Solution

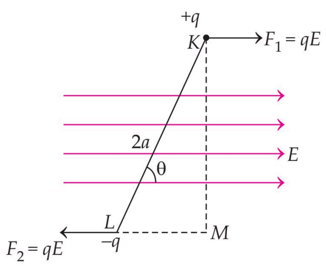
Final 50

(Most Probable Questions for Boards 2026)

CBSE PHYSIS 12TH

(Detailed Answers)

1. (i) Consider a dipole placed in uniform electric field **E** as shown in figure. Both charges of the dipole experience equal and opposite forces and hence, net translatory force on dipole is zero.



$\therefore \quad F = F_1 - F_2 = qE - qE = 0$

As the lines of action of forces $\mathbf{F}_1$ and $\mathbf{F}_2$ are different, so dipole experiences a torque given by

τ = Either force × perpendicular distance between lines of action of force

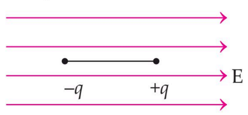
$= qE(2a\sin\theta)$

$\tau = pE\sin\theta$ ...(i)

In vector notation, $\tau = \mathbf{p} \times \mathbf{E}$

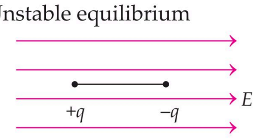
In case of non-uniform electric field, dipole will experience both force as well as torque.

(ii) (a) Stable equilibrium



$U = -pE\cos 0° = -pE$

(b) Unstable equilibrium

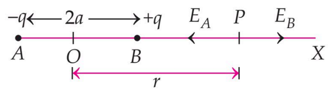


$U = -PE\cos 180° = +pE$

(iii)(a) When **E** is parallel to **p**, the dipole has net force in the direction of increasing field.

(b) When **E** is anti-parallel to **p**, the dipole has net force in the direction of decreasing field.

2. (i) **E at axial point or an end on position**



The electric field at axial point P due to charges of dipole is given by

$$E_A = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{AP^2} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{(r+a)^2} \text{ along } PB \quad \text{...(i)}$$

$$E_B = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{BP^2}$$

$$= \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{(r-a)^2} \text{ along } PX \quad \text{...(ii)}$$

Resultant electric field intensity,

$$E = E_B - E_A \text{ along } PX$$

$$E = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right]$$

$$E = \frac{q}{4\pi\varepsilon_0}\left[\frac{4ar}{(r^2-a^2)^2}\right]$$

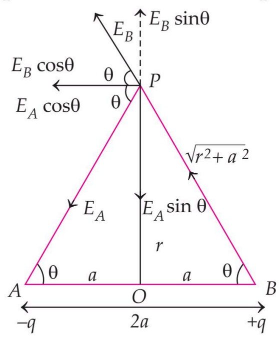
$$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2pr}{(r^2-a^2)^2} \quad [\because p = 2aq] \text{ ...(iii)}$$

If $r >> a$

$$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2pr}{r^4} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2p}{r^3} \quad \text{...(iv)}$$

The direction of electric field at axial point is in the direction of the dipole moment.

(ii) ***E* at equatorial line of electric dipole**



The electric field at equatorial point P due to charges of dipole is given by

$$E_A = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{(r^2 + a^2)} \text{ from } P \text{ to } A \qquad \text{...(v)}$$

$$E_B = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{(r^2 + a^2)} \text{ from } B \text{ to } P \qquad \text{...(vi)}$$

On resolving $\mathbf{E}_A$ and $\mathbf{E}_B$ into two rectangular components, their sine components being equal and opposite, cancel out each other, while cosine components act in same direction, so the net electric field intensity is

$$E = E_A \cos\theta + E_B \cos\theta = 2E_A \cos\theta$$

$$= 2 \times \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{(r^2 + a^2)} \cdot \frac{a}{\sqrt{r^2 + a^2}}$$

$$\left[\because \cos\theta = \frac{a}{\sqrt{r^2 + a^2}}\right]$$

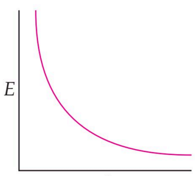
$$E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p}{(r^2 + a^2)^{\frac{3}{2}}} \qquad \text{...(vii)}$$

$$[\because p = 2aq]$$

If $r >> a$, $E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p}{r^3}$ ...(viii)

The direction of $\mathbf{E}$ is opposite to direction of dipole moment and parallel to line joining the charges of dipole.

In both cases for short dipole, $E \propto 1/r^3$.

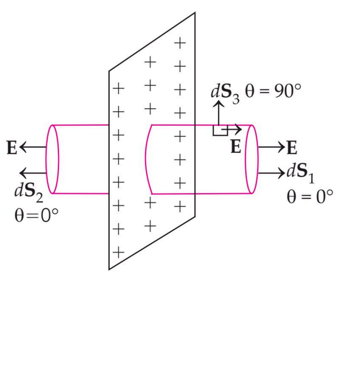


3. (i) **Electric flux** It is defined as the number of electric lines of force passing normal to the surface. It is a scalar quantity.

$$\phi = \mathbf{E} \cdot d\mathbf{S} = EdS\cos\theta$$

The SI unit of electric flux is $\frac{\text{Nm}^2}{\text{C}}$ or volt-metre.

(ii) Let electric charge be uniformly distributed over thin, non-conducting infinite sheet, so charge density is given by $\sigma = \frac{q}{A}$



In order to calculate $\mathbf{E}$ due to sheet, consider cylindrical Gaussian surface as shown in figure, then by Gauss' law

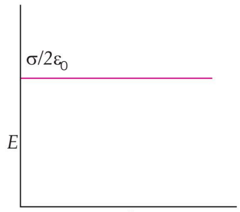
$$2\int_{\text{Circular faces}} \mathbf{E} \cdot d\mathbf{S} + \int_{\text{Cylindrical faces}} \mathbf{E} \cdot d\mathbf{S} = \frac{q}{\varepsilon_0}$$

$$2\int_{\text{Circular faces}} EdS\cos 0° + \int_{\text{Cylindrical faces}} EdS\cos 90° = \frac{\sigma A}{\varepsilon_0}$$

$$2EA = \frac{\sigma A}{\varepsilon_0} \qquad [\because \cos 90° = 0]$$

$$E = \frac{\sigma}{2\varepsilon_0} \qquad \text{...(i)}$$

Hence, $\mathbf{E}$ is independent of distance for uniformly charged infinite plane sheet.



(iii) As point A is on left hand side of all sheets, so

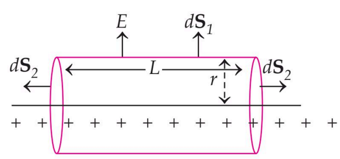
$$E_A = -\left(\frac{2\sigma}{2\varepsilon_0}\right) - \left(\frac{-2\sigma}{2\varepsilon_0}\right) - \left(\frac{\sigma}{2\varepsilon_0}\right) = -\frac{\sigma}{2\varepsilon_0}$$

Negative sign means direction of electric field is towards left. As point D is on right hand side of all sheets, so

$$E_D = \frac{2\sigma}{2\varepsilon_0} + \left(\frac{-2\sigma}{2\varepsilon_0}\right) + \left(\frac{\sigma}{2\varepsilon_0}\right) = \frac{\sigma}{2\varepsilon_0}$$

The direction of electric field at point D is on right hand side.

4. (i) Consider an infinitely long charged wire of linear charge density $\lambda = \frac{dq}{dl}$. In order to find electric field at distance 'r' from wire, assuming cylindrical Gaussian surface as shown in the figure and using Gauss' law, we have



$$\int \mathbf{E} \cdot d\mathbf{S}_1 + 2\int \mathbf{E} \cdot d\mathbf{S}_2 = \frac{q}{\varepsilon_0}$$

$$\int EdS_1 \cos 0° + 2\int EdS_2 \cos 90° = \frac{\lambda L}{\varepsilon_0}$$

$$E \cdot 2\pi rL = \frac{\lambda L}{\varepsilon_0} \qquad [\because \cos 90° = 0]$$

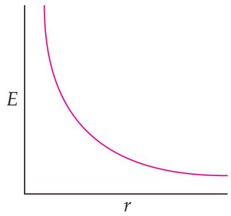
$$E = \frac{\lambda}{2\pi\varepsilon_0 r} \qquad \text{...(i)}$$

(ii) Given, $E = 9 \times 10^4 \text{ NC}^{-1}$, $r = 2 \times 10^{-2}$ m

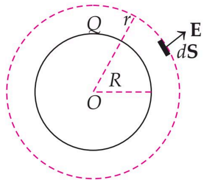
$$E = \frac{\lambda}{2\pi\varepsilon_0 r} = \frac{2\lambda}{4\pi\varepsilon_0 r}$$

$$9 \times 10^4 = \frac{2 \times 9 \times 10^9 \lambda}{2 \times 10^{-2}}$$

$$\Rightarrow \qquad \lambda = 10^{-7} \text{ C/m}$$



5. (i) **Electric field outside the shell** Consider a uniformly charged thin spherical shell of radius R carrying charge Q.



In order to find electric field at distance 'r' ($r > R$), imagine a spherical Gaussian surface concentric with shell, then direction of $\mathbf{E}$ and $d\mathbf{S}$ are same, so by Gauss' law

$$\oint \mathbf{E} \cdot d\mathbf{S} = \frac{q}{\varepsilon_0}$$

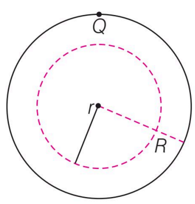
$$\oint E dS \cos 0° = \frac{q}{\varepsilon_0}$$

$$E \cdot 4\pi r^2 = \frac{q}{\varepsilon_0}$$

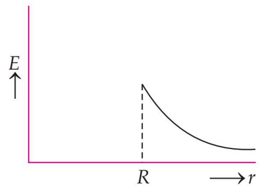
$$\Rightarrow \qquad E = \frac{q}{4\pi\varepsilon_0 r^2} \qquad \text{...(i)}$$

(ii) **Electric field inside the shell**

Consider a spherical Gaussian surface of radius r ($r < R$) concentric with shell. Since, Gaussian surface does not enclose any charge.



