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CHAPTER 1
ELECTRIC CHARGES AND FIELDS

- One of the Intrinsic property of matter is charge
- Atoms is neutral because number of protons is equal to number of electrons
- Ions are charged means number of protons $\neq$ number of electrons

$q_p = +1.6\times 10^{-19}$

$q_e = -1.6\times 10^{-19}$

$m_e = 9.1\times 10^{-31} kg$

$m_p = 1.6\times 10^{-27} kg$

Properties of charges (q or Q)

1. Like charges repel each other and unlike charges attract each other.
2. Law of conservation of charge

Total charge of an isolated system always conserved

Eg: $NaCl \rightarrow Na^{+} + Cl^{-}$

Nuclear reactions

$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He \quad Q = 92e \quad q^1 = 90 + 2 = 92e$

3. Quantisation of charge

Charge of a body is the integral multiple of a basic value to charge (e) $q = \pm ne$

$e = 1.6\times 10^{-19}$ n = 1,2,3.......

4. Additive property of charge

The charge of a body is the algebraic sum of different charges of the body charge is a scalar quantity

Dimension $\rightarrow q = It$ $\quad \therefore I = \frac{q}{t} \quad [q] = [A^1T^1]$ SI Unit - coulomb (C)

Conductors (Free electrons Metals)

Eg : Metals , Human body, Earth.....

Dielectric (Insulators) No free electrons

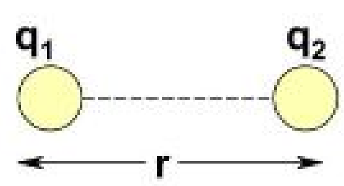
Eg : Water , dry air glass, plastics, wool amber ..

The process of grounding or earthing :-

The process of sharing excess charges on leakage current with earth through a conducting area

Coulomb's law

Electrostatic force of attraction or repulsion between two charges is directly proportional to the product of magnitude of 2 charges and inversely proportional to the square of distance between them. The force always acts along the line joining the two charges.



$F_E \alpha \frac{|q_1 q_2|}{r^2}$

In air $F_E = \frac{1}{4\pi\varepsilon_0}\frac{|q_1 q_2|}{r^2}$ -----(1) where $\frac{1}{4\pi\varepsilon_0} = 9\times 10^9 Nm^2C^{-2}$ ε_0 - epzilon zero

$\varepsilon_0 = 8.85 \times 10^{-12} C^2 N^{-1} m^{-2}$

In a dielectric medium

$$F = \frac{1}{4\pi\varepsilon_0 \varepsilon r} \frac{|q_1 \times q_2|}{r^2} \quad \varepsilon = \varepsilon_0 \varepsilon_r$$

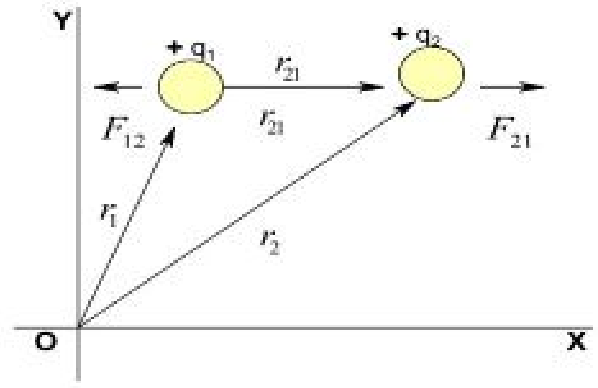
$$F \text{ medium} = \frac{F air}{\varepsilon r}$$

For air = $\varepsilon_r = 1$

For water, $\varepsilon_r = 80$

Coulomb's law in vectors form

(1) Like charge system ($q_1 q_2 > 0$)



$\vec{r}_{21} = \vec{r}_2 - \vec{r}_1$

$$\vec{F}_{21} = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r_{21}^2} \hat{r}_{21} \qquad \left[\hat{r}_{21} = \frac{\vec{r}_{21}}{|\vec{r}_{21}|}\right]$$

$$\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r_{12}^2} \hat{r}_{12} \qquad \left[\hat{r}_{21} = -\hat{r}_{12}\right]$$

$$\boxed{\vec{F}_{21} = -\vec{F}_{12}}$$

Electric field

- It is the space around a charge where another can be experienced an electrostatic force.
- Definition:- electric field at a point is the electrostatic force on a unit +ve test charge.

