambda = \frac{hc}{E} = \frac{6.6\times10^{-34}\times3\times10^8}{57\times10^{-3}\times1.6\times10^{-19}} = 217100\text{Å}.$$

9. **(B)** The diode in lower branch is forward biased and diode in upper branch is reverse biased

$$\therefore \quad i = \frac{5}{20+30} = \frac{5}{50} A.$$

10. **(B)** The current through circuit

$$i = \frac{P}{V} = \frac{100\times10^{-3}}{0.5} = 0.2A$$

$\therefore$ voltage drop across resistance = 1.5 – 0.5 = 1 V

$$\Rightarrow \quad R = \frac{1}{0.2} = 5\,\Omega.$$

11. **(D)** In common emitter configuration current gain

$$A_i = \frac{-h_{fe}}{1 + h_{oe}R_L} = \frac{-50}{1 + 25\times10^{-6}\times10^3} = -\,48.78.$$

12. **(C)** Voltage gain $= \frac{\text{Output voltage}}{\text{Input voltage}}$

$\Rightarrow V_{out} = V_{in} \times$ Voltage gain

$\Rightarrow V_{out} = V_{in} \times$ Current gain $\times$ Resistance gain

$$= V_{in} \times \beta \times \frac{R_L}{R_{BE}} = 10^{-3} \times 100 \times \frac{10}{1} = 1V.$$

13. **(A)** $n_e = 8\times10^{18}/m^3$, $n_h = 5\times10^{18}/m^3$

$$\mu_e = 2.3\frac{m^2}{volt - sec}, \quad \mu_h = 0.01\frac{m^2}{volt - sec}$$

$\because n_e > n_h$ so semiconductor is N-type

Also conductivity

$$\sigma = \frac{1}{\text{Resistivity}\,(\rho)} = e(n_e\mu_e + n_h\mu_h)$$

$$\Rightarrow \frac{1}{\rho} = 1.6\times10^{-19}[8\times10^{18}\times2.3 + 5\times10^{18}\times0.01]$$

$$\Rightarrow \rho = 0.34\ \Omega\text{-}m.$$

14. **(B)** $V_{rms} = \frac{V_0}{2} = \frac{200}{2} = 100V$

15. **(A)** At knee point voltage across the diode is 0.7V.

Hence voltage across resistance R is 5 – 0.7 = 4.3 V.

$\Rightarrow$ using $V = iR \Rightarrow 4.3 = 1\times10^{-3}\times R \Rightarrow R = 4.3\ k\Omega$.

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16. (D) In positive half cycle one diode is in forward biasing and other is in reverse biasing while in negative half cycle their polarity reverses, and direction of current is opposite through R for positive and negative half cycles so out put is not rectified.

Since R_1 and R_2 are different hence the peaks during positive half and negative half of the input signal will be different.

17. (B) In half wave rectifier $V_{dc} = \frac{V_0}{\pi} = \frac{10}{\pi}$

18. (A) In common base mode $\alpha = 0.98$, $R = 5\ k\Omega$, $R_{in} = 70\Omega$

$\therefore$ voltage gain $A_v = \alpha \times \frac{R}{R_{in}} = 0.98 \times \frac{5\times10^3}{70} = 70$

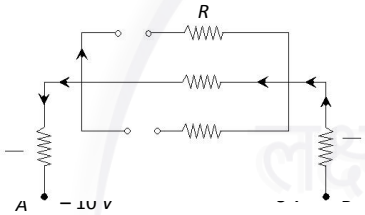
Power gain = Current gain × Voltage gain

$= 0.98 \times 70 = 68.6$

19. (A) $r_n = \varepsilon_r\left(\frac{n^2}{Z}\right)a_o = 12 \times \frac{(5^2)}{15} \times 0.53 = 10.6$ Å.

20. (C) (i) $V_A = -10V$ and $V_B = -5V$

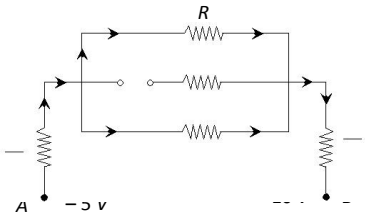
Diodes D_1 and D_3 are reveres biased and D_2 is forward biased.



$\Rightarrow R_{AB} = R + \frac{R}{4} + \frac{R}{4} = \frac{3}{2}R$

(ii) When $V_A = -5V$ and $V_B = -10V$

Diodes D_2 is reverse biased D_1 and D_3 are forward biased



$\Rightarrow R_{AB} = \frac{R}{4} + \frac{R}{2} + \frac{R}{4} = R.$

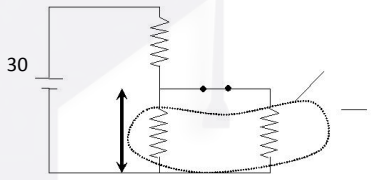
(iii) In this case equivalent resistance between A and B is also R.

Hence (ii) = (iii) < (i).

21. (B) According to the given polarity, diode D_1 is forward biased while D-$_2$ is reverse biased. Hence current will pass through D_1 only.

So current $i = \frac{6}{(150+50+100)} = 0.02\,A$

22. (A) Diode is in forwards biasing hence the circuit can be redrawn as follows



$V_{AB} = \frac{30}{(10+5)} \times 5 = 10\,V$

23. (D) The diode D will conduct for positive half cycle of *a.c.* supply because this is forward biased. For negative half cycle of *a.c.* supply, this is reverse biased and does not conduct. So out put would be half wave rectified and for half wave rectified out put

$V_{rms} = \frac{V_0}{2} = \frac{200\sqrt{2}}{2} = \frac{200}{\sqrt{2}}$

24. (D)

$\sigma = ne(\mu_e + \mu_h) = 2\times10^{19} \times 1.6\times10^{-19}(0.36+0.14)$

$= 1.6\,(\Omega\text{-m})^{-1}$

$R = \rho\frac{l}{A} = \frac{1}{\sigma A} = \frac{0.5\times10^{-3}}{1.6\times10^{-4}} = \frac{25}{8}\Omega$

$\therefore \quad i = \frac{V}{R} = \frac{2}{25/8} = \frac{16}{25}A = 0.64\,A$

25. (D) In diode the output is in same phase with the input therefore it cannot be used to built NOT gate.

26. (A) According to law of mass action, $n_i^2 = n_e n_h$. In intrinsic semiconductors $n_i = n_e = n_h$ and for P-type semiconductor n_e would be less than n_i, since n_h is necessarily more than n_i.

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27. (C) In common emitter transistor amplifier current gain $\beta > 1$, so output current > Input current, hence assertion is correct.

Also, input circuit has low resistance due to forward biasing to emitter base junction, hence reason is false.

28. (A) Input impedance of common emitter configuration

$$= \frac{\Delta V_{BE}}{\Delta i_B}\Big|_{V_{CE}=\text{constant}}$$

where ΔV_{BE} = voltage across base and emitter (base emitter region is forward biased)

Δi_B = base current which is order of few microampere.

Thus input impedance of common emitter is low.

29. (D) Resistivity of semiconductors decreases with temperature. The atoms of a semiconductor vibrate with larger amplitudes at higher temperatures there by increasing it's conductivity not resistivity.

30. (A) In semiconductors the energy gap between conduction band and valence band is small ($\approx 1\ eV$). Due to temperature rise, electron in the valence band gained thermal energy and may jump across the small energy gap, goes in to the conduction band. Thus conductivity increases and hence resistance decreases.

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CHAPTER 11

ELECTROMAGNETIC WAVES

I happen to have discovered a direct relation between magnetism and light, also electricity and light, and the field it opens is so large and I think rich.

"MICHAELFARADAY"

INTRODUCTION

We have seen that in certain situations light may be described as a wave. The wave equation for light propagating in x-direction in vacuum may be written ass

$$E = E_0 \sin \omega(t - x/c)$$

where E is the sinusoidally varying electric field at the position x at time t. The constant c is the speed of light in vacuum. The electric field E is in the Y-Z plane, that is perpendicular to the direction of propagation.

There is also a sinusoidally varying magnetic field associated with the electric field when light propagates. This magnetic is perpendicular to the direction of propagation as well as to the electric field E. It is given by

$$B = B_0 \sin \omega(t - x/c)$$

Such a combination of mutually perpendicular electric and magnetic fields is referred to as an electromagnetic wave in vacuum. The theory of electromagnetic wave was mainly developed by Maxwell around 1864.

DISPLACEMENT CURRENT

We have seen that an electrical current produces a magnetic field around it. Maxwell showed that for logical consistency, a changing electric field must also produce a magnetic field. This effect is of great importance because it explains the existence of radio waves, gamma rays and visible light, as well as all other forms of electromagnetic waves.

To see how a changing electric field gives rise to a magnetic field, let us consider the process of charging of a capacitor and apply Ampere's circuital law given by

$$\oint B.dl = \mu_0 i(t) \qquad \text{..... (1)}$$

to find magnetic field at a point outside the capacitor. Figure 1 (a) shows a parallel plate capacitor C which is a part of circuit through which a time-dependent current i (t) flows. Let us find the magnetic field at a point such as P, in a region outside the parallel plate capacitor. For this, we consider a plane circular loop of radius r whose plane is perpendicular to the direction of the current - Carrying wire, and which is centered symmetrically with respect to the wire. From symmetry, the magnetic field is directed along the circumference of the circular loop and is the same in magnitude at all points on the loop so that if B is the magnitude of the field, the left side of equation. (8.1) is B (2πr). So we have

$$B(2\pi r) = \mu_0 i(t) \qquad \text{..... (2)}$$

Now, consider a different surface, which has the same boundary. This is a pot like surface (Fig.1 (b)] which nowhere touches the current, but has its bottom between the capacitor plates; its mouth is the circular loop mentioned above. Another such surface is shaped like a tiffin box (without the lid) [Fig. 1 (c)]. On applying Ampere's circuital law to such surfaces with the same perimeter, we find that the left hand side of Eq. (1) has not changed but the right hand side is zero and not $\mu_0 i$, since no current passes through the surface of Fig 1 (b) and (c). So we have a contradiction; calculated one way, there is a magnetic field at a point P; calculated another way, the magnetic field at P is zero. Since the contradiction arises from our use of Ampere's circuital law, this law must be missing something. The missing term must be such that one gets the same magnetic field at point P, no matter what surface is used.