So, $$\oint \mathbf{E} \cdot d\mathbf{S} = \frac{0}{\varepsilon_0}, \; E = 0$$



6. Let q_1 and q_2 be the charges distributed on smaller and larger spheres, then according to question

$$\sigma = \frac{q_1}{4\pi r^2} = \frac{q_2}{4\pi R^2}$$

$$\Rightarrow \quad q_1 = 4\pi r^2 \sigma \text{ and } q_2 = 4\pi R^2 \sigma \qquad \text{...(i)}$$

Now, total charge $Q = q_1 + q_2$

$$Q = \sigma [4\pi r^2 + 4\pi R^2]$$

or $$\sigma = \frac{Q}{4\pi (r^2 + R^2)} \qquad \text{...(ii)}$$

Now, potential at common centre,

$$V = V_1 + V_2$$

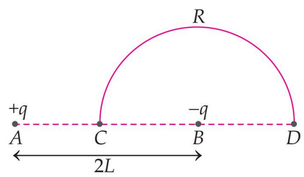
$$V = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1}{r} + \frac{q_2}{R}\right]$$

$$V = \frac{1}{4\pi\varepsilon_0}\left[\frac{4\pi r^2 \sigma}{r} + \frac{4\pi R^2 \sigma}{R}\right]$$

$$V = \frac{\sigma}{\varepsilon_0}(r + R) = \frac{Q(r + R)}{4\pi\varepsilon_0 (r^2 + R^2)}$$

{using Eq. (ii)}

7. According to the question,



From figure, $AC = L$, $BC = L$, $BD = BC = L$

$$AD = AB + BD = 2L + L = 3L$$

Potential at C is given by

$$V_C = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{AC} + \frac{(-q)}{BC}\right] = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{L} - \frac{q}{L}\right] = 0$$

Potential at D,

$$V_D = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{AD} + \frac{(-q)}{BD}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{3L} - \frac{q}{L}\right] = \frac{-2}{3} \cdot \frac{q}{4\pi\varepsilon_0 L}$$

Work done in moving charge $+Q$ along the semi-circle CRD,

$$W = Q(V_D - V_C) = Q\left[\frac{-2}{3}\frac{q}{4\pi\varepsilon_0 L} - 0\right] = \frac{-qQ}{6\pi\varepsilon_0 L}$$

8. Charge on shell A, $q_A = 4\pi a^2\sigma$

Charge on shell B, $q_B = -4\pi b^2\sigma$

Charge of shell C, $q_C = 4\pi c^2\sigma$

Potential of shell A Any point on the shell A lies inside the shells B and C.

$$V_A = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_A}{a} + \frac{q_B}{b} + \frac{q_C}{c}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{4\pi a^2\sigma}{a} - \frac{4\pi b^2\sigma}{b} + \frac{4\pi c^2\sigma}{c}\right]$$

$$= \frac{\sigma}{\varepsilon_0}(a - b + c)$$

Any point on B lies outside the shell A and inside the shell C. Potential of shell B,

$$V_B = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_A}{a} + \frac{q_B}{b} + \frac{q_C}{c}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{4\pi a^2\sigma}{b} - \frac{4\pi b^2\sigma}{b} + \frac{4\pi c^2\sigma}{c}\right]$$

$$= \frac{\sigma}{\varepsilon_0}\left[\frac{a^2}{b} - b + c\right]$$

Any point on shell C lies outside the shells A and B. Therefore, potential of shell C,

$$V_C = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_A}{a} + \frac{q_B}{b} + \frac{q_C}{c}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{4\pi a^2\sigma}{c} - \frac{4\pi b^2\sigma}{c} + \frac{4\pi c^2\sigma}{c}\right]$$

$$V_C = \frac{\sigma}{\varepsilon_0}\left[\frac{a^2}{c} - \frac{b^2}{c} + c\right]$$

According to the question

$$\therefore \quad V_A = V_C$$

$$a - b + c = \frac{a^2 - b^2}{c} + c$$

$$(a - b) = \frac{(a - b)(a + b)}{c} \Rightarrow c = a + b$$

9. (i) Total initial energy when switch S is closed and dielectrics are not inserted.

$$U_{\text{in}} = \frac{1}{2}CV^2 + \frac{1}{2}CV^2 = CV^2 \quad \ldots\text{(i)}$$

Now, when switch S is opened and dielectric is inserted, then for capacitor A, battery remains connected, while for capacitor B, battery is disconnected, so

$$U_F = \frac{1}{2}KCV^2 + \frac{1}{2}\cdot\frac{CV^2}{K}$$

$$= \frac{CV^2}{2}\left[K + \frac{1}{K}\right]$$

$$U_F = \frac{CV^2}{2}\left[\frac{K^2 + 1}{K}\right] \quad \ldots\text{(ii)}$$

Therefore, from Eqs. (i) and (ii), we get the ratio,

$$\Rightarrow \quad \frac{U_{\text{in}}}{U_F} = \frac{2K}{K^2 + 1} \quad \ldots\text{(iii)}$$

(ii) New capacitance of C_1 is

$$C_1 = \frac{K_1 A\varepsilon_0}{d} \quad \ldots\text{(i)}$$

For C_2, $$\frac{1}{C_2} = \frac{d}{2K_1A\varepsilon_0} + \frac{d}{2K_2A\varepsilon_0}$$

$$\Rightarrow \quad C_2 = \frac{2A\varepsilon_0}{d}\left(\frac{K_1K_2}{K_1 + K_2}\right) \quad \ldots\text{(ii)}$$

For C_3,

$$C_3 = \frac{K_3A\varepsilon_0}{2d} + \frac{K_4A\varepsilon_0}{2d}$$

$$= \frac{A\varepsilon_0}{2d}(K_3 + K_4) \quad \ldots\text{(iii)}$$

From Eqs. (i), (ii) and (iii), we get

$$K = \frac{2K_1K_2}{K_1 + K_2} = \frac{K_3 + K_4}{2}$$

This is the required relation between the dielectric constants K_1, K_2, K_3 and K_4

10. Given, area of each plate, $A = 6 \times 10^{-3}\,\text{m}^2$

Distance between the plates, $d = 3\text{ mm} = 3 \times 10^{-3}\text{ m}$

(i) Capacitance of parallel plate capacitor is given by

$$C = \frac{\varepsilon_0 A}{d} = \frac{8.85 \times 10^{-12} \times 6 \times 10^{-3}}{3 \times 10^{-3}}$$

$$\therefore \quad C = 1.77 \times 10^{-11}\text{F}$$

(ii) Charge on parallel plate capacitor is given by

$$Q = CV = 1.77 \times 10^{-11} \times 100$$

$$= 1.77 \times 10^{-9}\text{C}$$

(iii) Given, $K = 6$

Now, $C' = KC \Rightarrow \dfrac{Q'}{V} = \dfrac{KQ}{V}$

$$\therefore \quad Q' = KQ = 6 \times 1.77 \times 10^{-9} = 10.62 \times 10^{-9}\text{C}$$

11. (i) Resistance of rod having cross-sectional area A and length l is

$$R_1 = \frac{\rho l}{A}$$

Now, resistance of rod having cross-sectional area $\frac{A}{2}$ and length $2l$ is $R_2 = \dfrac{\rho(2l)}{\frac{A}{2}} = \dfrac{4\rho l}{A} = 4R_1$

According to question, $I = \dfrac{V}{R_1} = \dfrac{V'}{R_2} \Rightarrow \dfrac{V}{R_1} = \dfrac{V'}{4R_1}$

or potential across new rod, $V' = 4\text{V}$

(ii) (a) In series, current across wires remains the same, so $I_1 = I_2$

$v_1 A_1 ne = v_2 A_2 ne$

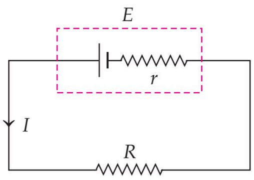
As material is same, so number density of free electrons (n) is same.

Hence, $\frac{v_1}{v_2} = \frac{A_2}{A_1}$

(b) In parallel combination, potential across wires remains same, so $\frac{v_1}{v_2} = \frac{eV\tau}{ml} \times \frac{ml}{eV\tau} = 1$

12. **Electromotive force (EMF)** The potential drop across the terminals of a cell when no current is drawn from it is known as emf of cell.

Terminal potential difference (V) When current is drawn from a cell, the potential drop across its terminals is known as terminal potential difference.



Now, $I = \frac{E}{R + r}$

where, r is internal resistance of a cell.

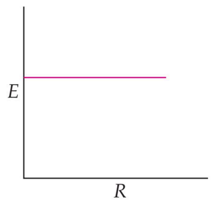
The terminal potential difference is given by

$$V = IR = \frac{ER}{R + r}$$

or $VR + Vr = ER$ or $r = \left(\frac{E}{V} - 1\right) R$

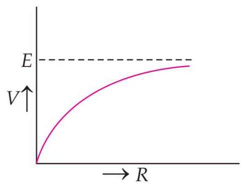
Graphs

(i)



As emf of cell is independent of external resistance R.

(ii)



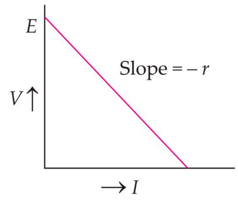
$$V = IR = \frac{ER}{R + r} = \frac{E}{\left(1 + \frac{r}{R}\right)}$$

As, R increases, V also increases.

(iii) As, $E = V + Ir$

So, at $V = 0$, $r = \frac{E}{I}$

and at $I = 0$, $E = V$



12. Let E and r be the emf and internal resistance of each cell.

***Case* I** When the cells are in series.

Total emf of cells = $14E$

Total resistance of circuit = $82.6 + 14r$

$\therefore$ Current in the circuit is given by

$$\frac{14E}{82.6 + 14r} = 0.25\,\text{A} \quad \ldots\text{(i)}$$

***Case* II** When the cells are in parallel.

Total emf of cells = E

Total resistance of circuit

$$= 0.053 + \frac{r}{14}$$

$\therefore$ Current in the circuit is given by

$$\frac{E}{0.053 + \frac{r}{14}} = 25\,\text{A} \quad \ldots\text{(ii)}$$

Dividing Eq. (i) by Eq. (ii), we get

$$14 \frac{\left(0.053 + \frac{r}{14}\right)}{(82.6 + 14r)} = 10^{-2}$$

$$\Rightarrow 14 \times \frac{14 \times 0.053 + r}{14} \times 10^2 = 82.6 + 14r$$

$$\Rightarrow \quad 5.3 \times 14 + 100r = 82.6 + 14r$$

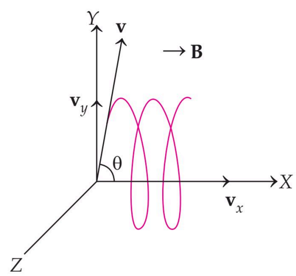
Solving, we get

$$r = 0.097\Omega \approx 0.1\Omega$$

Substituting the value of r in Eq. (i), we get

$$E = 1.5\,\text{V}$$

14. (i) Let charged particles enter magnetic field **B** with velocity **v** at an angle θ with the direction of magnetic field.