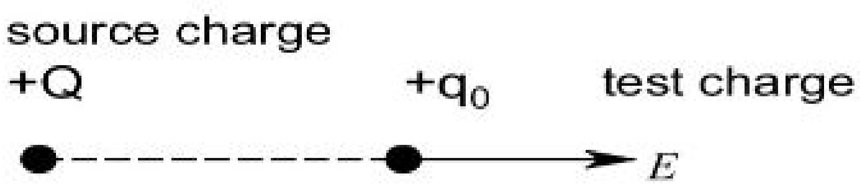
$$E = \frac{F}{q_0}, \; q_0 = 1\text{C or unit + ve charge}$$

SI unit = NC^{-1} or Vm^{-1}

$$[E] = \frac{MLT^{-2}}{AT} = MLT^{-3}A^{-1}$$

Direction of E is along the direction of F_E on the positive test charge.

Electric field at point due to a point charge



According to Coulomb's law, the force between two charges is given by

$$F = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2}$$

Here. $= \frac{1}{4\pi\varepsilon_0}\frac{Q\times q_0}{r^2}\hat{r}$

Then $E = \frac{F}{q_0} = \frac{\frac{1}{4\pi\varepsilon_0}\frac{Q\times q_0}{r^2}.\hat{r}}{q_0}$

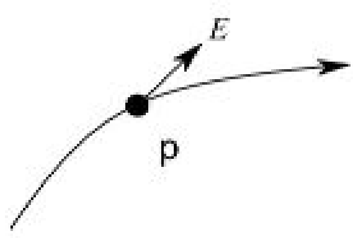
$$E_0 = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}.\hat{r}$$

Electric lines of force

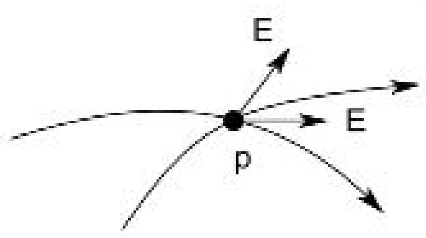
Electric field lines are imaginary lines around a charge such that tangent drawn at any point give the direction of electric field at that point.

Properties of Electric Field Lines

1. The tangent drawn at any point gives direction of electric field at that point

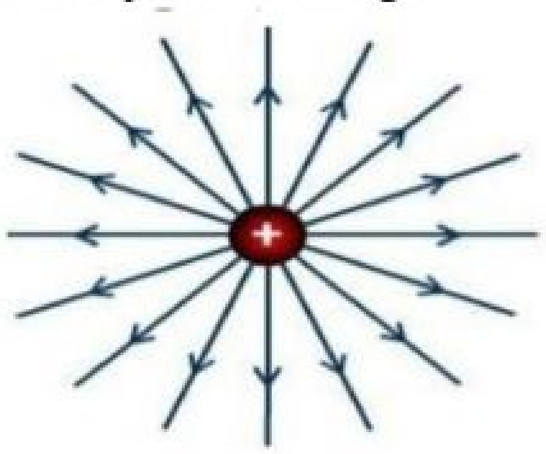


2. They are continuous curves
3. They never intersect. If they intersect, electric field at that point may have two direction. It is not possible as electric field is a vector quantity.



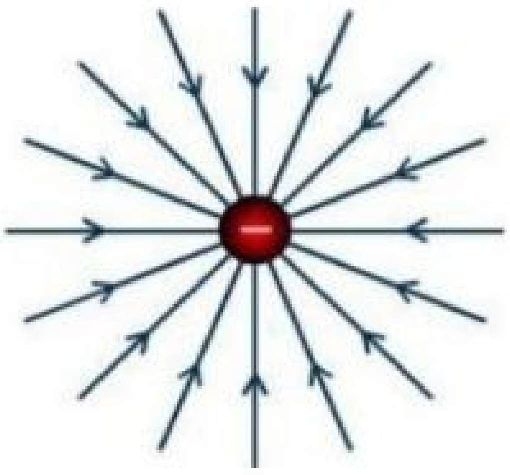
4. They always originate from +ve charge and terminates at -ve charge
5. The relative closeness of EFL indicates the strength of electric field in a region
6. They never form closed loop