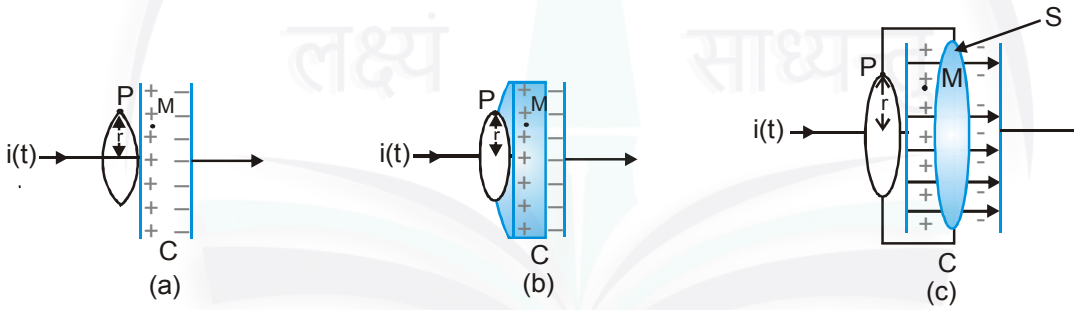


Figure 1

We can actually guess the missing term by looking carefully at Fig. 1 (c). Is there anything passing through the surface S between the plates of the capacitor ? Yes, of course, the electric field . If the plates of the capacitor have an area A, and a total charge Q, the magnitude of the electric field **E** between the plates is $(Q/A)/\varepsilon_0$. The field is perpendicular to the surface S of Fig.1 (c). It has the same magnitude over the area A of the capacitor plates, and vanishes outside it. So what is the electric flux Φ_E through the surface S ? Using Gauss's law, it is

$$\Phi_E = |E|\, A = \frac{1}{\varepsilon_0}\,\frac{Q}{A}\,A = \frac{Q}{\varepsilon_0} \qquad \text{..... (3)}$$

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Now if the charge Q on the capacitor plates changes with time, there is a current i = (dQ / dt), so that using Eq. (3), we have

$$\frac{d\Phi_E}{dt} = \frac{d}{dt}\left(\frac{Q}{\varepsilon_0}\right) = \frac{1}{\varepsilon_0}\frac{dQ}{dt}$$

This implies that for consistency,

$$\varepsilon_0\left(\frac{d\Phi_E}{dt}\right) = i \qquad \text{..... (4)}$$

This is the missing term in Ampere's circuital law. If we generalis this law by adding to the total current carried by conductors through the surface, another term which is ε_0 times the rate of change of electric flux through the same surface, the total has the same value of current i for all surfaces. If this is done, there is no contradiction in the value of B obtained anywhere using the generalized Ampere's law. B at the point P is non-zero no matter which surface is used for calculating it. B at a point P outside the plates [Fig.1 (a)] is the same as at a point M just inside, as it should be. The current carried by conductors due to flow of charges is called conduction current. The current, given by Eq. (4), is a new term, and is due to changing electric field (or electric displacement). It is therefore called displacement current or Maxwell's displacement current. Figure 2 shows the electric and magnetic fields inside the parallel plates capacitor discussed above. The generalisation made by Maxwell then is the following. The source of a magnetic field is not just the conduction electric current due to flowing charges, but also the time rate of change of electric field. More precisely, the total current i is the sum of the conduction current denoted by i_C, and the displacement current denoted by i_d ($= \varepsilon_0 (d\Phi_E)/ dt$). So we have

$$i = i_e + i_d = i_c + \varepsilon_0 \frac{d\Phi_E}{dt} \qquad \text{..... (5)}$$

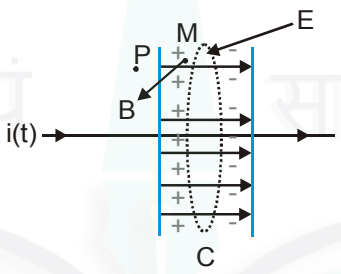


Figure 2 (a)

In explicit terms, this means that outside the capacitor plates, we have only conduction current $i_c = i$, and no displacement current, i.e., $i_d = 0$. On the other hand, inside the capacitor, there is no conduction current, i.e., $i_c = 0$, and there is only displacement current, so that $i_d = i$.

The generalised (and correct) Ampere's circuital law has the same form as Eq, (1), with one difference: " the total current passing through any surface of which the closed loop is the perimeter" is the sum of the conduction current and the displacement current The generalised law is

$$\oint B \bullet d\ell = \mu_0 i_c + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} \qquad \text{..... (6)}$$

and is known as Ampere-Maxwell law.

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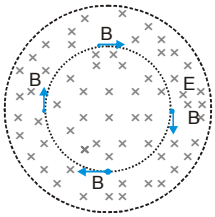


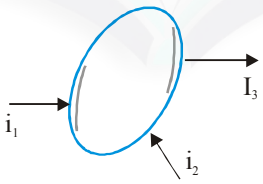
Figure 2(b)

In all respects, the displacement current has the same physical effects as the conduction current. In some cases, for example, steady electric fields in a conducting wire, the displacement current may be zero since the electric field E does not change with time. In other cases, for example, the charging capacitor above, both conduction and displacement currents may be present in different regions of space. In most of the cases, they both may be present in the same region of space, as there exist no perfectly conducting or perfectly insulating medium. Most interestingly, there may be large regions of space where there is no conduction current, but there is only a displacement current due to time-varying electric fields. In such a region, we expect a magnetic field, though there is no (conduction) current source nearby. The prediction of such a displacement current can be verified experimentally. For example, a magnetic field (say at point M) between the plates of the capacitor in Fig. 2 (a) can be measured and is seen to be the same as that just outside (at P).

The displacement current has (literally) far reaching consequences. One thing we immediately notice is that the laws of electricity and magnetism are now more symmetrical Faraday's law of induction states that there is an induced emf equal to the rate of change of magnetic flux. Now, since the emf between two points 1 and 2 is the work done per unit charge in taking it from 1 to 2, the existence of an emf implies the existence of an electric field. So,we can rephrase Faraday's law of electromagnetic induction by saying that a magnetic field, changing with time, gives rise to an electric field. Then, the fact that an electric field changing with time gives rise to a magnetic field, is the symmetrical counterpart, and is a consequence of the displacement current being a source of a magnetic field. Thus, time-dependent electric and magnetic field give rise to each other. Faraday's law of electromagnetic induction and Ampere-Maxwell law give a quantitative expression of this statement, with the current being the total current as in Eq. **(5)**. One very important consequence of this symmetry is the existence of electromagnetic waves, which we discuss qualitatively in the next section.

CONTINUITY OF ELECTRIC CURRENT

Consider a closed surface enclosing a volume (in figure). Suppose charges are entering into the volume and are also leaving it. If no charge is accumulated inside the volume, the total charge going into the volume in any time is equal to the total charge leaving it, during the same time. The conduction current is then continuous.



If charge is accumulated inside the volume, this continuity breaks. However, if we consider the conduction current plus the displacement current, the total current is still still continuous. Any loss of conduction current i_c appears as displacement current i_d. This can be shown as follows.

Suppose a total conduction current i_1 goes into the volume and a total conduction current i_2 goes out of it. The charge goiing into the volume in a time dt is i_1 dt and that coming out is i_2 dt. The charge accumulated inside the volume is

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$$d(q_{inside}) = i_1 dt - i_2 dt$$

or, $$\frac{d}{dt}(q_{inside}) = i_1 - i_2 \quad \text{..... (i)}$$

From Gayss's law,

$$\Phi_1 = \oint \vec{E}.\overrightarrow{dS} = \frac{q_{inside}}{\varepsilon_0}$$

or, $$\varepsilon_0 \frac{d\Phi_E}{dt} = \frac{d}{dt}(q_{inside})$$

Comparing with (i),

$$i_i - i_2 = i_d$$

$$i_1 = i_2 + i_d$$

Thus, the total current (conduction + displacement) going into the volume is equal to the total current counting out of it.

MAXWELL'S EQUATIONS AND PLANE ELECTROMAGNETIC WAVES

The whole subject of electricity and magnetism may be described mathematically with the help of four fundamental equations :

Gauss's law for electricity $$\Phi_1 = \oint \vec{E}.\overrightarrow{dS} = \frac{q}{\varepsilon_0}$$

Gauss's law for magnetism $$\Phi_1 = \oint \vec{B}.\overrightarrow{dS} = 0$$

Faraday's law $$\Phi_1 = \oint \vec{E}.\overrightarrow{dl} = -\frac{d\Phi_E}{dt}$$

Ampere's law $$\Phi_1 = \oint \vec{B}.\overrightarrow{dl} = \mu_0 i + \varepsilon_0 \mu_0 \frac{d\Phi_E}{dt}$$

These equations are correctively known as Maxwell's equations.

In vacuum there are no charges and hence no conduction currents. Faraday's law and Ampere's law take the form

$$\Phi_1 = \oint \vec{B}.\overrightarrow{dl} = -\frac{d\Phi_B}{dt} \quad \text{..... (i)}$$

and $$\Phi_1 = \oint \vec{B}.\overrightarrow{dl} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} \quad \text{..... (ii)}$$

respectively.

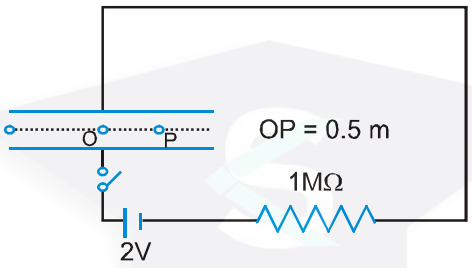
Let us check if these equations are satisfied by a plane electromagnetic wave given by

and $$\left.\begin{aligned} E = E_y &= E_0 \sin \omega(t - x/c) \\ B = B_2 &= B_0 \sin \omega(t - x/c) \end{aligned}\right] \quad \text{..... (7)}$$

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The wave described above propagates along the positive x-direction, the electric field remains along the y-direction and the magnetic field along the z-direction. The magnitudes of the fields oscillate between $\pm E_0$ and $\pm B_0$ respectively. It is a linearly polarized light, polarized along the y-axis.

Ex. A parallel plate capacitor with circular plates of radius 1 m has a capacitance of 1 nF. At t = 0, it is connected for charging in series with a resistor R = 1 M Ω across a 2 V battery (as shown). Calculate the magnetic field at a point P. halfway between the centre and the periphery of the plates, after $t = 10^{-3}$ s. (The charge on the capacitor at time t is $q(t) = CV[1 - \exp(-t/\tau)]$, where the time constant τ is equal to CR)



Sol. The time constant of the CR circuit is $\tau = CR = 10^{-3}$ s. Then we have

$$q(t) = CV[1 - \exp(-t/\tau)]$$
$$= 2 \times 10^{-9}[1 - \exp(-t/10^{-3})]$$

The electric field in between the plates at time t is

$$E = \frac{q(t)}{\varepsilon_0 A} = \frac{q}{\pi\varepsilon_0}; A = \pi(1)^2\ m^2 = \text{area of the plates.}$$

Consider now a circular loop of radius (1 / 2) m parallel to the plates passing through P. The magnetic field **B** at all points on the loop is along the loop and of the same value. The flux Φ_E through this loop is

$\Phi_E = E \times$ area of the loop

$$= E \times \pi \times \left(\frac{1}{2}\right)^2 = \frac{\pi E}{4} = \frac{q}{4\varepsilon_0}$$

The displacement current

$$i_d = \varepsilon_0 \frac{d\Phi_E}{dt} = \frac{1}{4}\frac{dq}{dt} = 0.5 \times 10^{-6} \exp(-1)$$

at $t = 10^{-3}$ s. Now, applying Ampere-Maxwell law to the loop, we get

$$B \times 2\pi \times \left(\frac{1}{2}\right) = \mu_0(i_c + i_d) = \mu_0(0 + i_d) = 0.5 \times 10^{-6}\ \mu_0 \exp(-1)$$

or, $B = 0.74 \times 10^{-3}$ T

Sources of Electromagnetic Waves

How are electromagnetic waves produced ? Neither stationary charges Nor charges in uniform motion (steady currents) can be sources of electromagnetic waves. The former produces only electrostatic field, while the latter produces magnetic fields that, however, do not vary with time. It is an important result of Maxwell's theory that accelerated charges radiate electromagnetic waves. The proof of this basic result is beyond the scope of this book,

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but we can accept it on the basis of rough qualitative reasoning. Consider a charge oscillating with some frequency. (An oscillating charge is an example of accelerating charge.) This produces an oscillating electric field in space, which produces an oscillating magnetic field, which in turn, is a source of oscillating electric field, and so on. The oscillating electric and magnetic fields thus regenerate each other as the waves propagates through the space. The frequency of electromagnetic wave naturally equals the frequency of oscillation of the charge. The energy associated with the propagating wave comes at the expense of the energy of the source-the accelerated charge.