Then, because of velocity component $v_y = v\sin\theta$ charged particle experiences Lorentz force and due to component $v_x = v\cos\theta$, it moves along the direction of magnetic field and resultant path will be helical in nature.

Now, magnetic Lorentz force = Centripetal force

$$Bqv\sin\theta = \frac{m(v\sin\theta)^2}{r}$$

or $$r = \frac{mv\sin\theta}{Bq} \quad \text{...(i)}$$

Time taken for one revolution,

$$T = \frac{2\pi r}{v\sin\theta} = \frac{2\pi m}{Bq} \quad \text{...(ii)}$$

Distance moved along the magnetic field in helical path,

$$x = v_x T = \frac{2\pi mv\cos\theta}{Bq} \quad \text{...(iii)}$$

(ii) As, charged particle experiences magnetic Lorentz force due to which it covers circular path, so

$$Bqv\sin 90^\circ = \frac{mv^2}{r}$$

or $$r = \frac{mv}{Bq} \quad \text{...(iv)}$$

Now, $$\frac{1}{2}mv^2 = qV$$

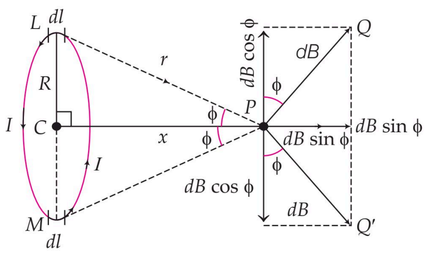
or $$v = \sqrt{\frac{2qV}{m}} \quad \text{...(v)}$$

Using Eq. (v) in Eq. (iv), we have

$$r = \frac{1}{B}\sqrt{\frac{2mV}{q}} \quad \text{...(vi)}$$

15. (i) **Magnetic field at the axis of a circular loop**

Consider a circular loop of radius R carrying a current I with its plane perpendicular to the plane of paper. Consider a small element of length dl of the coil at point A. The magnitude of the magnetic induction $d\mathbf{B}$ at point P due to this element is given by



$$d\mathbf{B} = \frac{\mu_0}{4\pi}\cdot\frac{Idl\sin\theta}{r^2} = \frac{\mu_0}{4\pi}\cdot\frac{Idl\sin 90^\circ}{r^2} = \frac{\mu_0 Idl}{4\pi r^2}$$

[$\because$ $d\mathbf{B}$ is perpendicular to plane containing $d\mathbf{l}$ and $\mathbf{r}$.]

By symmetry, components of magnetic field perpendicular to axis cancel out each other, while components along parallel axis remain in same direction, so total magnetic field is given by

$$B = \int dB\sin\phi = \int \frac{\mu_0}{4\pi}\cdot\frac{Idl}{r^2}\cdot\frac{R}{r}$$

$$B = \frac{\mu_0}{4\pi}\cdot\frac{I\cdot 2\pi R\cdot R}{(R^2+x^2)^{\frac{3}{2}}} = \frac{\mu_0}{4\pi}\frac{2\pi IR^2}{(R^2+x^2)^{\frac{3}{2}}}$$

(ii) For coil L_1,

$R_1 = 3$ cm, $x_1 = 4$ cm, $I_1 = 1$ A,

$$\sqrt{R_1^2 + x_1^2} = 5\text{ cm}$$

For coil L_2,

$R_2 = 4$ cm, $x_2 = 3$ cm, $I_2 = ?$,

$$\sqrt{R_2^2 + x_2^2} = 5\text{ cm}$$

For net magnetic field at point O, to be zero, current I_2 must be in opposite direction as that of loop L_1 and $B_1 = B_2$

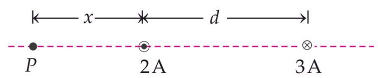
$$\frac{\mu_0}{4\pi}\cdot\frac{2\pi I_1 R_1^2}{(R_1^2+x_1^2)^{\frac{3}{2}}} = \frac{\mu_0}{4\pi}\cdot\frac{2\pi I_2 R_2^2}{(R_1^2+x_2^2)^{\frac{3}{2}}}$$

$$9\times 1 = 16 I_2$$

$$\frac{9}{16} = I_2 \text{ or } I_2 = 0.56\text{ A}$$

16. Let d be the distance between two current-carrying wires, then the magnetic field in

the region I at a point P at a distance x can be calculated using figure given below.



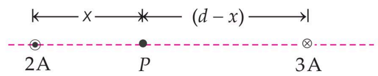
Due to 2 A, $B_1 = \frac{\mu_0\times I_1}{2\pi x} = \frac{\mu_0\times 2}{2\pi x}$, downward

Due to 3 A, $B_2 = \frac{\mu_0\times I_2}{2\pi(x+d)} = \frac{\mu_0\times 3}{2\pi(x+d)}$, upward

$\therefore$ Net magnetic field,

$$B_P = \frac{\mu_0}{2\pi}\left(\frac{2}{x} - \frac{3}{x+d}\right), \text{ downward} \quad \text{...(i)}$$

The magnetic field in region II is

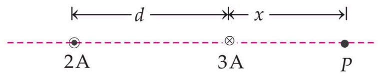


Due to 2 A, $B_1 = \frac{\mu_0\times 2}{2\pi x}$, upward

Due to 3 A, $B_2 = \frac{\mu_0\times 3}{2\pi(d-x)}$, upward

$\therefore$ Net magnetic field, $B_P = \frac{\mu_0}{2\pi}\left(\frac{2}{x} + \frac{3}{d-x}\right)$, upward

The magnetic field in region III is



Due to 2 A, $B_1 = \frac{\mu_0 \times 2}{2\pi(x+d)}$, upward

Due to 3 A, $B_2 = \frac{\mu_0 \times 3}{2\pi x}$, downward

$\therefore$ Net magnetic field,

$$B_P = \frac{\mu_0}{2\pi}\left(\frac{3}{x} - \frac{2}{x+d}\right), \text{ downward}$$

As the current and hence the magnetic field, due to 2 A, is less than that due to 3 A.

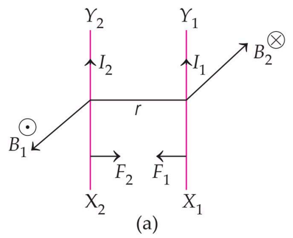
So, for zero magnetic field,

$$\frac{\mu_0}{2\pi}\left(\frac{2}{x} - \frac{3}{x+d}\right) = 0$$

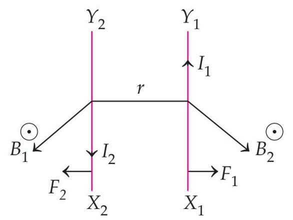
$\Rightarrow$ $2x + 2d = 3x$ or $x = 2d$

So, the point lies in region I.

17. (i) Consider two long thin conductors X_1Y_1 and X_2Y_2 parallel to each other in air or vacuum separated by distance r as shown in fig. (a). If I_1 and I_2 are the currents in the wires respectively, then



(a)



(b)

The magnetic field produced by current-carrying conductor X_2Y_2 at location of other wire X_1Y_1 is $B_2 = \frac{\mu_0}{4\pi}\cdot\frac{2I_2}{r}$

(in direction perpendicular to plane of paper directing inwards)

Then, force experience per unit length by conductor X_1Y_1 carrying current I_1 is

$$\frac{F_1}{l} = I_1(1 \times B_2) = \frac{\mu_0}{4\pi}\cdot\frac{2I_1I_2}{r}$$

According to Fleming's left hand rule, magnetic force is towards X_2Y_2 and similarly force experienced by conductor X_2Y_2 carrying current I_2, is towards X_1Y_1.

Thus, $$\left|\frac{\mathbf{F}_1}{l}\right| = -\left|\frac{\mathbf{F}_2}{l}\right|$$

Hence, if currents in parallel conductors are in same direction, force is attractive in nature and if currents in parallel conductors are in opposite direction, force is repulsive in nature.

Definition of SI unit of current (Ampere)

$$\frac{F}{l} = \frac{\mu_0}{4\pi}\cdot\frac{2I_1I_2}{r}$$

If $I_1 = I_2 = I$, $r = 1\,\text{m}$

and $$\frac{F}{l} = 2\times10^{-7}\ \text{N/m}$$

Then, $$2\times10^{-7} = \frac{2\times10^{-7}\ I^2}{1}$$

$\Rightarrow$ $I = 1\,\text{A}$

Hence, if two infinitely long parallel conductors carrying same current in air or vacuum separated by distance of 1 m experience force per unit length of 2×10^{-7} N/m, then current in each wire is 1 A.

(ii) (a) Magnetic field at point A due to conductor 2,

$$B_2 = \frac{\mu_0}{4\pi}\cdot\frac{2(3I)}{r} = \frac{\mu_0}{4\pi}\cdot\frac{6I}{r}$$

and due to conductor 3,

$$B_3 = \frac{\mu_0}{4\pi}\cdot\frac{2(4I)}{3r} = \frac{\mu_0}{4\pi}\cdot\frac{8I}{3r}$$

Net magnetic field,

$$B_A = B_2 - B_3 = \frac{\mu_0}{4\pi}\cdot\frac{10I}{3r}$$

lies perpendicular to plane of paper directing inwards.

(b) Magnetic force per unit length on conductor 2 is

$$F = F_1 - F_3 = \frac{\mu_0}{4\pi}\cdot\frac{6I^2}{r} - \frac{\mu_0}{4\pi}\cdot\frac{2(3I)(4I)}{2r}$$

$$F = \frac{\mu_0}{4\pi}\cdot\frac{I^2}{r}[6-12] = -\frac{\mu_0}{4\pi}\cdot\frac{6I^2}{r}$$

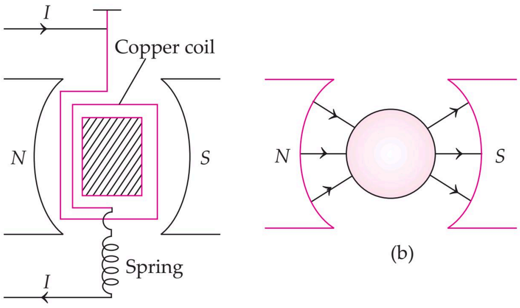
So, $|F| = \frac{\mu_0}{4\pi}\cdot\frac{6I^2}{r}$ in the direction of wire 1.