- Isolated positive charge



Radially outward

- Isolated Negative charge

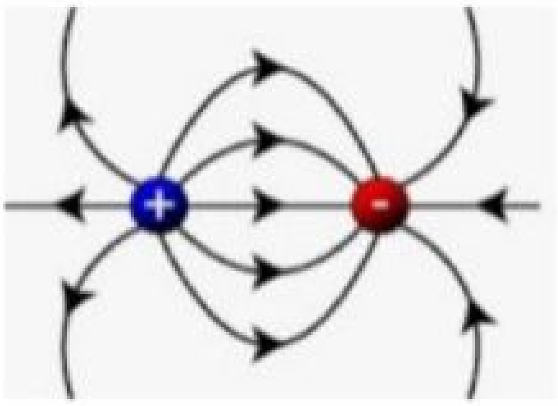


Radially inward

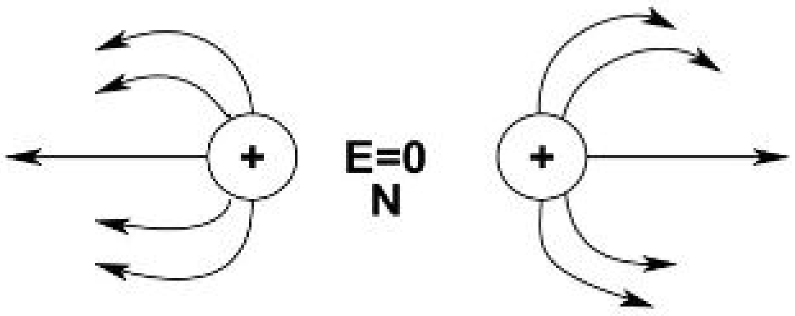
In case of an isolated +ve charge it is radially outwards (ends at infinity).

In case of an isolated -ve charge it is radially inwards (starts from infinity).

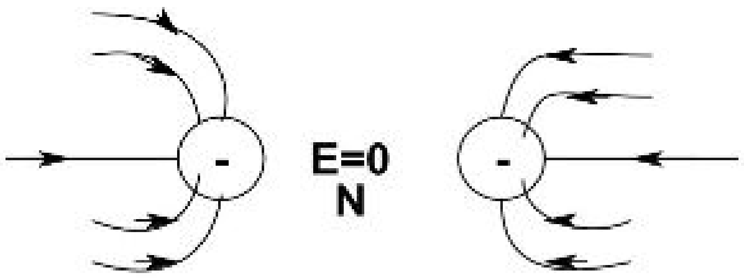
. Unlike charge system



Like charge system ($q_1q_2 > 0$)

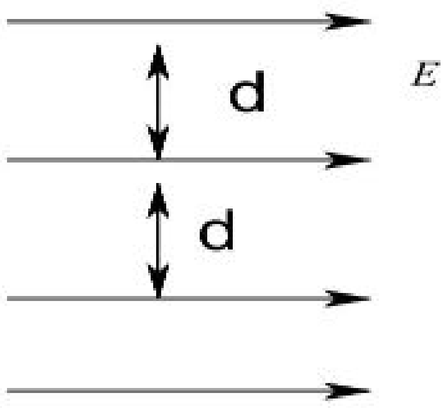


N - Neutral point



They diverge from each other

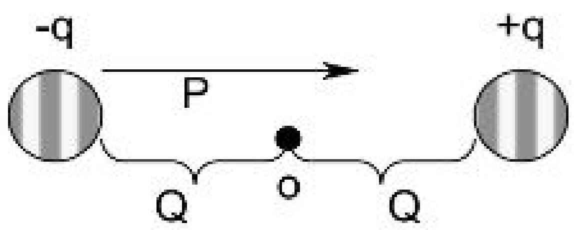
Uniform electric field



Parallel lines equidistant from each other.