Nature of Electromagnetic Wave

It can be shown from Maxwell's equations that electric and magnetic field in an electromagnetic wave are perpendicular to each other and to the direction of propagation. It appears reasonable, say from our discussion of the displacement current. Consider Fig 2. The electric field inside the plates of the capacitor is directed perpendicular to the plates. The magnetic field this gives rise to via the displacement current is along the perimeter of a circle parallel to the capacitor plates. So B and E are perpendicular in this case. This is a general feature.

In Fig 4, we show a typical example of a plane electromagnetic wave propagating along the z direction (the fields are shown as a function of the z coordinate, at a given time t). The electric field E_x is along the x-axis, and varies sinusoidally with z, at a given time. The magnetic field B_y is along the y-axis and again varies sinusoidally with z. The electric and magnetic fields E_x and B_y are perpendicular to each other, and to the direction z of propagation. We can write E_x and B_y as follows :

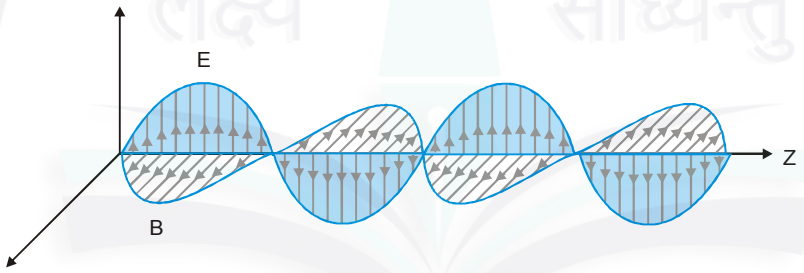
$$E_x = E_0 \sin(kz - \omega t) \quad \text{..... Eq. 7(a)}$$

$$B_y = B_0 \sin(kz - \omega t) \quad \text{..... Eq. 7 (b)}$$

Here k is related to the wave length λ of the wave by the usual equation

$$k = \frac{2\pi}{\lambda} \quad \text{..... Eq. 8}$$

and ω is the angular frequency. k is the magnitude of the wave vector (or propagation vector) k and its irection describes the direction of propagation of the wave. The speed of propagation of the wave is (ω/k). Using Eqs. [7 (a) and (b)] for E_x and B_y and Maxwells equation we finds that



$\omega = cK$, where, $c = 1/\sqrt{\mu_0 \varepsilon_0}$ .....Eq.9 (a)

The relation $\omega = cK$ is the standard one for waves. This relation is often written in terms of frequency. ν ($=\omega/2\pi$) and wavelength. λ ($= 2\pi/k$) as

$$2\pi\nu = c\left(\frac{2\pi}{\lambda}\right) \text{ or}$$

$$\nu\lambda = c \quad \text{.....Eq. 9(b)}$$

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It is also seen from Maxwell's equations that the magnitude of the electric and the magnetic fields in an electromagnetic waves are related as $B_0 = E_0 / c$. Electromagnetic waves are self-sustaining oscillations of electric and magnetic fields in free space, or vacuum. They differ from all the other wave we have studied so far, in respect that no material medium is involved in the vibrations of the electric and magnetic fields. Sound waves in air are longitudinal waves of compression and rarefaction. Transverse wave on water surface spreads horizontally and radially out wards. Transverse elastic (sound) waves can also propagate in a solid, which is rigid and that resists shear. Scientists in the nineteenth century were so much used to this mechanical picture that they thought that there must be some medium pervading all space and all matter, which responds to electric and magnetic fields just as any elastic medium does. They called this medium ether. We now accept that no such physical medium is needed. The famous experiment of Michelson and Morley in 1887 demolished conclusively the hypothesis of ether. Electric and magnetic fields oscillating in space and time, can sustain each other in vacuum.

But what if a material medium is actually there ? We known that light, and electromagnetic wave, does propagate through glass, for example. We have seen earlier that the total electric and magnetic fields inside a medium are described in terms of a permittivity ε and a magnetic permeability μ (These describe the factors by which the total fields differ from the external fields). These replace ε_0 and μ_0 in the description to electric and magnetic fields in maxwell's equation with the result that in a material medium of permittivity ε and magnetic permeability μ. The velocity of light becomes,

$$\upsilon = \frac{1}{\sqrt{\mu\varepsilon}} \qquad \text{.....(10)}$$

Thus, the velocity of light depends on electric and magnetic properties of the medium. The velocity of electromagnetic waves in free space or vacuum is an important fundamental constant. It has been shown by experiments on electromagnetic waves of different wavelength that this velocity is the same (independent of wavelength) to within a few metres per second, out of a value of 3×10^8 m/s. The constancy of the velocity of em waves in vacuum is so strongly supported by experiments and the actual value is so well known now that this is used to define a standard of length Hertz not only showed the existence of electromagnetic waves, but also that the light waves, could be diffracted, refracted and polarised.Thus, he conclusively established the wave nature of the radiation. Further, he produced stationary electromagnetic waves and determined their wavelength by measuring the distance between two successive nodes. Since the frequency of the wave was known (being equal to the frequency of the oscillator), he obtained the speed of the wave using the formula

$v = \nu\lambda$ and found that the waves travelled with the same speed as the speed of light.

Do electromagnetic waves carry energy and momentum like other waves ? Yes, they do. In a region of free space with electric field E, there is an energy density ($\varepsilon_0 E^2/ 2$). Similarly, as seen associated with a magnetic field B is a magnetic energy density ($B^2 / 2\mu_0$). As electromagnetic wave contains both electric and magnetic fields, there is a non-zero energy density associated with it. Now consider a plane perpendicular to the direction of propagation of the electromagnetic wave (Fig. 4). If there are, on this plane, electric charges the will be set and sustained in motion by electric and magnetic fields of the electromagnetic wave. The charges thus acquire energy and momentum from the waves. This just illustrates the fact that an electromagnetic wave (like other waves.) carries energy and momentum. Since it carries momentum, an electromagnetic wave also exerts pressure called radiation pressure. If the total energy transferred to a surface in time t is U. It can be shown that the magnitude of the total momentum delivered to this surface (for complete absorption) is,

$$p = \frac{U}{c} \qquad \text{..... (11)}$$

Light carries energy from the sun to the earth, thus making life possible on the earth.

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Ex. A plane electromagnetic wave of frequency 25 MHz travels in free space along the x-direction. At a particular point in space and time, $\mathbf{E} = 6.3\ \hat{j}$ V/m. What is B at this point ?

Sol. Using Eq. (8.10), the magnitude of B is

$$B = \frac{E}{c}$$

$$= \frac{6.3 V/m}{3\times10^8 m/s} = 2.1\times10^{-8} T$$

To find the direction, we note that E is along y-direction and the wave propagate along x-axis. Therefore, B should be in a direction perpendicular to both x- and y-axes. Using vector algebra, E × B should be along x-direction. Since, $(+\hat{j})\times(+\hat{K}) = \hat{i}$, B is along the z-direction

Thus, $B = 2.1\times10^{-8}$ kT

Ex. The magnetic field in a plane electromagnetic wave is given by $B_y = 2\times10^{-7}\sin(0.5\times10^3 x + 1.5\times10^{11}t)$ T.

(a) What is the wavelength and frequency of the wave ?

(b) Write an expression for the electric field.

Sol. **(a)** Comparing the given equation with

$$B_y = B_0 \sin\left[2\pi\left(\frac{x}{y}+\frac{t}{T}\right)\right]$$

$$\text{we get, } \lambda = \frac{2\pi}{0.5\times10^3}\ m = 1.26\ cm,$$

and $$\frac{1}{T} = \nu = (1.5\times10^{11})/2\pi = 23.9\ GHz$$

(b) $E_0 = B_0 c = 2\times10^{-7}\ T\times3\times10^8\ m/s = 60\ V/m$

The electric field component is perpendicular to the direction of propagation and the direction of magnetic field. Therefore, the electric field component along the z-axis is obtained as

$$E_z = 60\sin(0.5\times10^3 x + 1.5\times10^{11}t)\ V/m$$

Ex. Light with an energy flux of 18 W/cm^2 falls on a nonreflecting surface at normal incidence. If the surface has an area of 20cm^2, find the average force exerted on the surface during a 30 minute time span.

Sol. The total energy falling on the surface is

$$U = (18\ W/cm^2)\times(20 cm^2)\times(30\times60)$$

$$= 6.48\times10^5\ J$$

Therefore, the total momentum delivered (for complete absorption) is

$$p = \frac{U}{c} = \frac{6.48\times10^5 J}{3\times10^8 m/s} = 2.16\times10^{-3}\ kg\ m/s$$

The average force exerted on the surface is

$$F = \frac{p}{t} = \frac{2.16\times10^{-3}}{0.18\times14^4} = 1.2\times10^{-6} N$$

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Ex. Calculate the electric and magnetic fields produced by the radiation coming from a 100 W bulb at a distance of 3 m. Assume that the efficiency of the bulb is 2.5% and it is a point source.

Sol. The bulb, as a point source, radiates light in all directions uniformly. At a distance of 3 m, the surface area of the surrouding sphere is

$$A = 4\pi r^2 = 4\pi(3)^2 = 113\ m^2$$

The intensity at this distance is

$$I = \frac{\text{Power}}{\text{Area}} = \frac{100\,W \times 2.5\%}{113\,m^2} = 0.022\ W/m^2$$

Half of this intensity is provided by the electric field and half by the magnetic field.

$$\frac{1}{2}I = \frac{1}{2}\left(\varepsilon_0 E_{rms}^2 c\right) = \frac{1}{2}(0.022\ W/m^2)$$

$$E_{rms} = \sqrt{\frac{0.022}{(8.85\times10^{-12})(3\times10^8)}}\ V/m = 2.9\ V/m$$

The value of E found above is the root mean square value of the electric field. Since the electric field in a light beam is sinusoidal, the peak electric field, E_0 is

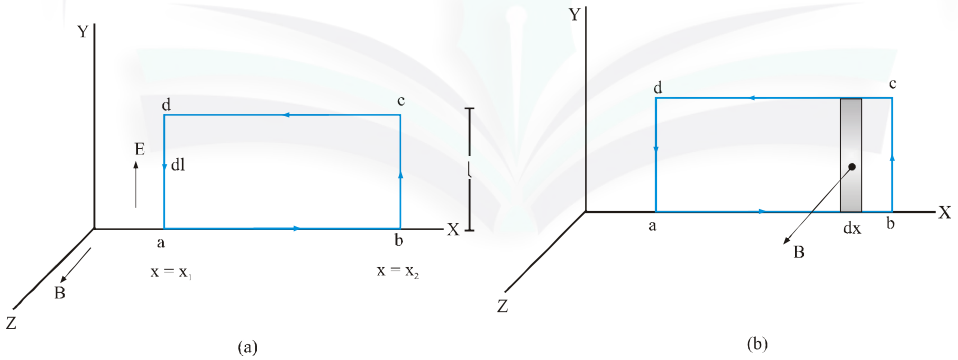
$$E_0 = \sqrt{2}\,E_{rms} = \sqrt{2} \times 2.9\ V/m = 4.07\ V/m$$

Electric field strength of light is fairly large

$$B_{rms} = \frac{E_{rms}}{c} = \frac{2.9\,Vm^{-1}}{3\times10^8\,ms^{-1}} = 9.6\times10^{-9}\,T$$

Agains, since the field in the light beam is sinusoidal, the peak magnetic field is $B_0 = \sqrt{2}\ B_{rms} = 1.4 \times 10^{-8}$ T. Note that although the energy in the magnetic field is equal to the energy in the electric field, the magnetic field strength is evidently very weak.