18. (i) Moving coil galvanometer is used to detect the current in a circuit. It works on principle that current-carrying coil placed in uniform magnetic field experiences a torque.

It consists of a light aluminium frame filled with soft iron. Copper coils are wounded on frame which is suspended between two concave pole pieces of strong magnet by means of phosphor-bronze wire and other end of copper coil is connected to spring which provides restoring torque.

Concave pole pieces of magnet provides radial magnetic field in which plane of coil always remains parallel to magnetic field, so when current passes through coil, it experiences

maximum force and makes **scale linear**.



(a) (b)

When current I passes through coil placed in magnetic field B, it experiences a torque, which is balanced by restoring torque produced in spring, so

Deflecting torque = Restoring torque

$$BINA = K\theta$$

$$\frac{NBAI}{K} = \theta$$

or $\theta = GI$

or $\theta \propto I$ ...(i)

where, $G = \frac{NBA}{K}$ = Galvanometer constant

(ii) Phosphor-bronze wire is used because it is a good conducting material having high tensile strength and low force constant, thus it increases the current sensitivity.

Current sensitivity It is defined as deflection of coil per unit current flowing in coil. Its SI unit is radian/ampere.

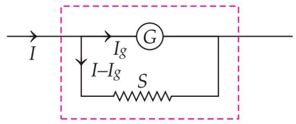
$$\text{CS} = \frac{\theta}{I} = \frac{NBA}{K}$$

Voltage sensitivity It is defined as deflection of coil per unit potential difference applied across it. Its SI unit is radian/volt.

$$\text{VS} = \frac{\theta}{V} = \frac{NBA}{KR} = \frac{CS}{R}$$

On increasing the number of turns of coil, the current sensitivity increases but it also increases the resistance which may not necessarily increase the voltage sensitivity.

19. (i) By connecting low resistance known as shunt S in parallel with coil of galvanometer, an ammeter is obtained.



$$S = \frac{I_g G}{I - I_g}$$

The ideal resistance of ammeter is zero.

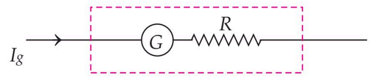
(ii) Given, $G = 15\,\Omega$, $I_g = 4 \times 10^{-3}$ A and $I = 6$ A

$$\therefore \quad S = \frac{I_g G}{I - I_g} = \frac{4 \times 10^{-3} \times 15}{6 - 4 \times 10^{-3}} \approx 0.01\,\Omega$$

Thus, on connecting a shunt of $0.01\,\Omega$ in parallel with galvanometer, the required ammeter is obtained.

20. (i) A galvanometer can be converted into voltmeter by connecting a high resistance in series with it. The ideal resistance of voltmeter is infinite.

(ii)



$$R = \frac{V}{I_g} - G$$

If the galvanometer's full- scale current is I_g, then for a $2V$ range, the series resistance R_1 is,

$$R_1 = \frac{2V}{I_g} - G \quad \text{...(i)}$$

For V,

$$R_2 = \frac{V}{I_g} - G \quad \text{...(ii)}$$

For $\frac{V}{2}$,

$$R_3 = \frac{V}{2I_g} - G \quad \text{...(iii)}$$

Subtracting Eq. (ii) from Eq. (i), we get

$$R_1 - R_2 = \frac{V}{I_g} \quad \text{...(iv)}$$

Subtracting Eq. (iii) from Eq. (i), we get

$$R_1 - R_3 = \frac{3}{2}\frac{V}{I_g} \quad \text{...(v)}$$

Dividing Eq. (v) by Eq. (iv), we get

$$\frac{R_1 - R_3}{R_1 - R_2} = \frac{3}{2}$$

$$\Rightarrow \quad 3R_2 - 2R_3 = 3R_1 - 2R_1$$

$$\therefore \quad \boxed{R_1 = 3R_2 - 2R_3}$$

21. (i) Work done, $U = MB[\cos\theta_1 - \cos\theta_2]$

(a) $U = MB[\cos 60° - \cos 90°]$

$$= \frac{1}{2}MB = \frac{1}{2} \times 6 \times 0.44 = 1.32\text{ J}$$

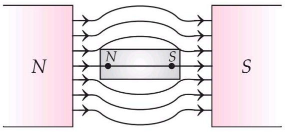
(b) $U = MB[\cos 60° - \cos 180°]$

$$= MB\left[\frac{1}{2} + 1\right] = \frac{3}{2}MB = 3.96 \text{ J}$$

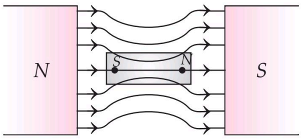
(ii) Torque, $\tau = MB\sin\theta$

For $\theta = 180°$, $\tau = 6 \times 0.44 \sin 180° = 0$

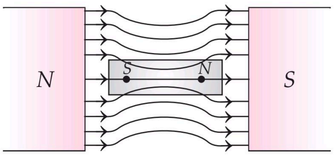
22. (i) When a bar of dimagnetic material (copper) is placed in an external magnetic field, the field lines are repelled or expelled and the field inside the material is reduced.



(ii) When a bar of paramagnetic material (Aluminium) is placed in an external field, the field lines gets concentrated inside the material and the field inside is enhanced.



(iii) When a ferromagnetic material (Iron) is placed in an internal magnetic field, the field lines are highly concentrated inside the material.



23.

Property	Ferromagnetic	Paramagnetic	Diamagnetic
Magnetic susceptibility (χ)	Very large and positive ($\chi >> 1$)	Small and positive ($\chi << 1$)	Small and negative ($\chi < 0$)
Behaviour in external magnetic field	Strongly attracted, can be permanently magnetised	Weakly attracted, cannot be permanently magnetised	Weakly repelled
Origin of magnetism	Due to parallel alignment of magnetic dipoles in domains	Due to incomplete atomic orbitals with unpaired electrons	Due to induced magnetic moment opposing applied field (Lenz's law)
Example	Iron (Fe), cobalt(Co), nickel (Ni)	Aluminium (Al), platinum (Pt)	Copper (Cu), bismuth (Bi)

24. (i) Consider a solenoid of length l, radius r $(r << l)$ having n number of turns per unit length. The magnetic field inside the solenoid when current I passes through it is $B = \mu_0 nI$

Magnetic flux linked with one turn of solenoid

$$= BA$$
$$= \mu_0 nIA$$

Total magnetic flux linked with entire solenoid,

$$\phi = \mu_0 nIAnl$$
$$LI = \mu_0 n^2 AIl$$

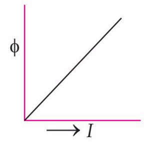
or $$L = \mu_0 n^2 Al \quad \ldots(i)$$

$$L = \frac{\mu_0 N^2 A}{l} \quad \ldots(ii)$$

$$\left[\because n = \frac{\text{Number of turns } N}{\text{length } (l)}\right]$$

Self-inductance of a solenoid depends on the number of turns, area of cross-section of solenoid and permeability of the core material.

(ii) (a) Graph for magnetic flux *versus* current



$\phi \propto I$

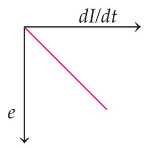
$\phi = LI$

(b) Graph for induced emf *versus* $\frac{dI}{dt}$

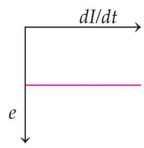
We, know that ,

$$e = \frac{-d\phi}{dt} = -L\frac{dI}{dt}$$

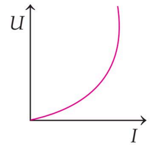
1. When $\frac{dI}{dt}$ increases linearly with e, the graph is given as



2. When $\frac{dI}{dt}$ is constant with respect to e the graph is given as

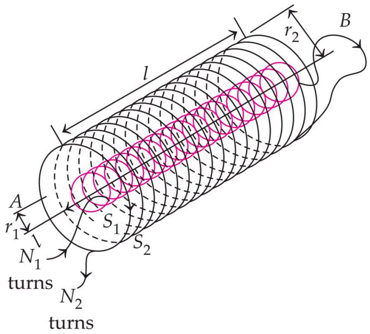


(c) Graph for magnetic otential energy stored (U) *versus* the current.



$U = \frac{1}{2} LI^2$

25. (i) Whenever changing current is passing through a coil, magnetic flux linked with neighbouring coil changes, and an induced emf is produced in the neighbouring coil. This phenomenon is known as mutual induction.



Mutual inductance is numerically equal to the flux linked with a secondary coil when a unit current passes through the primary coil. The SI unit of mutual inductance is henry.

Consider two long co-axial solenoids each of length l, radii r_1, r_2 and let n_1, n_2 be the number of turns per unit length respectively.

Magnetic field produced in S_2 when current I_2 (time varying) is passing through it is $B_2 = \mu_0 n_2 I_2$

Magnetic flux links with one turn of S_1

$$= \mu_0 n_2 I_2 A_1$$

Total magnetic flux links S_1,

$$\phi = \mu_0 n_2 I_2 A_1 n_1 l$$

$$M_{12} I_2 = \mu_0 n_1 n_2 A_1 l I_2$$

$$M_{12} = \mu_0 n_1 n_2 A_1 l \quad \text{...(i)}$$

M_{12} = Mutual inductance of solenoid S_1 with respect to solenoid S_2.

Similarly, $M_{21} = \mu_0 n_1 n_2 A_2 l$ ...(ii)

If radius of both solenoids are same, then

$$M = M_{12} = M_{21} = \mu_0 n_1 n_2 A l$$

(ii) For solenoid, $B = \mu_0 nI = \mu_0 n I_0 \sin \omega t$

Magnetic flux linked with solenoid

$$\phi = BA = \mu_0 n I_0 A \sin \omega t$$

$$= \mu_0 n I_0 \pi r^2 \sin \omega t \quad \text{...(iii)}$$

(a) Induced emf, $e = \frac{-Nd\phi}{dt}$

$$= -\mu_0 N n I_0 \pi r^2 \omega \cos \omega t = -e_0 \cos \omega t$$

where, $e_0 = \mu_0 N n \omega \pi r^2 I_0$

(b) Mutual inductance between coil and solenoid,

$$M = \frac{N\phi}{I} = \mu_0 N n \pi r^2$$

26. (i) According to Faraday's law of electromagnetic induction

(a) As long as magnetic flux linked with coil or circuit changes, an emf is induced in the coil or circuit.