Electric Dipole

It is a system of unlike charges with equal magnitude separated by a very small distance.



Electric dipole moment (p)

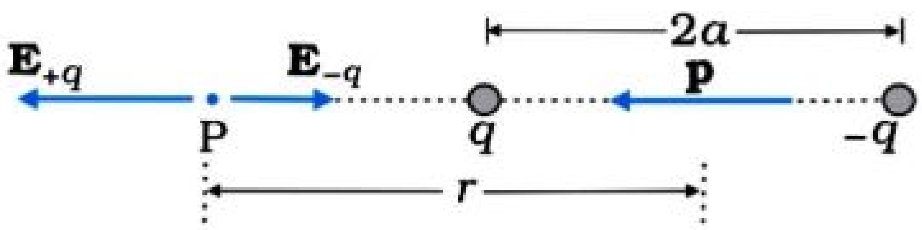
It is product of magnitude of one of the charges and the vector distance between them.

p = 2a q where 2a is the length of the dipole.

unit of p $\rightarrow$ Cm

Dipole moment is a vector quantity and it is directed from negative charge to positive charge.

Electric field due to an electric dipole along its axial line



- The field at the point P due to positive charge is

$$\mathbf{E}_{+q} = \frac{q}{4\pi\varepsilon_0 (r-a)^2}\hat{\mathbf{p}}$$

- The field due to negative charge is

$$\mathbf{E}_{-q} = -\frac{q}{4\pi\varepsilon_0 (r+a)^2}\hat{\mathbf{p}}$$

- The total field at P is

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

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

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

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

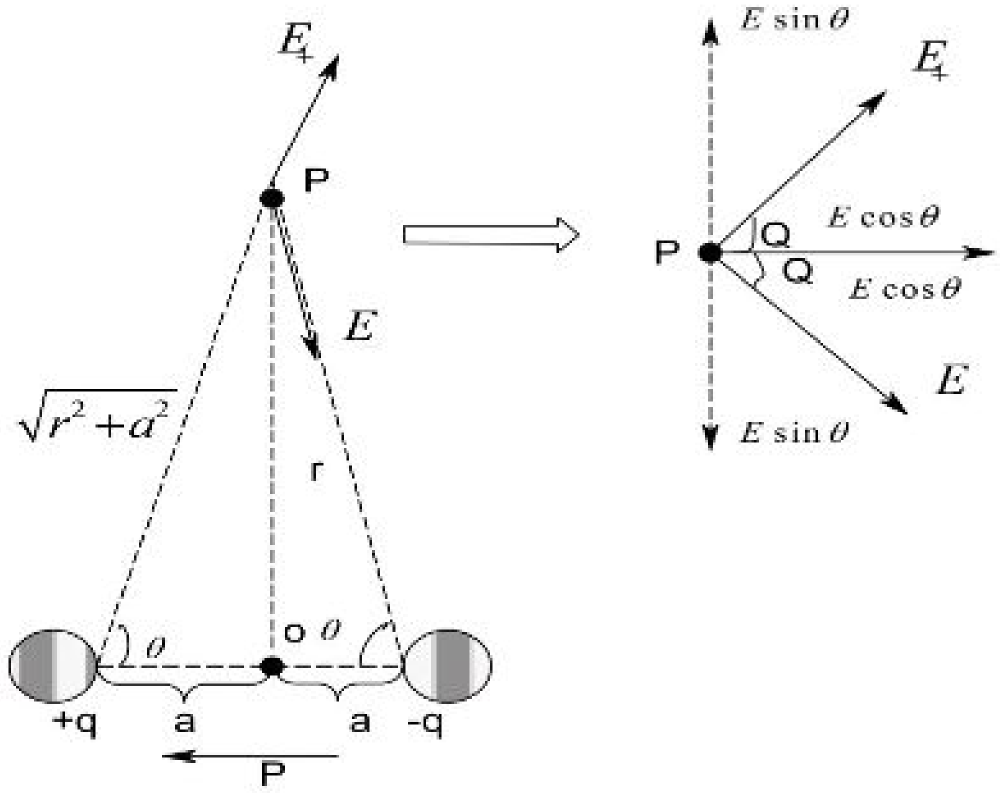
$$= \frac{1}{4\pi\varepsilon_0}\frac{2(q\times 2a)r}{(r^2-a^2)^2}\;\hat{p}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{2pr}{(r^2-a^2)^2}\;\hat{p}$$