Faraday's Law



Let us consider the rectangular path abcd in the x–y plane as shown in figure. Let us evaluate the terms in the Faraday's law on this path. The electric field is parallel to the y-axis. The circulation of E is

$$\oint \vec{E}.d\vec{l} = \int_a^b \vec{E}.d\vec{l} + \int_b^c \vec{E}.d\vec{l} + \int_c^d \vec{E}.d\vec{l} + \int_d^a \vec{E}.d\vec{l}$$

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$$= 0 + E(x_2)l + 0 + E(x_1)(-l)$$

$$= E_0 l[\sin\omega(t - x_2/c) - \sin\omega(t - x_1/c)] \quad \text{..... (i)}$$

Next, let us calculate the flux of the magnetic field Φ_B, through the same rectangle abcd (in figure (b)). The flux through a strip of width dx at x is

$$B(x)l\ dx = B_0[\sin\omega(t - x/c)]l\ dx$$

The flux through the rectangle abcd is

$$\Phi_B = \int_{x_1}^{x_2} B_0 l \sin(t - x/c)dx$$

$$= \frac{c}{\omega} B_0 l[-\cos\omega(t - x_2/c) + \cos\omega(t - x_1/c)]$$

Thus,

$$\frac{d\Phi_B}{dt} = cB_0\ l[\sin\omega(t - x_2/c) - \sin\omega(t - x_1/c)] \quad \text{..... (ii)}$$

The Faraday's law for vacuum is

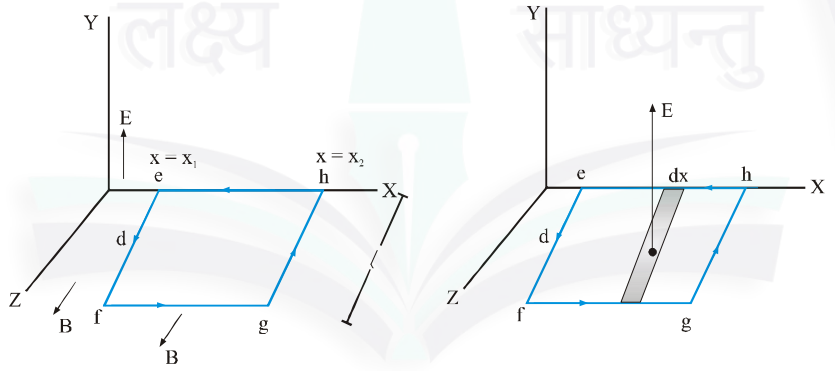
$$\oint \vec{E}.d\vec{l} = \frac{d\Phi_B}{dt}$$

Putting from (i) and (ii) in this equation, we see that Faraday's law is satisfied by the wave given by equation if

$$E_0 = cB_0 \quad \text{..... (12)}$$

Ampere's Law

Let us consider the rectangular path efgh in the x-z plane as shown in figure (a).



(a) (b)

The circulation of $\vec{B}$ is

$$\oint \vec{B}.d\vec{l} = \int_e^f \vec{B}.d\vec{l} + \int_f^g \vec{B}.d\vec{l} + \int_g^h \vec{B}.d\vec{l} + \int_h^e \vec{B}.d\vec{l}$$

$$= B(x_1)l + 0 - B(x_2)l + 0$$

$$= B_0 l[\sin\omega(t - x_1/c) - \sin\omega(t - x_2/c)] \quad \text{..... (i)}$$

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The flux of the electric field through theb same rectangle efgh (figure (b)) is

$$\Phi_E = \int \vec{E}.\overrightarrow{dS}$$

$$= \int_{x_1}^{x_2} E(x) l \, dx$$

$$= E_0 \, l \int_{x_1}^{x_2} \sin \omega(t - x/c) \, dx$$

$$= -\frac{c}{\omega} E_0 l[-\cos \omega(t - x_2/c) + \cos \omega(t - x_1/c)]$$

or, $$\frac{d\Phi_E}{dt} = -cE_0 l[\sin \omega(t - x_2/c) - \sin \omega(t - x_1/c)] \quad \text{..... (ii)}$$

The Ampere's law for vacuum is

$$\oint \vec{B}.d\vec{l} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}$$

Putting from (i) and (ii) in this equation, we see that Ampere's law is satisfied if

$$B_0 = \mu_0 \varepsilon_0 \, c \, E_0$$

or, $$\mu_0 \varepsilon_0 = \frac{B_0}{E_0 c}$$

Using equation (iii),

$$\mu_0 \varepsilon_0 = \frac{1}{c^2}$$

or, $$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \quad \text{..... (13)}$$

Thus, Maxwell's equations have a solution giving a plane electromagnetic wave of the form (7) with $E_0 = cB_0$ and the speed of this wave is $\frac{1}{\sqrt{\mu_0 \varepsilon_0}}$.

In older days, μ_0 and ε_0 were defined in terms of electric and magnetic measurements. Putting these values of μ_0 and ε_0, the speed of electromagnetic waves came out to be $c = 2.99793 \times 10^8$ m/s which was the same as the measured speed of light in vacuum. This provided a confirmatory proof that light is an electromagnetic wave.

it may be revalled that the speed of electromagnetic waves, which is the same as the speed of light, is now an exactly defined constant. Similarly, the constant $\mu_0 = 4\pi \times 10^{-7}$ T – m/A is an exactly defined constant. The quantity ε_0 is defined by the equation (13).

Ex. The maximum electric field in a plane electromagnetic wave is 600 N C^{-1}. The wave is going in the x-direction and the electric field is in the y-direction. Find the maximum magnetic field in the wave and its direction.

Sol. We have $B_0 = \frac{E_0}{c} = \frac{600 \, NC^{-1}}{3 \times 10^8 \, ms^{-1}} = 2 \times 10^{-6} \, T$

As $\vec{E}, \vec{B}$ and the direction of propagation are mutually perpendicular, $\vec{B}$ should be along the z-direction.

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ENERGY DENSITY AND INTENSITY

The electric and magnetic field in a plane electromagnetic wave are given by

$$E = E_0 \sin \omega(t - x/c)$$

and $$B = B_0 \sin \omega(t - x/c)$$

In any small volume dV, the energy of the electric field is

$$U_E = \frac{1}{2}\varepsilon_0 E^2 dV$$

and the energy of the magnetic field is

$$U_B = \frac{1}{2\mu_0} B^2 dV$$

Thus, the total energy is

$$U = \frac{1}{2}\varepsilon_0 E^2 dV + \frac{1}{2\mu_0} B^2 dV$$

The energy density is $u = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2\mu_0} B^2$

$$= \frac{1}{2}\varepsilon_0 E_0^2 \sin^2 \omega(t - x/c) + \frac{1}{2\mu_0} B^2 \sin^2 \omega(t - x/c)$$

If we take the average over a long time, the $\sin^2$ terms have an average value of 1/2.

Thus, $$u_{au} = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4\mu_0} B_0^2$$

From equations **(12)** and **(13)**,

$$\frac{1}{4\mu_0} B_0^2 = \frac{\varepsilon_0 c^2}{4}\left(\frac{E_0}{c}\right)^2 = \frac{1}{4}\varepsilon_0 E_0^2$$

Thus, the electric energy density is equal to the magnetic energy density in average.

or, $$u_{au} = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4}\varepsilon_0 E_0^2 = \frac{1}{2}\varepsilon_0 E_0^2 \quad \text{..... (14)}$$

Also, $$\frac{1}{4\mu_0} B_0^2 + \frac{1}{4\mu_0} B_0^2 = \frac{1}{2\mu_0} B_0^2 \quad \text{..... (15)}$$

Ex. The electric field in an electromagnetic wave is given by

$E = (50\ N\ C^{-1}) \sin \omega(t - x/c)$

Find the energy contained in a cylinder of cross-section 10 cm^2 and length 50 cm along the x-axis.

Sol. The energy density is

$$u_{au} = \frac{1}{2}\varepsilon_0 E_0^2 \times (8.85 \times 10^{-12} C^2 N^{-1} m^{-2}) \times (50 NC^{-1})^2$$

$= 1.1 \times 10^{-8}\ J\ m^{-3}$

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The volume of the cylinder is

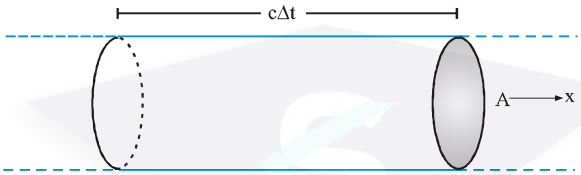
$$V = 10\ cm^2 \times 50\ cm = 5 \times 10^{-4}\ m^3$$

The energy contained in this volume is

$$U = (1.1 \times 10^{-8}\ J\ m^{-3}) \times (5 \times 10^{-4}\ m^3)$$
$$= 5.5 \times 10^{-12}\ J$$

Intensity

The energy crossing per unit area per unit time perpendicular to the direction of propagation is called the intensity of a wave.



Consider a cylindrical volume with area of cross section A and length c Δt along the X-axis (in figure). The energy contained in this cylinder crosses the area A in time Δt as the wave propagates at speed c. The energy contained is

$$U = u_{av}(c\ \Delta t)A$$

The intensity is $I = \frac{U}{A\Delta t} = u_{av}c$

In terms of maximum electric field,

$$I = \frac{1}{2}\varepsilon_0 E_0^2 c \qquad \text{..... (14)}$$

Ex. Find the intensity of the wave discussed in above example.

Sol. The intensity is

$$I = \frac{1}{2}\varepsilon_0 E_0^2 c = (1.1 \times 10^{-8}\ Jm^{-3}) \times (3 \times 10^8\ ms^{-1})$$

$$= 3.3\ W\ m^{-2}$$

Electromagnetic Spectrum

At the time Maxwell predicted the existence of electromagnetic waves, the only familiar electromagnetic waves were the visible light waves. The existence of ultraviolet and infrared waves was barely established. By the end of the nineteenth century, X -rays and gamma rays had also been discovered. We now know that, electromagnetic waves include visible light waves, X-rays gamma rays, radio waves, microwaves, ultraviolet and infrared waves. The classification of electromagnetic waves according to frequency is the electromagnetic spectrum (Fig. 5). There is no sharp division between one kind of wave and the next. The classification is based roughly on how the waves are produced and / or detected.

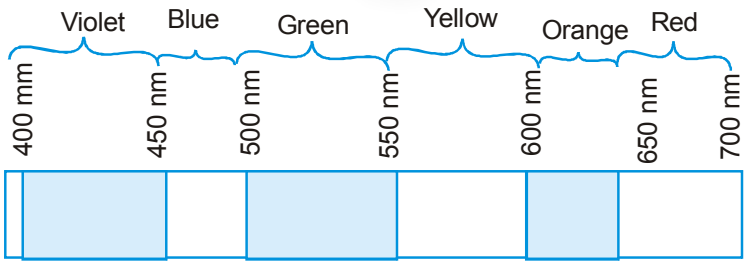


Figure - spectrum of visible light

We briefly describe these different types of electromagnetic waves, in order of decreasing wavelengths.