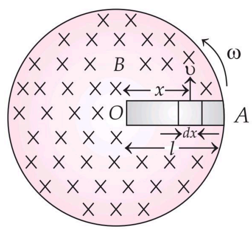
(b) The induced emf produced in coil or circuit is directly proportional to the rate of change of magnetic flux.

$$e \propto \frac{d\phi}{dt}, \quad e = -\frac{d\phi}{dt}$$

Negative sign indicates that the induced emf acts in such a manner that it opposes the change in flux.

(ii) **Expression for Induced emf in a Rotating Rod**

Let a metallic rod OA of length l rotate with angular velocity ω in a uniform magnetic field B, the plane of rotation being perpendicular to the magnetic field. Consider a small element of length dx at a distance x from centre. If v is the linear velocity of this element, then area swept by the element per second = $v\,dx$.



The emf induced across the ends of element,

$$d\varepsilon = B\frac{dA}{dt} = Bv\,dx$$

But $v = x\omega$

$\therefore \quad d\varepsilon = Bx\omega\,dx$

$\therefore$ The emf induced across the rod,

$$\varepsilon = \int_0^l Bx\omega\,dx = B\omega\int_0^l x\,dx$$

$$= B\omega\left[\frac{x^2}{2}\right]_0^l = B\omega\left[\frac{l^2}{2} - 0\right] = \frac{B\omega l^2}{2}$$

Current induced in rod,

$$I = \frac{\varepsilon}{R} = \frac{1}{2}\cdot\frac{B\omega l^2}{R}$$

If circuit is closed, power dissipated

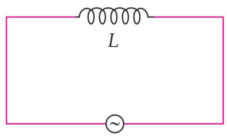
$$= \frac{\varepsilon^2}{R} = \frac{B^2\omega^2 l^4}{4R}$$

27. Consider a coil of self-inductance L and negligible ohmic resistance connected across the source of alternating emf,

$$V = V_0 \sin \omega t \qquad \ldots\text{(i)}$$

Induced emf produced in coil is given by

$$e = -L\frac{dI}{dt} \qquad \ldots\text{(ii)}$$



$V = V_0 \sin \omega t$

Applying Kirchhoff's loop rule, $V + e = 0$

or $$L\frac{dI}{dt} = V_0 \sin \omega t$$

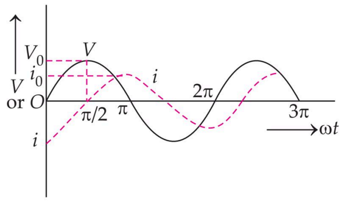
$$\int dI = \int \frac{V_0}{L} \sin \omega t \; dt$$

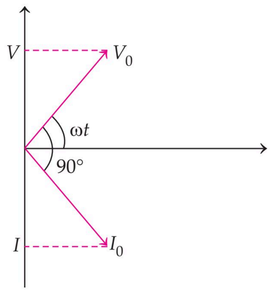
$$I = \frac{-V_0}{\omega L}\cos \omega t = \frac{V_0}{X_L}\sin\left(\omega t - \frac{\pi}{2}\right)$$

or $$I = I_0 \sin\left(\omega t - \frac{\pi}{2}\right) \qquad \ldots\text{(iii)}$$

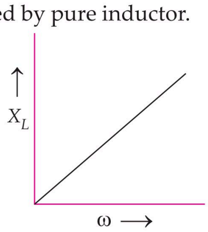
Thus, comparing Eqs. (i) and (iii), it is clear that current lags voltage by phase angle of $\frac{\pi}{2}$.

Phasor diagram





Inductive reactance It is defined as opposition to the current offered by pure inductor.



$$X_L = \omega L = 2\pi f L$$

Thus, $X_L \propto L$.

28. We have, $V = V_0 \sin \omega t$ and $i = i_0 \sin(\omega t + \phi)$

and instantaneous power, $P = Vi$

$$= V_0 \sin \omega t \cdot i_0 \sin(\omega t + \phi)$$

$$= V_0 i_0 \sin \omega t \sin(\omega t + \phi)$$

$$= \frac{1}{2} V_0 i_0 \, 2\sin \omega t \cdot \sin(\omega t + \phi)$$

From trigonometric formula,

$$2\sin A \sin B = \cos(A - B) - \cos(A + B)$$

$\therefore$ Instantaneous power,

$$P = \frac{1}{2} V_0 i_0 \,[\cos(\omega t - \omega t - \phi) - \cos(\omega t + \phi + \omega t)]$$

$$= \frac{1}{2} V_0 i_0 [\cos \phi - \cos(2\omega t + \phi)]$$

Average power for complete cycle,

$$\overline{P} = \frac{1}{2} V_0 i_0 [\cos \phi - \overline{\cos(2\omega t + \phi)}]$$

where, $\overline{\cos(\omega t + \phi)}$ is the mean value of $\cos(2\omega t + \phi)$ over complete cycle. But for a complete cycle, $\cos(2\omega t + \phi) = 0$.

Average power, $$P_{av} = \frac{V_0 I_0}{2}\cos\phi$$

$$= \frac{V_0}{\sqrt{2}}\frac{i_0}{\sqrt{2}}\cos\phi = V_{rms}\, i_{rms} \cos\phi$$

(i) If phase angle $\phi = 90°$ i.e., in case of pure inductor or pure capacitor, no power is consumed by AC circuit as $P_{av} = V_{rms}\, i_{rms} \cos 90° = 0$

(ii) If phase angle $\phi = 0°$ i.e, in case of pure capacitor, maximum power is consumed in AC circuit as

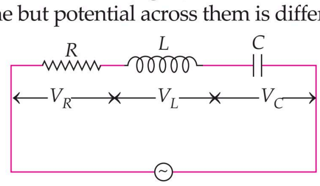
$P_{av} = V_{rms}\, i_{rms} \cos 0° = V_{rms}\, i_{rms}$

29. (i) **Impedance** The opposition offered by the combination of a resistor and reactive component to the flow of AC is called impedance. Mathematically, it is the ratio of rms voltage applied and rms current produced in circuit i.e.,

$$Z = \frac{E_V}{I_V}$$

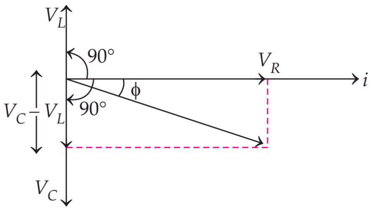
Its unit is ohm (Ω).

Expression for Impedance in *L-C-R* series circuit
Suppose resistance R, inductance L and capacitance C, are connected in series and an alternating source of voltage $V = V_0 \sin \omega t$ is applied across it (fig. a). In series, circuit current is same but potential across them is different.



$V = V_0 \sin \omega t$

(a)



(b)

V_R and $(V_C - V_L)$ are mutually perpendicular and the phase difference between them is 90°. As applied voltage across the circuit is V, the resultant of V_R and $(V_C - V_L)$ will also be V. From fig. (b).

$$E_v^2 = V_R^2 + (V_C - V_L)^2$$

$$\Rightarrow \qquad E_v = \sqrt{V_R^2 + (V_C - V_L)^2}$$

But $V_R = Ri$, $V_C = X_C i$ and $V_L = X_L i$

where, $X_C = \frac{1}{\omega C}$ = capacitance reactance and

$X_L = \omega L$ = inductive reactance.

$$E_V = \sqrt{(Ri)^2 + (X_C i - X_L i)^2}$$

Impedance of circuit,

$$Z = \frac{V}{i} = \sqrt{R^2 + (X_C - X_L)^2}$$

i.e., $\quad Z = \sqrt{R^2 + (X_C - X_L)^2}$

$$= \sqrt{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}$$

Instantaneous current,

$$I = \frac{E_0 \sin(\omega t + \phi)}{\sqrt{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}}$$

The phase difference (ϕ) between current and voltage is given by

$$\tan \phi = \frac{X_C - X_L}{R}$$

$\Rightarrow$ $\tan \phi = 0$ or $\phi = 0°$

$\therefore$ At resonance, $X_L = X_C$

$$\omega L = \frac{1}{\omega C}$$

Resonant angular frequency, $\omega = \frac{1}{\sqrt{LC}}$

Resonant frequency, $f = \frac{1}{2\pi\sqrt{LC}}$

(ii) In L-R circuit if $X_L = R$, then

$$Z_1 = \sqrt{R^2 + X_L^2} = \sqrt{R^2 + R^2} = R\sqrt{2}$$

$\therefore$ Power factor, $P_1 = \frac{R}{Z} = \frac{1}{\sqrt{2}}$

Now, $X_L = X_C$, then

$$Z_2 = \sqrt{R^2 + (X_L - X_L)^2} = R$$

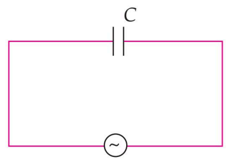
So, new power factor, $P_2 = \frac{R}{Z_2} = 1$

$$\therefore \qquad \frac{P_1}{P_2} = \frac{1}{\sqrt{2}}$$

30. Consider a source of alternating emf

$$E = E_0 \sin \omega t \qquad \text{...(i)}$$

which is applied across a capacitor of capacitance C.



$E = E_0 \sin \omega t$

Then, $q = CE = CE_0 \sin \omega t$

$$I = \frac{dq}{dt} = CE_0 \frac{d}{dE}(\sin \omega t) = \omega C E_0 \cos \omega t$$

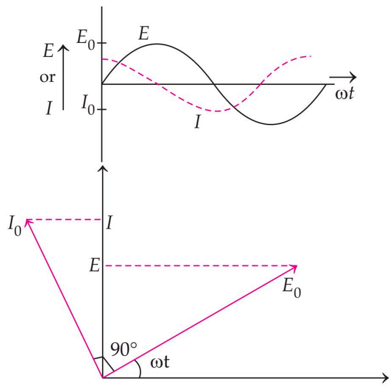
$$I = \frac{E_0}{\frac{1}{\omega C}} \sin\left(\omega t + \frac{\pi}{2}\right)$$

$$I = \frac{E_0}{X_C} \sin\left(\omega t + \frac{\pi}{2}\right)$$

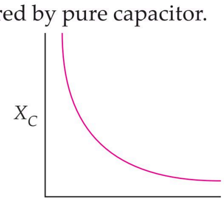
$$I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right) \qquad \text{...(ii)}$$

Thus, comparing Eqs. (i) and (ii), it is clear that current leads the voltage by phase angle of $\frac{\pi}{2}$.

Phasor diagram



Capacitive reactance It is defined as opposition to the current offered by pure capacitor.