If $r^2 \gg a^2, a^2$ can be neglected,then

$$\boxed{\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}\hat{p}}$$

Electric field due to electric dipole along its equatorial line



Consider a point P along the equatorial line at a distance 'r' from the centre. The electric field at P due to +q

$$E_+ = \frac{1}{4\pi\varepsilon_0}\frac{q}{\left(\sqrt{r^2 a^2}\right)^2} \text{ along PC}$$

Electric field P due to a $-q$

$$E_- = \frac{1}{4\pi\varepsilon_0}\frac{q}{\left(\sqrt{r^2 a^2}\right)^2} \text{ along PO}$$

Taking rectangular components of E_+ and E_-. $E\sin\theta$ components cancelled each other.

$\therefore$ The resultant electric field at P, $E_{(p)} = 2E\cos\theta$

$$E_{(p)} = -2\times\frac{1}{4\pi\varepsilon_0}\frac{q\ \ a}{(r^2+a^2)}\times\frac{}{(r^2\ \ a^2)^{3/2}}$$

$$E_{(p)} = -\frac{1}{4\pi\varepsilon_0}\frac{p}{(r^2+a^2)^{3/2}}$$ where, $\vec{p} = q(2a)\hat{p}$

Since $r >> a$ $\qquad \cos\theta = \frac{a}{(r^2+a^2)^{1/2}}$

$$(r^2+a^2)^{3/2} \approx (r^2)^{3/2} = r^3$$

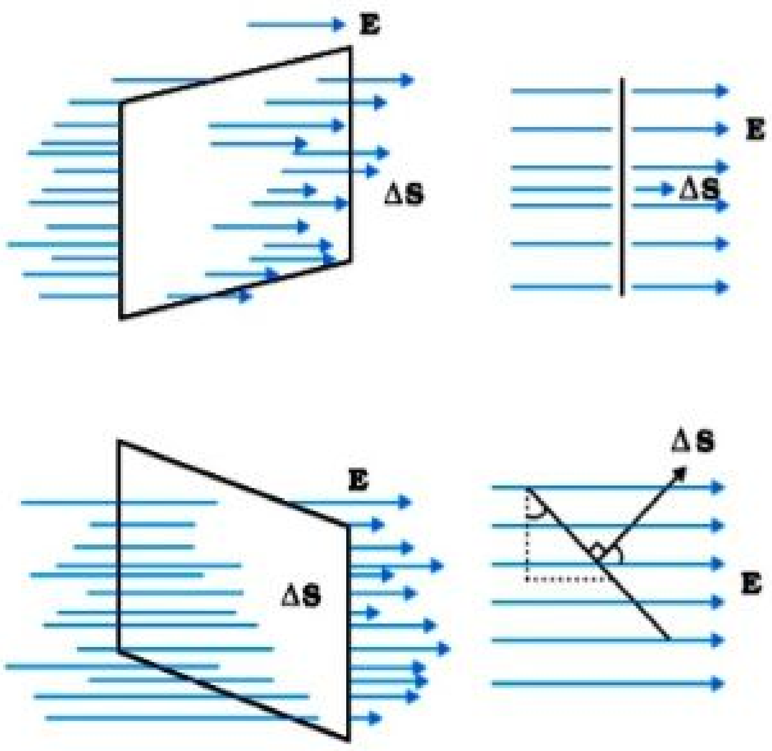
$$E_{(p)} = \frac{-1}{4\pi\varepsilon_0}\frac{p}{r^3}$$

$E_{(p)}$ = opposite to p

Note; $E_{axial} = 2\ E_{equitorial}$

Electric Flux (ϕ_E)

- Electric flux through a surface is the number of electric field lines passing normally through the surface.
- The flux through an area is given by the product of the electric field and the component of area perpendicular to the field.