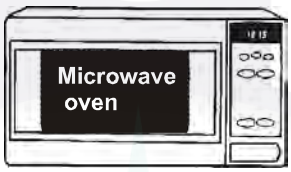
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Radio waves

Radio waves are produced by the accelerated motion of charges in conducting wires. They are used in radio and television communication systems. They are generally in the frequency range from 500 kHz to about 1000 MHz. The AM (amplitude modulated) band is from 530 kHz to 1710 kHz. Higher frequencies upto 54 MHz are used for short wave bands. TV waves range from 54 MHz to 890 MHz. The FM (frequency modulated) radio band extends from 88 MHz to 108 MHz. Cellular phones use radio waves to transmit voice communication in the ultrahigh frequency (UHF) band.

Microwaves

Microwaves (short-wavelength radio waves), with frequencies in the gigahertz (GHz) range, are produced by special vacuum tubes (called klystrons, magnetrons and Gunn diodes). Due to their short wavelengths, they are suitable for the radar systems used in aircraft navigation. Microwave ovens are an interesting domestic application of these waves. In such ovens, the frequency of the microwaves is selected to match the resonant frequency of water molecules so that energy from the waves is transferred efficiently to the kinetic energy of the molecules. This raises the temperature of any food containing water.



Infrared waves

Infrared waves are produced by hot bodies and molecules. This band lies adjacent to the low-frequency or long-wave length end of the visible spectrum. Infrared waves are sometimes referred to as heat waves. This is because water molecules present in most materials readily absorb infrared waves). After absorption, their thermal motion increases, that is they heat up and heat their surroundings. Infrared lamps are used in physical therapy. I R radiation maintain the earth's warmth or average temperature through the greenhouse effect. Incoming visible light (which passes relatively easily through the atmosphere) is absorbed by the earth's surface and reradiated as infrared (longer wavelength) radiations. This radiation is trapped by green house gases such as carbon dioxide and water vapour. Infrared detectors are used in earth satellites, both for military purpose and to observe growth of crops. Electronic devices (for example semiconductor light emitting diodes) also emit infrared and are widely used in the remote switches of household electronic systems such as TV sets, video recorders and hi-fi systems.

Visible rays

It is the most familiar form of electromagnetic waves. It is the part of the spectrum that is detected by the human eye. It runs from about 4×10^{14} Hz to about 7×10^{14} Hz or a wavelength range of about 700- 400 nm. Visible light emitted or reflected from objects around us provides us information about the world. Our eyes are sensitive to this range of wavelengths. Different animals are sensitive to different range of wavelengths. For example, snakes can detect infrared waves, and the 'visible' range of many insects extends well into the ultraviolet.

Ultraviolet rays

It covers wavelengths ranging from about 4×10^{-7} m (400 nm) down to 6×10^{-10} m (0.6 nm). Ultraviolet (UV) radiation is produced by special lamps and very hot bodies. The sun is an important source of ultraviolet light. But fortunately, most of it is absorbed in the ozone layer in the atmosphere at an altitude of about 40-50 km. UV light in large quantities has harmful effects on humans. Exposure to UV radiation induces the production of more melanin, causing tanning of the skin. UV radiation is absorbed by ordinary glass. Hence, one cannot get tanned or sunburn through glass windows.

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Welders wear special glass goggles or face masks with glass windows to protect their eyes from large amount of UV produced by welding arcs. Due to its shorter wavelength, UV radiations can be focussed into very narrow beams for high precision application such as LASIK (Laser assisted in situ keratomileusis) eye surgery. UV lamps are used to kill germs in water purifiers.

Ozone layer in the atmosphere plays a protective role, and hence its depletion by chlorofluorocarbons (CFCs) gas (such as freon) is a matter of international concern.

X-rays

Beyond the UV region of the electromagnetic spectrum lies the X-ray region. We are familiar with X-rays because of its medical applications. It covers wavelengths from about 10^{-8} m (10 nm) down to 10^{-13} m (10^{-4} nm). One common way to generate X-rays is to bombard a metal target by high energy electrons. X-rays are used as a diagnostic tool in medicine and as a treatment for certain forms of cancer. Because X-rays damage or destroy living tissues and organisms, care must be taken to avoid unneccessary or over exposure.

Gamma rays

They lie in the upper frequency range of the electromagnetic spectrum and have wavelength of from about 10^{-10} m to less than 10^{-14} m. This high frequency radiation is produced in nuclear reactions and also emitted by radioactive nuclei. They are used in medicine to destroy cancer cells.

Table 8.1 summarises different types of electromagnetic waves, their production and detections. As mentioned earlier, the demarcation between different region is not sharp and there are over laps.

Different Type of Electromagnetic Waves

Type	Wavelength range	Production	Detection
Radio	> 0. 1 m	Rapid acceleration and decelerations of electrons in aerials	Receiver's aerials
Microwave	0.1 m to 1 mm	Klystron value or magnetron Valve	Point contact diodes
Infra-red	1 mm to 700 nm	Vibration of atoms and molecules	Thermopiles Bolometer, Infrared photographic film
Light	700 nm to 400 nm	Electrons in atoms emit light when they move from one energy level to a lower energy	The eye, photocells, Photographic film
Ultraviolet	400 nm to 1 nm	Inner shell electrons in atoms moving from one energy level to a lower level	Photocells Photographic film
X-rays	1 nm to 10^{-3} nm	X-ray tubes or inner shell electrons	Photograpic film, Geiger tubes, Ionisation chamber
Gamma rays	< 10^{-3} nm	Radioactive decay of the nucleus	do

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TIP&FORMULAS

1. Cathode Rays :

(a) Generated in a discharge tube in which a high vaccum is maintained.

(b) They are electrons accelerated by high potential difference (10 to 15 kV)

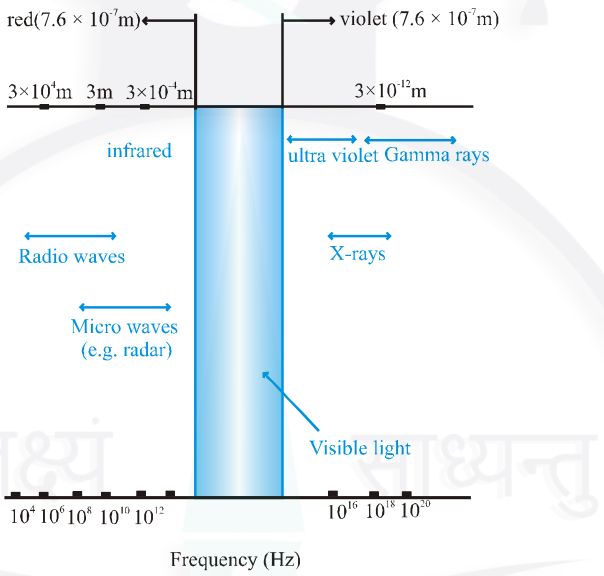
(c) K.E. of C.R. particle accelerated by a p.d V is $eV = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

(d) Can be deflected by Electric & magnetic fields.

2. Electromagnetic Spectrum

Ordered arrangement of the big family of electro magneti waves (EMW) either in ascending order of frequencies or decending order of wave lengths.

Speed of E.M.W. in vaccum : $c = 3 \times 10^8$ m/s = $v\lambda$



3. Plancks Quantam Theory

A beam of EMW is a stream of discrete packets of energy called photons; each photon having a frequancy v and energy = E = hv

where h = planck's constant = 6.63×10^{-34} J-s.

(a) According to Planck the energy of a photon is directly proportional to the frequency of the radiation.

$$E = \frac{hc}{\lambda} = \frac{12400}{\lambda} eV - \mathring{A} \left[\because \frac{hc}{e} = 12400 (\mathring{A} - eV) \right]$$

(b) Effective mass of photon $m = \frac{E}{c^2} = \frac{hc}{c^2\lambda} = \frac{h}{c\lambda}$ i.e. $m \propto \frac{1}{\lambda}$

So mass of violet light photon is greater than the mass of red light photon.

$(\because \lambda_R > \lambda_V)$

(c) Linear momentum of photon $p = \frac{E}{c} = \frac{hv}{c} = \frac{h}{\lambda}$

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4. Intensity of light : $I = \frac{E}{At} = \frac{P}{A}$ ....(i)

Here P = power of source, A = Area, t = time taken

E = energy incident in t time = Nhv N = no. of photon incident in t time

Intensity $I = \frac{N(h\nu)}{At} = \frac{n(h\nu)}{A}$ ....(ii) $[\because n = \frac{N}{t} = \text{no. of photon per sec.}]$

From equation (i) and (ii), $\frac{P}{A} = \frac{n(h\nu)}{A} \Rightarrow n = \frac{P}{h\nu} = \frac{P\lambda}{hc} = 5\times10^{24}\,J^{-1}m^{-1}\times P\times\lambda$

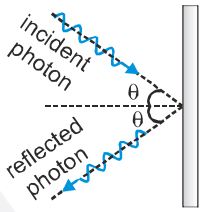
5. Force exerted on perfectly reflecting surface

$\therefore\ F = n\left(\frac{2h}{\lambda}\right) = \frac{2P}{c}$ and Pressure $= \frac{F}{A} = \frac{2P}{cA} = \frac{2I}{c}\ \left[\because I = \frac{P}{A}\right]$

Force exerted on perfectly absorbing surface

$F = \frac{P}{c}\left(\because n = \frac{P\lambda}{hc}\right)$ and Pressure $= \frac{F}{A} = \frac{P}{Ac} = \frac{I}{c}$

When a beam of light is incident at angle θ on perfectly reflector surface



$F = \frac{2IA\cos^2\theta}{c}$

When a beam of light is incident at angle θ on perfectly absorbing surface $F = \frac{IA\cos\theta}{c}$

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SOLVED EXAMPLE

Ex.1 A parallel-plate capacitor with plate area A and separation between the plates d, is charged by a constant current i. Consider a plane surface of are A/2 parallel to the plates and drawn symmetrically between the plates. Find the displacement current through this area.

Sol. Suppose the charge on the capacitor at time t is Q.The electric field between the plates of the capacitor is $E = \frac{Q}{\varepsilon_0 A}$. The flux through the area considered is

$$\Phi_E = \frac{Q}{\varepsilon_0 A} \cdot \frac{A}{2} = \frac{Q}{2\varepsilon_0}$$

The displacement current is

$$i_d = \varepsilon_0 \frac{d\Phi_E}{dt} = \varepsilon_0 \left(\frac{1}{2\varepsilon_0}\right)\frac{dQ}{dt} = \frac{i}{2}$$

Ex.2 A plane electromagnetic wave propagating in the x-direction hass a wavelength of 5.0 mm. The electric field is in the y-direction and its maximum magnitude is 30 V m^{-1}. Write suitable equations for the electric and magnetic fields as a function of x and t.