$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

Thus,

$$X_C \propto \frac{1}{C}$$

31. **AC generator** A dynamo or generator is a device which converts mechanical energy into electrical energy.

Principle It works on the principle of electromagnetic induction. When a coil rotates in a magnetic field, the effective area of the coil linked normally with the magnetic field lines, changes with time. This result in the production of an alternating emf in the coil.

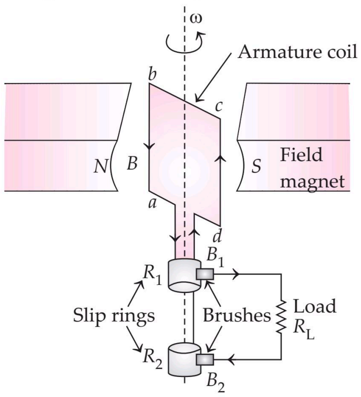
Construction It consists of the four main parts.

(i) **Field Magnet** In the case of a low power dynamo, the magnetic field is generated by a permanent magnet, while in the case of large power dynamo, the magnetic field is produced by an electromagnet.

(ii) **Armature** It consists of a large number of turns of insulated wire wounded on the soft iron drum. It can rotate a round an axle between the two poles of the field magnet. The drum serves the two purposes: (a) It serves as a support to coils and (b) It increases the magnetic field as air core gets replaced by an iron core.

(iii) **Slip Rings** The slip rings R_1 and R_2 are the two metal rings connected to armature. These rings are fixed to the shaft which rotates the armature coil, so that the rings also rotate along with the armature.

(iv) **Brushes** These are two flexible carbon rods (B_1 and B_2) which are fixed and constantly touch the revolving rings. The output current in external load R_L is taken through these brushes.



Working When the armature coil is rotated in the strong magnetic field, the magnetic flux linked with the coil changes and the current is induced in the coil, its direction being given by Fleming's right hand rule.

Expression for Induced emf When the coil is rotated with a constant angular speed ω, the angle θ between the magnetic field vector B and the area vector A of the coil at any instant t is $\theta = \omega t$ (assuming $\theta = 0°$ at $t = 0$). As a result, the effective area of the coil exposed to the magnetic field lines changes with time, the flux at any time t is $\phi_B = BA\cos\theta = BA\cos\omega t$

Induced emf produced,

$$e = \frac{-d\phi_B}{dt} = NBA\omega \sin\omega t$$

$$e = e_0 \sin\omega t$$

where, $e_0 = NBA\omega$ is maximum value of induced emf. If R is resistance of coil, then induce current is $i = \frac{e}{R} = \frac{e_0}{R}\sin\omega t = i_0 \sin\omega t$

Moving coil galvanometer cannot measure current in AC generator because average value of AC over complete cycle is zero.

32. (i) Energy density of electric field is, $U_E = \frac{1}{2}\varepsilon_0 E^2$

Energy density due to magnetic field B is,

$$U_B = \frac{1}{2}\frac{B^2}{\mu_0}$$

Total energy density of wave $= \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}$

Now, $(U_E)_{av} = \frac{1}{T}\int_0^T U_E\,dt = \frac{1}{T}\int_0^T \frac{1}{2}\varepsilon_0 E^2$

$$= \frac{\varepsilon_0}{2T}\int_0^T E_0^2 \sin^2(kz - \omega t)\,dt$$

$$= \frac{\varepsilon_0}{2T}\left(E_0^2 \times \frac{T}{2}\right) = \frac{1}{4}\varepsilon_0 E_0^2$$

$$\left(\int_0^T \sin^2(kz - \omega t)\,dt = T/2\right)$$

Similarly, $(U_B)_{av} = \frac{1}{4}\frac{B_0^2}{\mu_0}$

$$\therefore U_{av} = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4}\frac{B_0^2}{\mu_0}$$

(ii) $\because \quad E = cB_0$

and $\quad c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

$$\therefore \frac{1}{4}\frac{B_0^2}{\mu_0} = \frac{1}{4}\frac{E_0^2/c^2}{\mu_0} = \frac{E_0^2}{4\mu_0} \times \mu_0\varepsilon_0 = \frac{1}{4}\varepsilon_0 E_0^2$$

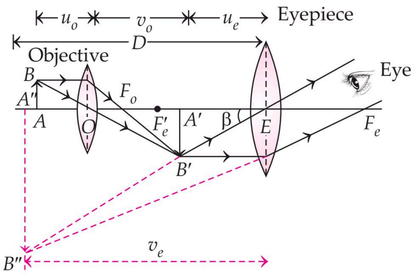
$$U_{av} = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4}\frac{B_0^2}{\mu_0} = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4}\varepsilon_0 E_0^2$$

$$= \frac{1}{2}\varepsilon_0 E_0^2 = \frac{1}{2}\frac{B_0^2}{\mu_0}$$

Time averaged intensity,

$$I_{av} = U_{av}\,c = \frac{1}{2}c\varepsilon_0 E_0^2$$

33. Diagram of compound microscope.



Magnifying power, $M = \frac{-v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$

Here, $M = -20, m_e = 5, v_e = -20\,\text{cm}, L = 14\,\text{cm}$

For eye piece, $m_e = \frac{v_e}{u_e}$

$\Rightarrow \quad 5 = \frac{-20}{u_e} \quad \Rightarrow \quad u_e = \frac{-20}{5} = -4\,\text{cm}$

Using lens formula, $\frac{1}{v_e} - \frac{1}{u_e} = \frac{1}{f_e}$

$\Rightarrow \quad -\frac{1}{20} + \frac{1}{4} = \frac{1}{f_e} \Rightarrow \frac{-1+5}{20} = \frac{1}{f_e} \Rightarrow f_e = 5\,\text{cm}$

Now, total magnification,

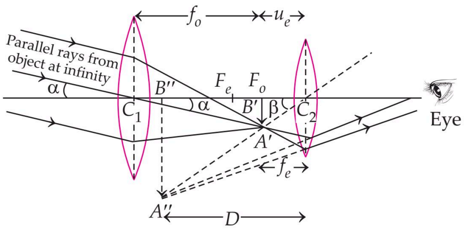
$\Rightarrow \quad M = m_e \times m_o$

$\Rightarrow \quad M = -\frac{L}{f_o}\left(1 + \frac{D}{f_e}\right)$

$\Rightarrow \quad -20 = -\frac{14}{f_o}\left(1 + \frac{20}{5}\right)$

$\Rightarrow \quad f_o = 3.5\,\text{cm}$

34. (i) Diagram of astronomical telescope when image is formed at the least distance of distinct vision.



Magnifying power, $M = -f_o\left(\frac{1}{f_e} + \frac{1}{D}\right)$

In normal adjustment when final image is formed at infinity, $M = -\frac{f_o}{f_e}$

(ii) For first lens, $u_1 = -30\,\text{cm}$,

$f_1 = +10\,\text{cm}$

$\therefore$ From lens formula,

$$\frac{1}{f_1} = \frac{1}{v_1} - \frac{1}{u_1}$$

$$\Rightarrow \quad \frac{1}{v_1} = \frac{1}{f_1} + \frac{1}{u_1}$$

$$= \frac{1}{10} - \frac{1}{30} = \frac{3-1}{30}$$

$\Rightarrow \quad v_1 = 15\,\text{cm}$

The image formed by the first lens serves as the object for the second. This is at a distance of $(15-5)\,\text{cm} = 10\,\text{cm}$ to the right of the second lens. Though the image is real, it serves as a virtual object for the second lens.

For second lens, $f_2 = -10\,\text{cm}$,

$$u_2 = 15 - 5 = +10\,\text{cm}$$

$\therefore \quad \frac{1}{v_2} = \frac{1}{f_2} + \frac{1}{u_2} = -\frac{1}{10} + \frac{1}{10} \Rightarrow v_2 = \infty$

The virtual image is formed at an infinite distance to the left of the second lens. This acts as an object for the third lens.

For third lens, $f_3 = +30\,\text{cm}, u_3 = \infty$

From lens formula,

$$\frac{1}{v_2} = \frac{1}{f_3} + \frac{1}{u_3} = \frac{1}{30} + \frac{1}{\infty}$$

$\therefore \quad v_3 = 30\,\text{cm}$

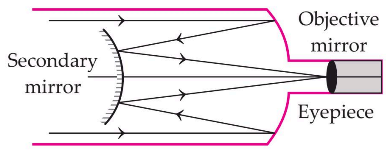
The final image is formed at a distance 30 cm to the right of third lens.

35. (i) The main considerations for choosing the objective of astronomical telescope are

(a) the aperture of objective lens is kept large, so that it may collect sufficient light to form a bright image of a distant object.

(b) the focal length of objective is kept large, so that the magnifying power is high.

(ii)



If f_o and f_e are the focal lengths of objective and eye piece respectively, then magnifying power when the image is formed at the least distance of distinct vision, $m = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$

If final image is formed at infinity, $m = \frac{f_o}{f_e}$.

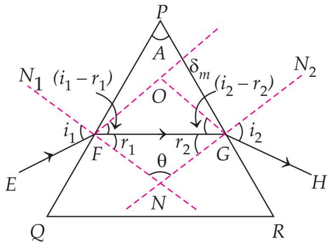
(iii) The advantages of reflecting type telescope over refracting type telescope are

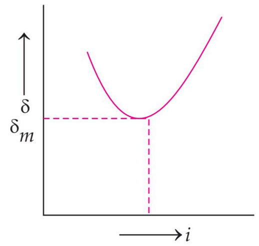
(a) large light gathering power, high resolving power and large magnifying power.

(b) as mirrors are used, so it is free from chromatic aberration.

(c) spherical aberration can be removed by using proper concave parabolic mirror.

36. Let EF be the incident ray which deviates while passing through prism following path $EFGH$ as shown in figure. If δ is the angle of deviation, then





In ΔOFG,

$$\delta = \angle OFG + \angle OGF$$

$$\delta = i_1 - r_1 + i_2 - r_2$$

$$= (i_1 + i_2) - (r_1 + r_2) \quad \ldots\text{(i)}$$

In ΔFGN,

$$r_1 + r_2 + \theta = 180° \quad \ldots\text{(ii)}$$

In quadrilateral $PFNG$,

$$A + \angle PFN + \theta + \angle PGN = 360°$$

or $$A + \theta = 180°$$

$$[\text{As } \angle PFN = \angle PGN = 90°] \quad \ldots\text{(iii)}$$

From, Eq. (ii) and Eq. (iii)

$$A = r_1 + r_2 \quad \ldots\text{(iv)}$$

Hence, Eq. (i) becomes

$$\delta = i_1 + i_2 - A$$

δ will be minimum at $i_1 = i_2 = i$

So, $$\delta_m = 2i - A$$

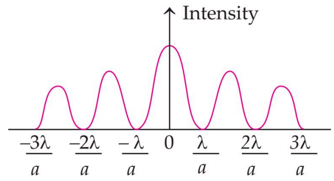
$$\Rightarrow \quad i = \frac{A + \delta_m}{2} \quad \ldots\text{(v)}$$

and at $i_1 = i_2$, $r_1 = r_2 = r$

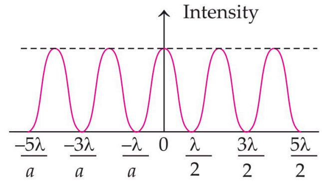
So, $$r = \frac{A}{2} \quad \ldots\text{(vi)}$$

Hence, $$n = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin \frac{A}{2}}$$

37. (i) Intensity pattern for single slit diffraction.
The central bright fringe has maximum intensity and as we move away from central fringe, the intensity of bright fringes goes on decreasing.



Intensity pattern for double slit Interference The intensity of all bright fringes are same.



(ii)

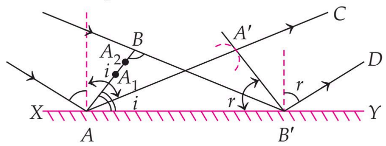
Interference	Diffraction
Fringe width of all fringes are same.	Fringe width of central bright fringe is double as compared to other fringes.
Intensity of all bright fringes are same.	Intensity of bright fringes goes on decreasing as we move away from central fringe.
Good contrast between bright and dark fringes.	Poor contrast between bright and dark fringes.
Maxima occurs at $\theta_n = n\lambda / d$	Minima occurs at $\theta_n = n\lambda / d$

38. **Wavefront** It is defined as locus of all particles of a medium vibrating in same phase.

Laws of reflection by Huygens' principle

Consider a plane wavefront AB incident on mirror XY at point A at an angle of incidence i. According to Huygens' principle, all particles on AB lie in same phase acting as secondary wavelengths, so if in time t light reaches from B to B', then in same time light reaches from A to A' such that $AA' = BB' = vt$

With A as centre draw an arc of radius AA', then tangent $A'B'$ represents reflected wavefront.



Now, in right-angled triangles ABB' and $AA'B'$

$$\angle ABB' = \angle AA'B' = 90° \text{ (each)}$$

$$BB' = AA' = vt$$

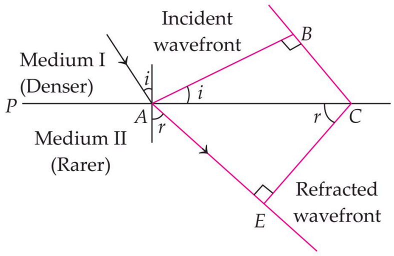
$$AB' = AB' \text{ (common)}$$

Hence, triangles are congruent.

So, $\angle BAB' = \angle AB'A'$, $\angle i = \angle r$

which is the law of reflection.

39. We assume a plane wavefront AB propagating in denser medium incident on the interface PP' at angle i as shown in figure. Let t be the time taken by the wavefront to travel a distance BC. If v_1 is the speed of the light in medium I.



So, $BC = v_1 t$

In order to find the shape of the refracted wavefront, we draw a sphere of radius $AE = v_2 t$, where v_2 is the speed of light in medium II (rarer medium). The tangent plane CE represents the refracted wavefront.

In ΔABC, $\sin i = \frac{BC}{AC} = \frac{v_1 t}{AC}$

In ΔACE, $\sin r = \frac{AE}{AC} = \frac{v_2 t}{AC}$

$\therefore \quad \frac{\sin i}{\sin r} = \frac{BC}{AE} = \frac{v_1}{v_2} = n$ (refractive index)

which is Snell's law of refraction.

40. (i) As from de-Broglie wavelength,

$$\lambda = \frac{h}{p} \qquad [v = \text{Same}]$$

$$\frac{\lambda_\alpha}{\lambda_p} = \frac{h}{m_\alpha v_\alpha} \times \frac{m_p v_p}{h} = \frac{1}{4}$$

(ii) We know, $p = \sqrt{2m(\text{KE})}$ [KE = Same]

$$\frac{\lambda_\alpha}{\lambda_p} = \frac{h}{\sqrt{2m_\alpha(\text{KE})_\alpha}} \times \frac{\sqrt{2m_p(\text{KE})_p}}{h}$$

$$= \sqrt{\frac{m_p}{m_\alpha}} = \frac{1}{2}$$

(iii) And $v = \sqrt{\frac{2qV}{m}}$ [V = Same]

$$\frac{\lambda_\alpha}{\lambda_p} = \frac{h}{m_\alpha v_\alpha} \times \frac{m_p v_p}{h}$$

$$= \frac{m_p}{m_\alpha}\sqrt{\frac{2q_p V}{m_p}} \times \sqrt{\frac{m_\alpha}{2q_\alpha V}}$$

$$= \frac{m_p}{m_\alpha}\sqrt{\frac{m_\alpha}{m_p}} \times \sqrt{\frac{q_p}{q_\alpha}} = \frac{1}{2\sqrt{2}}$$

41. Einstein's photoelectric equation, $h\nu = h\nu_0 + eV_0$

where, ν = incident frequency, ν_0 = threshold frequency and V_0 = stopping potential

(i) Incident energy of photon is used in two ways (a) to liberate electron from the metal surface (b) rest of the energy appears as maximum energy of electron.

(ii) Only one electron can absorb the energy of one photon. Hence, increasing intensity increases the number of emitted electrons and thus the current.

(iii) If incident energy is less than work function, then no emission of electrons will take place.

(iv) Increasing ν (incident frequency) will increase maximum kinetic energy of electrons but number of electrons emitted remains the same.

For wavelength λ_1, $\frac{hc}{\lambda_1} = \phi_0 + K = \phi_0 + eV_0$ ...(i)

where, $K = eV_0$

For wavelength λ_2,

$$\frac{hc}{\lambda_2} = \phi_0 + 2eV_0 \qquad \text{...(ii)}$$

From Eqs. (i) and (ii), we get

$$\frac{hc}{\lambda_2} = \phi_0 + 2\left(\frac{hc}{\lambda_1} - \phi_0\right)$$

$$= \phi_0 + \frac{2hc}{\lambda_1} - 2\phi_0$$

$$\Rightarrow \quad \phi_0 = \frac{2hc}{\lambda_1} - \frac{hc}{\lambda_2}$$

For threshold wavelength λ_0, kinetic energy, $K = 0$, and work function $\phi_0 = \frac{hc}{\lambda_0}$

$$\therefore \quad \frac{hc}{\lambda_0} = \frac{2hc}{\lambda_1} - \frac{hc}{\lambda_2}$$

$$\Rightarrow \quad \frac{1}{\lambda_0} = \frac{2}{\lambda_1} - \frac{1}{\lambda_2} \Rightarrow \lambda_0 = \frac{\lambda_1\lambda_2}{2\lambda_2 - \lambda_1}$$

Work function, $\frac{hc(2\lambda_2 - \lambda_1)}{\lambda_1\lambda_2}$

42. In ground state, the kinetic energy of the electron is

$$K_1 = -E_1 = \frac{+13.6 \text{ eV}}{1^2} = 13.6 \times 1.6 \times 10^{-19} \text{ J}$$

$$= 2.18 \times 10^{-18} \text{ J}$$

de-Broglie wavelength,

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK_1}}$$

$$= \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 2.18 \times 10^{-18}}}$$

$$= 0.33 \times 10^{-9} \text{ m} = 0.33 \text{ nm}$$

Kinetic energy in the first excited state ($n = 2$)

$$K_2 = -E_2 = \frac{E_1}{4}$$

de-Broglie wavelength, $\lambda' = \frac{h}{\sqrt{2mK_2}}$

$$= \frac{2h}{\sqrt{2mE_1}} = 2\lambda = 0.66 \text{ nm}$$

43. (i) According to Bohr's model of hydrogen atom, electrostatic force of attraction between nucleus and electron provides required centripetal force by electron to revolve around nucleus.

So, $$F_E = F_C$$

$$\frac{kZe^2}{r^2} = \frac{mv^2}{r}$$

$$\frac{kZe^2}{r} = mv^2 \qquad \ldots\text{(i)}$$

According to Bohr's second postulate

$$mvr = \frac{nh}{2\pi}$$

or $$v = \frac{nh}{2\pi mr} \qquad \ldots\text{(ii)}$$

From Eqs. (i) and (ii), we have

$$\frac{kZe^2}{r} = \frac{mn^2h^2}{4\pi^2m^2r^2}$$

or $$r = \frac{n^2h^2}{4\pi^2kZe^2m} \qquad \ldots\text{(iii)}$$

Using Eq. (iii) in Eq. (ii), we have

$$v = \frac{nh}{2\pi m} \times \frac{4\pi^2kZe^2m}{n^2h^2}$$

$$v = \frac{2\pi kZe^2}{nh} \qquad \ldots\text{(iv)}$$

(ii) Kinetic energy of electron

$$\text{KE} = \frac{1}{2}mv^2 = \frac{kZe^2}{2r} \qquad \text{[From Eq. (i)]}$$

$$\text{PE} = \frac{k(Ze)(-e)}{r} = \frac{-kZe^2}{r}$$

So, total energy of electron,

$$E = \text{KE} + \text{PE}$$

$$= -\frac{kZe^2}{2r}$$

$$E = -\frac{kZe^2}{2n^2h^2} \cdot 4\pi^2kZe^2m$$

From Eq. (iii) (For hydrogen atom $Z = 1$)

$$E = -\frac{2\pi^2mk^2e^4}{n^2h^2} = -\frac{13.6}{n^2}\text{ eV} \qquad \ldots\text{(v)}$$

(iii) $E_i - E_f = h\nu$

$$\frac{2\pi^2mk^2e^4}{h^3}\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right] = \nu$$

$$Rc\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right] = \nu \qquad \ldots\text{(vi)}$$

where, R = Rydberg constant

$$= \frac{2\pi^2mk^2e^4}{h^3c}$$

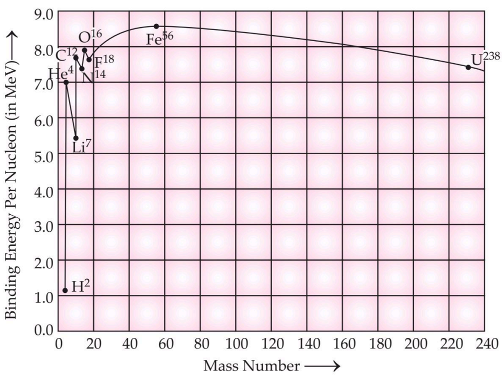
44. The variation of binding energy per nucleon *versus* mass number is shown in graph.