Sol. The equation for the electric and the magnetic fields in the wave may be written as

$$E = E_0 \sin\omega\left(t - \frac{x}{c}\right)$$

$$B = B_0 \sin\omega\left(t - \frac{x}{c}\right)$$

We have,

$$\omega = 2\pi v = \frac{2\pi}{\lambda}c$$

Thus, $E = E_0 \sin\left[\frac{2\pi}{\lambda}(ct - x)\right]$

$$= (30\ \text{V m}^{-1}) \sin\left[\frac{2\pi}{5.0\,\text{mm}}(ct - x)\right]$$

The maximum magnetic field is

$$B_0 = \frac{E_0}{c} = \frac{30\ \text{V m}^{-1}}{3\times10^8\ \text{ms}^{-1}} = 10^{-7}\ \text{T}$$

So, $B = B_0 \sin\left[\frac{2\pi}{\lambda}(ct - x)\right]$

$$= (10^{-7}\ \text{T}) \sin\left[\frac{2\pi}{5.0\,\text{mm}}(ct - x)\right].$$

The magnetic field is along the z-axis.

Ex.3 A light beam travelling in the x-direction is described by the electric field $E_y = (300\ \text{V m}^{-1}) \sin\omega(t - x/c)$. An electron is constrained to move along the y-direction with a speed of 2.0×10^7 m s^{-1}. Find the maximum electric force and the maximum magnetic force on the electron.

Sol. The maximum electric field is $E_0 = 300$ V m^{-1}. The maximum magnetic field is

$$B_0 = \frac{E_0}{c} = \frac{300\ \text{V m}^{-1}}{3\times10^8\ \text{ms}^{-1}} = 10^{-6}\ \text{T}$$

along the z-direction.

The maximum electric force on the electron is

$$F_e = qE_0 = (1.6\times10^{-19}\ \text{C}) \times (300\ \text{V m}^{-1})$$
$$= 4.8\times10^{-17}\ \text{N}.$$

The maximum magnetic force on the electron is

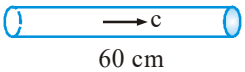
$$F_b = \left|q\vec{v}\times\vec{B}\right|_{max} = qvB_0$$

$$= (1.6\times10^{-19}\ \text{C}) \times (2.0\times10^7\ \text{ms}^{-1}) \times (10^{-6}\ \text{T})$$

$$= 3.2\times10^{-18}\ \text{N}.$$

Ex.4 Find the energy stored in a 60 cm length of a laser beam operating at 4mW .

Sol.



60 cm

The time taken by the electromagnetic wave to move through a distance of 60 cm is $t = \frac{60\,\text{cm}}{c} = 2\times10^{-9}\,\text{s}$.

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The energy contained in the 60 cm length passes through a cross-section of the beam in 2×10^{-9} s. But the energy passing through any cross section in 2×10^{-9} s is

$$U = (4\,\text{mW}) \times (2 \times 10^{-9}\,\text{s})$$
$$= (4 \times 10^{-3}\,\text{Js}^{-1}) \times (2 \times 10^{-9}\,\text{s})$$
$$= 8 \times 10^{-12}\,\text{J}.$$

Ex.5 Find the amplitude of the electric field in a parallel beam of light of intensity 2.0 Wm^{-2}.

Sol. The intensity of a plane electromagnetic wave is

$$I = u_{av} c = \frac{1}{2}\varepsilon_0 E_0^2 c$$

or,
$$E_0 = \sqrt{\frac{2I}{\varepsilon_0 c}}$$

$$= \sqrt{\frac{2 \times (2.0\,\text{W m}^{-2})}{(8.85 \times 10^{-12}\,\text{C}^2\text{N}^{-1}\text{m}^{-2}) \times (3 \times 10^8\,\text{ms}^{-1})}}$$

$$= 38.8\,\text{N C}^{-1}.$$

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Exercise # 1 SINGLE OBJECTIVE NEET LEVEL

1. The ionosphere does not allow to pass the waves which are termed as
(A) microwaves
(B) visible light waves
(C) 1 and 2 both
(D) amplitude modulated waves

2. Practically ozone layer absorbs the radiation of wavelength
(A) less than 3×10^{-7} m
(B) greater than 3×10^{-7} m
(C) equal to 3×10^{-7} m
(D) all the above

3. The waves which can travel directly along surface of the earth are known as
(A) ground waves **(B)** X–rays
(C) α–rays **(D)** sky waves

4. The ionosphere bends the e. m. waves having the frequencies
(A) less than 40 MHz
(B) beyond 40 MHz
(C) nothing is certain
(D) depends on the moisture present

5. The S.I unit of displacement current is
(A) H **(B)** A
(C) Fm^{-1} **(D)** C

6. Transmission of T. V. signals from the surface of the moon can be received on earth. But transmitted T. V. Signals from Delhi can not be received beyond 110 km distance. The reason is
(A) there is no atmosphere on the moon
(B) strong gravitational effect on T. V. signals
(C) T. V. signals travel along a straight line, they do not follow the curvature of earth
(D) there is atmosphere around the earth

7. The number of radio frequency carrier waves transmitted by a television transmitter is
(A) three **(B)** two
(C) one **(D)** four

8. The speed of electromagnetic waves is independent of
(A) wavelength
(B) frequency
(C) intensity
(D) medium, in which it travels

9. An electromagnetic radiation of frequency ν, wavelength λ, travelling with velocity c in air, enters a glass slab of refractive index μ. The frequency, wavelength and velocity of light in the glass slab will be respectively :
(A) $\frac{\nu}{\mu}, \frac{\lambda}{\mu}$ and $\frac{c}{\mu}$ **(B)** $\nu, \frac{\lambda}{\mu}$ and $\frac{c}{\mu}$
(C) $\nu, 2\lambda$ and $\frac{c}{\mu}$ **(D)** $\frac{2\nu}{\mu}, \frac{\lambda}{\mu}$ and c

10. If ε_0 and μ_0 are the electric permittivity and magnetic permeability in free space, ε and μ are the corresponding quantities in a medium, then index of refraction of the medium is
(A) $\sqrt{\frac{\varepsilon_0\mu}{\varepsilon\mu_0}}$ **(B)** $\sqrt{\frac{\varepsilon}{\varepsilon_0}}$
(C) $\sqrt{\frac{\varepsilon_0\mu_0}{\varepsilon\mu}}$ **(D)** $\sqrt{\frac{\varepsilon\mu}{\varepsilon_0\mu_0}}$

11. Dimension of $\varepsilon_0\mu_0$ is :
(A) LT^{-1} **(B)** $L^{-1}T$
(C) L^2T^{-2} **(D)** $L^{-2}T^2$

12. For television transmission, the frequency employed is normally in the range
(A) 30–300 MHz **(B)** 30–300 GHz
(C) 300–300 kHz **(D)** 30–300 Hz

13. Red light differs from blue light in its
(A) speed. **(B)** frequency
(C) intensity **(D)** amplitude

14. If an electromagnetic wave propagating through vacuum is described by
$E = E_0 \sin(kx - \omega t)$; $B = B_0 \sin(kx - \omega t)$,
(A) $E_0 k = B_0 \omega$ **(B)** $E_0 B_0 = \omega k$
(C) $E_0 \omega = B_0 k$ **(D)** $E_0 B_0 = \omega / k$

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15. The electromagnetic waves used in the telecommunication are

(A) ultraviolet **(B)** infra-red

(C) visible **(D)** microwaves.

16. A magnetic field can be produced by

(A) A charge at rest only

(B) A moving charge only

(B) a changing electric field

(D) both by (B) and (C)

17. Which of the following is independent of wavelength ?

(A) k **(B)** ω

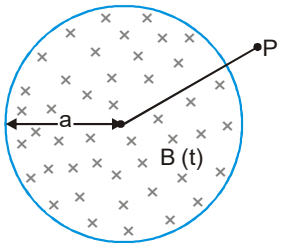
(C) ωk **(D)** k / ω

18. Finger prints on a piece of paper may be detected by sprinkling flourescent powder on the paper and then looking it into

(A) dark-light **(B)** sun-light

(C) Infra-red-light **(D)** ultraviolet light

19. A uniform but time varying magnetic field B (t) exists in a circular region of radius a is directed into the plane of the paper as shown. The magnitude of the induced electric field at point P at a distance r from the centre of the circular region.



(A) is zero **(B)** decreases as $1/r$

(C) increases as r **(D)** decreases as $1/r^2$

20. If $\in_0$ and μ_0 represent the permittivity and permeability of vacuum and $\in$ and μ represent the permittivity and permeability of medium, then refractive index of the medium is given by

(A) $\sqrt{\frac{\mu_0 \in_0}{\mu \in}}$ **(B)** $\sqrt{\frac{\mu \in}{\mu_0 \in_0}}$

(C) $\sqrt{\frac{\in}{\mu_0 \in_0}}$ **(D)** $\sqrt{\frac{\mu_0 \in_0}{\mu}}$

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Exercise # 2 SINGLE OBJECTIVE AIIMS LEVEL

1. The fundamental source of e. m. waves
(A) is varying magnetic field
(B) constant magnetic and electric fields
(C) are continous oscillations of electric charge
(D) is planets

2. The displacement current was first postulated by
(A) Ampere **(B)** Maxwell
(C) Hertz **(D)** Marconi

3. An accelerated electric charge emits
(A) β – rays **(B)** γ – rays
(C) e.m. waves **(D)** none of the above

4. The speed of e. m. waves is given by the relation
(A) $\mu_0\varepsilon_0$ **(B)** $\sqrt{\mu_0\varepsilon_0}$
(C) $1/\mu_0\varepsilon_0$ **(D)** $1/\sqrt{(\mu_0\varepsilon_0)}$

5. Electromagnetic waves in nature are
(A) longitudinal
(B) longitudinal stationary
(C) transverse
(D) transverse – stationary

6. An accelerated charge
(A) emits an electromagnetic wave
(B) does not emits electromagnetic wave
(C) produces a gravitational field
(D) none of the above

7. Electromagnetic waves
(A) are longitudinal waves
(B) travel in free space at the speed of light
(C) are produced by charges moving with uniform velocity
(D) travel with the same speed in all media

8. Choose the only wrong statement from the following about electromagnetic waves
(A) are transverse
(B) travels free space at the speed of light
(C) are produced by accelerating charges
(D) travel with the same speed in all media

9. In an electromagnetic wave, electric field E and magnetic field B are
(A) mutually perpendicular to each other
(B) all parallel
(C) at 30^0 to each other
(D) at 60^0 to each other

10. Electromagnetic wave obey the principle of
(A) superposition **(B)** interference
(C) 1 and 2 both **(D)** none of the above

11. If E and B be the electric and magnetic fields of electromagnetic waves, then the direction of propagation of e. m. wave is along the direction of
(A) E **(B)** B
(C) $E \times B$ **(D)** None of the above

12. Which of the following pairs of space and time varying E and B fields would generate a plane electromagnetic wave travelling in the Z– direction
(A) E_x, B_y **(B)** E_y, B_x
(C) E_x, B_z **(D)** E_z, B_x

13. Choose the correct statement about electromagnetic waves
(A) they are supersonic waves
(B) they are the electric charged particles
(C) they travel with the speed of light
(D) they can only be produced in laboratory.