Inferences from graph are as follows

1. The nuclei having mass number below 20 and above 180 have relatively small binding energy and hence they are unstable.
2. The nuclei having mass number 56 and about 56 have maximum binding energy (~8.8 MeV) and so they are most stable.
3. Some nuclei have peaks, e.g., ${}^4_2\text{He}$, ${}^{12}_6\text{C}$, ${}^{16}_8\text{O}$. This indicates that these nuclei are relatively more stable than their neighbours.

(i) **Explanation of constancy of binding energy** Nuclear force is short ranged, so every nucleon interacts with its neighbours only,therefore binding energy per nucleon remains constant.

Explanation of nuclear fission When a heavy nucleus ($A \geq 235$ say) breaks into two lighter nuclei (nuclear fission), the binding energy per nucleon increases i.e, nucleons get more tightly bound. This implies that energy would be released in nuclear fission.



Explanation of nuclear fusion When two very light nuclei ($A \leq 10$) combine to form a heavy nucleus, the binding energy per nucleon of fused heavier nucleus is more than the binding energy per nucleon of lighter nuclei, so again energy would be released in nuclear fusion.

45. (i) The radius R of nucleus related to its mass number is given by

$$R = R_0A^{\frac{1}{3}}$$

where, $R_0 = 1.1 \times 10^{-15}$ m

Now, density of nucleus is given by

$$\rho = \frac{\text{Mass of nucleus}}{\text{Volume of nucleus}}$$

$$= \frac{mA}{\frac{4}{3}\pi R^3} = \frac{3\,mA}{4\pi R_0^3A} = \frac{3m}{4\pi R_0^3}$$

where, m is mass of one nucleon.

Hence, nuclear density is independent of mass number.

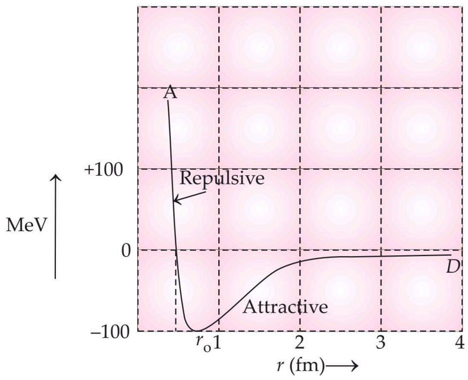
(ii) The graph between potential energy *versus* distance between pair of nucleons is as shown in figure.

Attractive region

For $r > r_0$, the slope of the potential energy curve is negative, showing that the nuclear force is attractive.

Repulsive region

For $r < r_0$ the potential energy increases rapidly indicating that the nuclear force becomes strongly repulsive at very short distances.



Conclusions

(i) Nuclear force acts only at very short distances. It is negligible at larger distances.

(ii) The nuclear force is attractive at medium distances but becomes repulsive at very short distances to prevent nucleons from collapsing into each other .

46. (i)

	Intrinsic semiconductor	Extrinsic semiconductor
1.	It is a semiconductor in pure form.	It is a semiconductor doped with trivalent or pentavalent impurity atoms.
2.	Intrinsic charge carriers, i.e. electrons and holes have equal concentration.	In an *n*-type semiconductor, electrons concentration is more, while in a *p*-type semiconductor, holes concentration is more.
3.	Current caused by charge carriers is of order of μA.	Current due to charge carriers is of the order of mA.

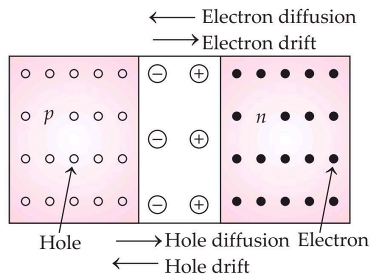
(ii) As *p* and *n* sections of *p*-*n* junction diode are heavily doped, more diffusion of electrons from *n*-region to *p*-region and holes from *p*-region to *n* -region takes place forming depletion layer very thin of order of 1 μm. So, electric field directing from *n*-region to *p*-region is very large. For reverse bias voltage of 5 volt

$$E = \frac{\Delta V}{\Delta x} = \frac{5\text{V}}{1\,\mu\text{m}} = 5 \times 10^6 \text{ V/m}$$

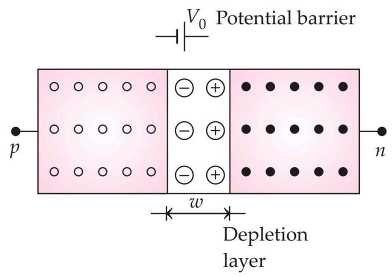
47. Two important processes occurring during the formation of a *p*-*n* junction are (i) diffusion and (ii) drift.

(i) **Diffusion** In *n*-type semiconductor, the concentration of electrons is much greater as compared to concentration of holes, while in the *p*-type semiconductor, the concentration of holes is much greater than the concentration of electrons. When a *p*-*n* junction is formed, then due to concentration gradient, the holes diffuse from *p*-side to *n*-side ($p \rightarrow n$) and electrons diffuse from *n*-side to *p*-side ($n \rightarrow p$).

This motion of charge carriers gives rise to diffusion current across the junction.



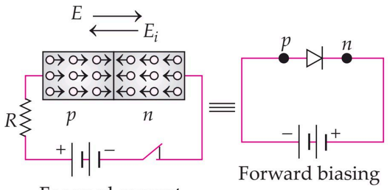
(ii) **Drift** The drift of charge carriers occurs due to electric field. Due to built in potential barrier, an electric field directed from *n*-region to *p*-region is developed across the junction. This field causes motion of electrons on *p*-side of the junction to *n*-side and motion of holes on *n*-side of junction to *p*-side. Thus, a drift current starts. This current is opposite to the direction of **diffusion current**.



Potential barrier During the formation of a *p*-*n* junction, the electrons diffuse from *n*-region to *p*-region and holes diffuse from *p*-region to *n*-region. This forms recombination of charge carriers. In this process immobile positive ions are collected at a junction towards *n*-region and negative ions at a junction towards *p*-region. This causes a potential difference across the unbiased junction. This is called potential barrier.

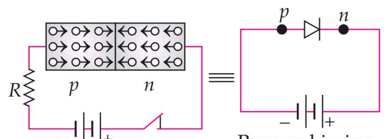
48. (i) **Forward bias** The circuit diagram of p-n junction diode in forward bias is as shown in figure. The external electric field acts opposite to internal field, so width of depletion layer decreases. The current set up in diode is due to both type of majority charge carriers but in external circuit it is due to electrons only.

Since, current is due to diffusion of majority charge carriers, so it is of the order of few milliamperes.



Forward current   Forward biasing

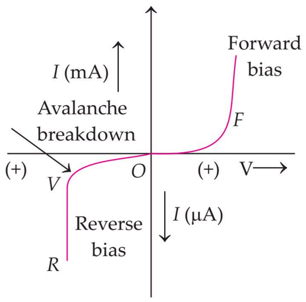
(ii) **Reverse bias** The circuit diagram of p-n junction diode in reverse bias is as shown in figure. Here, the external electric field favours the internal electric field, so width of potential barrier increases. As reverse bias opposes the motion of majority charge carriers but aids the minority charge carriers to move across the junction. Hence, current is very small of the order of μA. In reverse bias, current within junction is due to both types of minority charge carriers, but in the external circuit, it is due to electrons.



Reverse current   Reverse biasing

Characteristics of a p-n junction diode The graph of voltage V *versus* current I in forward bias and reverse bias of a p-n junction is shown in the figure.

Avalanche breakdown or breakdown voltage If the reverse bias is made sufficiently high, the covalent bonds near the junction breakdown releasing free electrons and holes. These electrons and holes gain sufficient energy to break other covalent bonds. Thus, a large number of electrons and holes get free. The reverse current increases abruptly to high value. This is called Avalanche break down and may damage the junction.



49. (i) The order of energy band gap (E_g) of an insulator is greater than 3 eV. Thus, more energy is required to move the electrons from valance band to conduction band.

(ii) Given, $\lambda = 300\,\text{nm}$

$= 300 \times 10^{-9}$ m

$\therefore$ Energy band gap, $E_g = \dfrac{hc}{\lambda}$

$$\therefore \quad E_g = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{300 \times 10^{-9} \times 1.6 \times 10^{-19}} = 4.14\,\text{eV}$$

(iii) Given, $E_g = 10\,\text{eV}, \lambda = ?$

$$\therefore \quad E_g = \frac{hc}{\lambda}$$

$$\Rightarrow 10 \times 1.6 \times 10^{-19} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{\lambda}$$

$$\therefore \quad \lambda = 124.3\,\text{nm}$$

(iv) In the energy band diagram, conduction band is responsible for current flow in a semiconductor in presence of applied electric field.

50. Given, forward biased resistance $= 25\,\Omega$

Reverse biased resistance $= \infty$

As the diode in branch CD is in reverse biased which having resistance infinite,

So, $\quad I_3 = 0$

Resistance in branch $AB = 25 + 125 = 150\,\Omega$ (say R_1)

Resistance in branch $EF = 25 + 125 = 150\,\Omega$ (say R_2)

AB is parallel to EF.

So, resultant resistance,

$$\frac{1}{R'} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{150} + \frac{1}{150} = \frac{2}{150}$$

$$\Rightarrow \quad R' = 75\,\Omega$$

Total resistance,

$$R = R' + 25 = 75 + 25 = 100\,\Omega$$

Current, $\quad I_1 = \dfrac{V}{R} = \dfrac{5}{100} = 0.05$ A

$I_1 = I_4 + I_2 + I_3 \quad$ [here, $I_3 = 0$]

So, $\quad I_1 = I_4 + I_2$

Here, the resistances R_1 and R_2 are same.

i.e. $\quad I_4 = I_2$

$\therefore \quad I_1 = 2I_2$

$\Rightarrow \quad I_2 = \dfrac{I_1}{2} = \dfrac{0.05}{2} = 0.025$ A

and $\quad I_4 = 0.025$ A

Thus, $\quad I_1 = 0.05$ A,

$I_2 = 0.025$ A, $I_3 = 0$

and $\quad I_4 = 0.025$ A