14. Hertz produced electromagnetic wave by using
(A) L C R circuit **(B)** C R circuit
(C) L C circuit **(D)** None of the above

15. The shortest wavelength is for
(A) γ – rays **(B)** x – rays
(C) ultraviolet rays **(D)** microwaves

16. Visible range of wavelength in cm is
(A) 3×10^{-6} to 10^{-10}
(B) 7×10^{-5} to 4×10^{-5}
(C) 4×10^{-5} to 3×10^{-6}
(D) 6×10^{4} to 1.5×10^{3}

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17. Which has the longest wavelength `
(A) infrared light (B) ultraviolet light
(C) radio–waves (D) X–rays

18. The earth's atmosphere is richer in
(A) infra - red radiation
(B) ultraviolet radiations
(C) visible radiations
(D) blue colour radiations

19. Microwaves are used for
(A) television (B) radio transmission
(C) radar system (D) all the above

20. Ionosphere is mainly composed of
(A) electrons and positive ions
(B) ozone gas
(C) nitrogen and oxygen
(D) b and c both

21. The upper atmosphere layer is known as
(A) troposphere (B) mesosphere
(C) ionospere (D) chromosphere

22. Greenhouse effect keeps the earth surface
(A) cold in night (B) dusty and cold
(C) warm in night (D) moist in night

23. Greenhouse effect is due to
(A) visible radiations (B) red colour radiation
(C) violet colour radiation (D) infra - red radiation

24. Ozone layer in atmosphere exist at the height of
(A) 20 km (B) 50 km
(C) 120 km (D) 150 km

25. Ozone layer exist in
(A) ionosphere (B) mesosphere
(C) troposphere (D) stratosphere

26. Ozone layer protectes the living cells from
(A) ultraviolet radiations
(B) unfra –red radiations
(C) X–rays
(D) all the radiations

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Exercise # 3

ASSERTION & REASONING

These questions contains, Statement I (assertion) and Statement II (reason).

(A) If both assertion and reason are true and the reason is the correct explanation of the assertion.

(B) If both assertion and reason are true but reason is not the correct explanation of the assertion.

(C) If assertion is true but reason is false.

(D) If assertion is false but reason is true.

(E) If the assertion and reason both are false.

1. **Assertion :** Sound waves are not electromagnetic waves.

Reason : Sound waves require a material medium for propagation.

2. **Assertion :** Displacement current arises on account of change in electric flux.

Reason : $I_d = \epsilon_0 \left(\frac{d\Phi_E}{dt} \right)$

3. **Assertion :** A changing electric field produces a magnetic field

Reason : A changing magnetic field produces an electric field.

4. **Assertion :** In an e.m. wave magnitude of magnetic field vector $\vec{B}$ is much smaller than the magnitude of vector $\vec{E}$.

Reason : This is because in an e.m. wave $E/B = c = 3 \times 10^8 \, m/s$.

5. **Assertion :** Electromagnetic waves exert pressure called radiation pressure.

Reason : This is because they carry energy.

6. **Assertion :** Electromagnetic waves are transverse in nature

Reason : The electric and magnetic fields of an e.m. wave are perpendicular to each other and also perpendicular to the direction of wave propagation.

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Exercise # 4 PART - 1 PREVIOUS YEAR (NEET/AIPMT)

1. The frequency of γ-rays, X-rays and ultraviolet rays are a, b and c respectively.

Then,

(A) $a > b > c$ **(B)** $a < b < c$

(C) $a = b = c$ **(D)** $a > c > b$

2. In a certain region of space electric field E and magnetic field B are perpendicular to each other and an electron enters in region perpendicular to the direction of B and E both and moves undeflected, then velocity of electron is

(A) $\frac{|E|}{|B|}$ **(B)** $E \times B$

(C) $\frac{|B|}{|E|}$ **(D)** $E \cdot B$

3. The velocity of electromagnetic wave is along the direction of

(A) $B \times E$ **(B)** $E \times B$

(C) E **(D)** B

4. Which of the following has minimum wavelength?

(A) X-rays

(B) Ultraviolet rays

(C) γ-rays

(D) Cosmic rays

5. Which of the following rays are not electromagnetic waves?

(A) β-rays **(C)** Heat rays

(C) X-rays **(D)** γ-rays

6. If λ_v, λ_x and λ_m represent the wavelengths of visible light, X-rays and microwaves respectively, then

(A) $\lambda_m > \lambda_x > \lambda_v$

(B) $\lambda_v > \lambda_m > \lambda_x$

(C) $\lambda_m > \lambda_v > \lambda_x$

(D) $\lambda_v > \lambda_x > \lambda_m$

7. The electric field part of an electromagnetic wave in a medium is represented by $E_x = 0$;

$$E_y = 2.5\frac{N}{C}\cos\left[\left(2\pi\times10^6\frac{rad}{m}\right)t-\left(\pi\times10^{-2}\frac{rad}{s}\right)x\right];.$$

$E_z = 0$.

The wave is

(A) moving along y-direction with frequency $2\pi \times 10^6$ Hz and wavelength 200 m

(B) moving along x-direction with frequency 10^6 Hz and wavelength 100 m

(C) moving along x-direction with frequency 10^6 Hz and wavelength 200 m

(D) moving along – x-direction with frequency 10^6 Hz and wavelength 200 m.

8. Which of the following statement is false for the properties of electromagnetic waves?

(A) Both electric and magnetic field vectors attain the maxima and minima at the same place and same time

(B) The energyin electromagnetic wave is divided equally between electric and magnetic vectors

(C) Both electric and magnetic field vectors are parallel to each other and perpendicular to the direction of propagation of wave

(D) These waves do not require any material medium for propoagation

9. The decreasing order of wavelengthof infrared, microwave, ultraviolet and gamma rays is

(A) gamma rays, ultraviolet, infrared, microwaves

(B) microwaves, gamma rays, infrared, ultraviolet

(C) infrared, microwave, ultraviolet, gamma rays

(D) microwave, infrared, ultraviolet, gamma rays

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10. The electric and the magnetic field, associated with an electromagnetic wave, propagating along the +z-axis, can be represented by

(A) $\left[E = E_0\hat{k}, B = B_0\hat{i}\right]$ **(B)** $\left[E = E_0\hat{j}, E = B_0\hat{j}\right]$

(C) $\left[E = E_0\hat{j}, B = B_0\hat{k}\right]$ **(D)** $\left[E = E_0\hat{i}, B = B_0\hat{j}\right]$

11. The electric field associated with an electro magnetic wave in vacuum is given by $E = \hat{i}\ 40\ \cos(kz - 6 \times 10^8\ t)$, where E, z and t are in volt/metre and second respectively. The value of wave vector k is

(A) $2\ m^{-1}$ **(B)** $0.5\ m^{-1}$

(C) $6\ m^{-1}$ **(D)** $3\ m^{-1}$

12. The condition under which a microwave oven heats up a food item containing water molecules most efficiently is

(A) the frequency of the microwave must match the resonant frequency of the water molecules

(B) the frequency of the microwave has no relation with natural frequency of water molecules

(C) microwave are heat waves, so always produce heating

(D) infra-red waves prodcue heating in a microwave oven

13. The energy of the EM waves is of the order of 15 keV. To which part of the spectrum does it belong?

(A) X-rays **(B)** Infrared rass

(C) Ultraviolet rays **(D)** γ-rays

14. Out of the following options which one can be used to produce a propagating electromagnetic wave?

(A) A stationary charge

(B) A chargeless particle

(C) An accelerating charge

(D) A charge moving at constant velocity

15. In an electromagnetic wave in free space the root mean square value of the electric field is $E_{rms} = 6$ V/m. The peak value of the magnetic field is

(A) 1.41×10^{-8} T **(B)** 2.83×10^{-8} T

(C) 0.70×10^{-8} T **(D)** 4.23×10^{-8} T

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Exercise # 4 PART - 2 PREVIOUS YEAR (AIIMS)

1. A light of intensity I_0 passes through a material of thickness d. The resultant intensity is
(A) $I = I_0 e^{-d\lambda}$ (B) $I = I_0 (1 - e^{-d\lambda})$
(C) $I = I_0 e^{-d/\lambda}$ (D) $I = I_0 (1 - e^{-d/\lambda})$

2. X-ray beams are affected by
(A) electric field (B) magnetic field
(C) both (A) and (B) (D) none of these

3. Light propagates rectilinearly because of its
(A) frequency (B) velocity
(C) wavelength (D) wave nature.

4. Velocity of light is equal to
(A) $\sqrt{\varepsilon_0 \mu_0}$ (B) $\sqrt{\varepsilon_0 / \mu_0}$
(C) ε_0 / μ_0 (D) $\sqrt{\frac{1}{\varepsilon_0 \mu_0}}$

5. The pressure exerted by an electromagnetic wave of intensity I (watt/m^2) on a nonreflecting surface is [c is the velocity of light]
(A) Ic (B) Ic^2
(C) I/c (D) I/c^2

6. Which wavelength of sun is used finally as electric energy ?
(A) Radio waves (B) Infrared waves
(C) Visible light (D) Micro waves

7. The velocity of electromagnetic radiation in a medium of permittivity ε_0 and permeability μ_0 is given by
(A) $\frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ (B) $\sqrt{\frac{\mu_0}{\varepsilon_0}}$
(C) $\sqrt{\frac{\varepsilon_0}{\mu_0}}$ (D) $\sqrt{\mu_0 \varepsilon_0}$

8. If v_s, v_x and v_m are the speeds of gamma rays, X-rays and microwaves respectively in vacuum, then
(A) $v_s > v_x > v_m$ (B) $v_s < v_x < v_m$
(C) $v_s > v_x > v_m$ (D) $v_s = v_x = v_m$

9. The frequency order for X-rays (A), γ-rays (B), UV rays (C) is
(A) B > A > C (B) A > B > C
(C) C > B > A (D) A > C > B

10. Astronomical wavelength increase due to doppler effect known as
(A) Red shift (B) Voilet shift
(C) UV (D) IR shift

11. The temperature of an object that emits electromagnetic radiation must be
(A) The temperature of an object that emits electromagnetic radiation must be
(A) higher than 0°C
(B) higher than 0 K
(C) higher than that of its surroundings
(D) high enough for it to glow

ASSERTION AND REASON

12. **Assertion :** Quasar emits radiowaves more than radio galaxy.
Reason : Quasar has very small size.

13. **Assertion :** Microwave communication is preferred over optical communication.
Reason : Microwaves provide large number of channel and bandwidth compared to optical signals.

14. **Assertion :** Dipole oscillations produce electromagnetic waves.
Reason : Accelerated charge produces electromagnetic waves.

15. **Assertion :** Electromagnetic waves are transverse in nature
Reason : the electric and magnetic fields of an e.m. wave are perpendicular to each other and also perpendicular to the direction of wave propogation.

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16. **Assertion :** In electromagnetic waves electric field and magnetic field lines are perpendicular to each other.

Reason : Electric field and magnetic field are self sustaining.

17. **Assertion :** electromagnetic radiations exert pressure.

Reason : Electromagnetic-waves carry both momentum and energy.

18. **Assertion :** Static crashes are heard on radio, when lightning flash occurs in the sky.

Reason : electromagnetic waves having frequency of radio wave range interfere with radio waves.

19. **Assertion :** UV radiation causes photo dissociation of ozone into O_2 and O, thus causing damage to the stratospheric ozone layer.

Reason : Ozone hole is resulting in global warming and climate change.

20. **Assertion :** The electromagnetic waves are transverse in nature.

Reason : Waves of wavelength 10 mm are radiowave and microwave.

21. **Assertion :** When a charged particle moves in a circular path. It produces electromagnetic wave.

Reason : Charged particle has acceleration.

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ANSWER KEY

EXERCISE - 1

1. D **2.** A **3.** A **4.** B **5.** B **6.** C **7.** B **8.** C **9.** B **10.** D **11.** D **12.** A **13.** B
14. A **15.** D **16.** D **17.** D **18.** D **19.** B **20.** B

EXERCISE - 2

1. C **2.** B **3.** C **4.** D **5.** C **6.** A **7.** B **8.** D **9.** A **10.** C **11.** C **12.** A **13.** C
14. C **15.** A **16.** B **17.** C **18.** A **19.** C **20.** A **21.** C **22.** C **23.** D **24.** B **25.** D **26.** A

EXERCISE - 3

1. A **2.** A **3.** B **4.** A **5.** B **6.** A

EXERCISE - 4 : PART # 1

1. A **2.** A **3.** B **4.** D **5.** A **6.** C **7.** C **8.** C **9.** D **10.** D **11.** A **12.** A **13.** A
14. C **15.** B

PART # 2

1. C **2.** D **3.** D **4.** D **5.** C **6.** B **7.** A **8.** D **9.** A **10.** A **11.** B **12.** B **13.** D
14. A **15.** A **16.** B **17.** B **18.** A **19.** B **20.** C **21.** A

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HINTS & SOLUTIONS

EXERCISE - 1
NEET LEVEL

1.	D	2.	A	3.	A	4.	B	5.	B	6.	C
7.	B	8.	C	9.	B	10.	D	11.	D	12.	A
13.	B	14.	A	15.	D	16.	D	17.	D	18.	D
19.	B	20.	B								

EXERCISE - 2
AIIMS LEVEL

1.	C	2.	B	3.	C	4.	D	5.	C	6.	A
7.	B	8.	D	9.	A	10.	C	11.	C	12.	A
13.	C	14.	C	15.	A	16.	B	17.	C	18.	A
19.	C	20.	A	21.	C	22.	C	23.	D	24.	B
25.	D	26.	A								

EXERCISE - 3
(Assertion & Reason)

1.	A	2.	A	3.	B	4.	A	5.	B

6. 1. $\lambda = (c/\nu) = 1.5 \times 10^{-2}$ m
   2. $B_0 = (E_0/c) = 1.6 \times 10^{-7}$ T
   3. Energy density in E field : $u_E = (1/2)\varepsilon_0 E^2$
      Energy density in B field: $u_B = (1/2\mu_0)B^2$

EXERCISE - 4
P-1 (NEET/AIPMT)

1. **(A)** Frequency of radiations given are listed below.

	Waves		Frequency (in Hz)
1.	γ-rays	**(A)**	3×10^{21} to 3×10^{18}
2.	X-rays	**(B)**	3×10^{18} to 3×10^{16}
3.	Ultraviolet radiation	**(C)**	3×10^{16} to 7.5×10^{14}

Thus, corrent order is a > b > c.

2. **(A)** For electron to pass undeflected, electric force on electron
= magnetic force on electron
i.e. $eE = evB$

or $v = \frac{E}{B}$ or $v = \frac{|E|}{|B|}$

3. **(B)** An electromaggnetic wave is the wave composed of the oscillations of electric and magnetic fields in mutually perpendicular planes and these oscillations are perpendicular to the direction of propagation of wave.
The direction of propagation of electromagnetic wave is given by poynting vector

$$s = E \times H = \frac{E \times B}{\mu_0}$$

This is parallel to E × B.

4. **(D)** The wavelength order of waves are given below

Waves	Wavelength (in Å)
(A) X-rays	0.001 Å to 100 Å
(B) Ultraviolet rays	10 Å to 4000 Å
(C) γ-rays	0.0001 Å to 1 Å
(D) Cosmic rays	upto 4×10^{-3} Å

5. **(A)**
(A) β-rays are fast moving electrosn. So, they are not electromagnetic waves.
(B) Heat rays can travel through vaccum *via* radiation process. They are electromagnetic waves.
(C) X-rays are electromagnetic waves having wavelengths from about 10^{-8} m to 10^{-12} m.
(D) γ-rays are electromagnetic waves having wavelengths ranging from about 10^{-16} m to 10^{-14} m.
Hence, choice **(A)** is correct.

6. **(C)** Wavelength order of given rays are listed below

Waves	Wavelength (in Å)
Visible light	4000 – 7000
X-rays	$10^{-3} - 10^{2}$
Microwaves	$10^{7} - 10^{9}$

So, $\lambda_x < \lambda_v < \lambda_m$

7. **(C)** Comparing the given equation

$$E_y = 2.5\frac{N}{C}\cos\left[\left(2\pi \times 10^6 \frac{\text{rad}}{\text{m}}\right)t - \left(\pi \times 10^{-2}\frac{\text{rad}}{\text{sec}}\right)x\right]$$

With the standard equation

$$E_y = E_0 \cos(\omega t - kx)$$

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we get $\omega = 2\pi f = 2\pi \times 10^6$

$\therefore \quad f = 10^6$ Hz

Moreover, we know that

$$\frac{2\pi}{\lambda} = k = \pi \times 10^{-2}\, m^{-1}$$

$\Rightarrow \quad \lambda = 200$ m

As direction of field E of electromagnetic wave is in y direction so, the wave is moving along positive x-direction with frequency 10^6 Hz and wavelength 200 m.

8. **(C)** The time varying electric and magnetic fields are mutually perpendicular to each other and also perpendicular to the direction of propagation.

9. **(D)** Decreasing order of wavelength of various rays is Microwave > Infrared > Ultraviolet > Gamma rays

10. **(D)** As we know that $\mu = E \times B = E_0\hat{i} + B_0\hat{j}$

E × B points in the directio of wave propagation.

11. **(A)** Electromagnetic wave equation is given by

$$E = E_0 \cos(kz - \omega t) \qquad ...(i)$$

Speed of electromagnetic wave, $v = \frac{\omega}{k}$

Given, equation is

$$E = \hat{i}40\cos(kz - 6\times10^8 t) \qquad ...(ii)$$

Comparing Eqs. (i) and (ii), we get

$\omega = 6 \times 10^8$

and $E_0 = 40\,\hat{i}$

Here, wave factor, $k = \frac{\omega}{v} = \frac{6\times10^8}{3\times10^8} = 2\ m^{-1}$

12. **(C)** It is an electromagnetic wave. The frequency of the microwave oven must match the resonant frequency of the water molecules.

Note :

In the presence of microwaves, water molecules oscillate with frequecny of microwaves and large heat is developed.

13. **(A)** Given, energy of EM waves is of the order of 15 ke V

i.e. $E = hv = h \times \frac{c}{\lambda}$

$$\Rightarrow \quad \lambda = \frac{h\times c}{E} = \frac{6.624\times10^{-34}\times3\times10^{18}}{15\times10^3\times1.6\times10^{-19}}$$

$$= \frac{1.3248\times10^{-29}}{1.6\times10^{-19}} = 0.828\times10^{-10}\ m$$

$= 0.828$ Å $\qquad [\because 1Å = 10^{-10} m]$

$\lambda = 0.828$ Å

Thus, this spectrum is a part of X-rays.

14. **(C)** A particle is known that an electric charge at rest has electric field in the region around it, but no magnetic field. A moving charge produces both the electric and magnetic fields. If a chargr is movign with a constant velocity, the electric and magnetic fields will not change with time, hence no EM wave will be produced. But if the charge is moving with a non-zero acceleration, both the electric and magnetic field will change with space and time, it then produces EM wave. This shows that accelerated charge emits electromagnetic waves.

15. **(B)** Given, root mean square value of electric field,

$E_{rms} = 6$ V/m

We know that, peak value of electric field,

$$E_0 = \sqrt{2}\, E_{rms}$$

$$\Rightarrow \quad E_0 = \sqrt{2}\times6 \text{ V/m}$$

Also, we know that, $c = \frac{E_0}{B_0}$

where, c = speed of light in vacuum

B_0 = peak value of magnetic field

$$\Rightarrow \quad B_0 = \frac{E_0}{c} \Rightarrow B_0 = \frac{\sqrt{2}\times6}{3\times10^8}$$

$$\Rightarrow \quad B_0 = \frac{8.48}{3}\times10^{-8} \Rightarrow E_0 = 2.83\times10^{-8}\ T$$

EXERCISE - 4

P-2 (AIIMS)

1. **(C)** Alternatives **(A)** and **(B)** are dimensionally incorrect. When $d \to 0$, $I \to I_0$. Alternative **(C)** meets this requirement.

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2. **(D)** X-rays are electromagnetic waves. They are not affected by electric field and magnetic field.

3. **(D)** Light propagates rectilinearly. But it can take a slight turn at obstacles. This property of light is due to its wave nature.

4. **(D)** Relation for velocity of light $(c) = \sqrt{\frac{1}{\varepsilon_0 \mu_0}}$ (where ε_0 = permittivity constant equal to 8.85×10^{-12} F/m) and μ_0 = permeability constant equal to 1.26×10^{-6} H/m.

$$\text{Velocity of light } (c) = \sqrt{\frac{1}{\varepsilon_0 \mu_0}}$$

$$= \sqrt{\frac{1}{(8.85\times10^{-12})\times(1.26\times10^{-6})}} \approx 3\times10^{8}\ \text{m/s}.$$

5. **(C)** Pressure = Force/area

$$I = \frac{\text{Energy}}{\text{area} - \text{time}} = \frac{F \cdot S}{At} = \frac{Fc}{A}. \text{ or } I/c = P.$$

6. **(B)** Infrared rays or heat rays used for heating thermocouples to produce electricity.

7. **(A)** Velocity of electromagnetic wave is

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

8. **(D)**

9. **(A)** The frequency order for given electromagnetic waves is as follows.

$\upsilon_{\gamma\text{-rays}} > \upsilon_{\text{X-Rays}} > \upsilon_{\text{UV}}$

B > A > C

10. **(A)** In physics (namely astrophysics), redshift happens when light or other electromagnetic radiation from an object moving away from the observer is increased in wavelength or shifted to the red end of the spectrum.

11. **(B)**

12. **(A)** A quasar is a very big source of radio waves and its size is very small as compared to the size of a galaxy. A radio galaxy emits radio waves which lie in the range 10^{30} to 10^{38} watt. A quasar emits radio waves which lie in the range of 10^{37} to 10^{38} watt.

13. **(D)** If the frequencies of the waves are less than that of the critical frequency, they will be reflected back as the ionosphere has refractive index less than free space. This is the principle of sky wave propagation. Therefore the assertion is wrong.

14. **(A)** Assertion is true. The reason is also true according to the classical theory of Maxwell. The dipole oscillation gives radiation because the charges are accelerated. (Any oscillation has acceleration).

15. **(A)** The sky waves are the radio waves used for very long distance radio communication at medium and high frequencies (i.e., shortwave band). In shorter wavelength, attenuation is very less.

16. **(B)** Electromagnetic waves are those waves in which there are sinusoidal variation of electric and magnetic field vectors at right angles to each other as well as at right angles to the direction of wave propagation. They are self-sustaining oscillations of electric and magnetic fields in free space or vacuum.

17. **(B)** Electromagnetic wave transport energy, momentum and information. Electromagnetic waves exert radiation pressure on surface.

18. **(A)**

19. **(B)** $O_3 \xrightarrow{\text{UV(sun)}} O_2 + O$

20. **(C)** Wavelength of 10 mm lies in infrared region.

21. **(A)** Accelerated charges radiate electromagnetic waves.

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