- Electric flux through a surface is given by $\phi_E = \vec{E}\,.\,\vec{S}$; where S is the area of the surface and E is the electric field on the surface. S is a vector whose direction is normal to S. If θ is the angle between the direction of E and the normal to the surface, $\phi_E = E\ S\ cos\theta$.

  The total electric flux through the surface S is given by

  $\phi = \oint \vec{E}\,.\,d\vec{S}$

  $\theta = 90^0$

  $\Delta\phi_E = E\Delta S\ \cos 90^0 = 0$
- Electric flux is a scalar quantity.
- Si unit = $NC^{-1}m^2 = Nm^2C^{-1}$ or Vm (Volt - metre)
- $[\phi_E] = \frac{MLT^{-2}}{AT}L^2 = [M^1L^3T^{-3}A^{-1}]$

Here area is taken a vector called is 'area vector' Direction of area vector ΔS is outward normal from surface $\Delta S = \Delta S n$

In general

$\phi_E = E\Delta S\ \cos$

$$E_{(\theta)} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

$$\phi_E = E\Delta S \cos\theta$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\Delta S\cos\theta$$

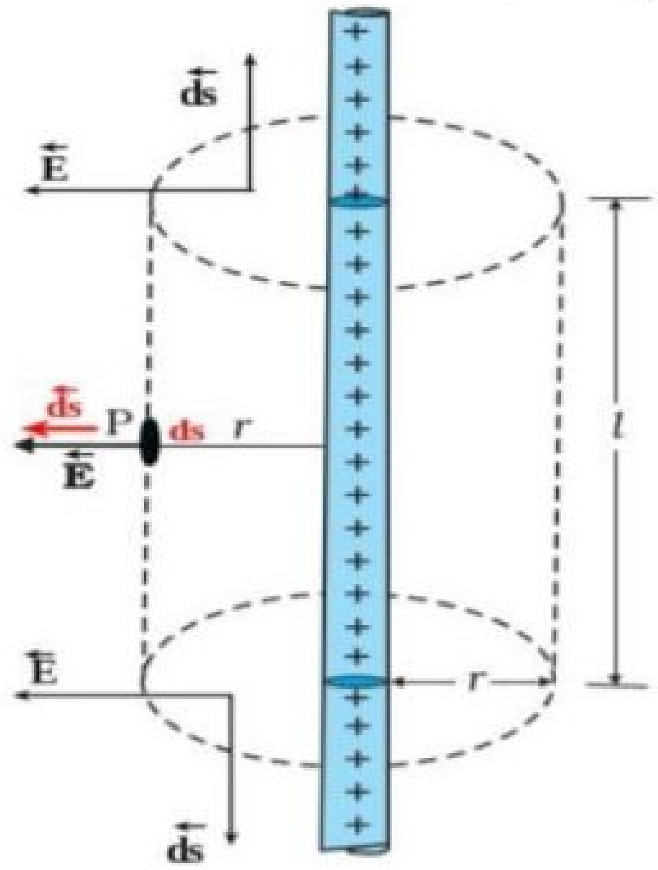
Total electric flux through centre sphere

$$\phi_E = \sum_{\Delta s} E\Delta s\cos\theta = \frac{q}{4\pi\varepsilon_0 r^2}\sum_{\Delta s}\Delta S$$

$$\phi_E = \frac{q}{4\pi\varepsilon_0 r^2} 4\pi r^2 \text{ or } \phi_E = \frac{1}{\varepsilon_0}\times q$$

Application of Gauss's Theorem

1.Electric field due to uniformly charged infinitely long straight line



- Consider an infinitely long line charge of line charge density $\lambda = \frac{\Delta q}{\Delta l}$
- Consider a point P at a distance 'r' from the wire. the resultant electric field 'E' is horizontally outward (Super position principle)
- Assume a cylindrical Gaussian surface of radius 'r' and length 'l'

$$\phi_E = \phi_{end} + \phi_{end} + \phi_{curved}$$

$$= E\pi r^2\cos 90^0 + E\pi r^2\cos 90^0 + E2\pi rl\cos\theta$$

$$= \phi_E = E2\pi rl$$

Also q enclosed = λl

According to Gauss's Law = $\sum E.\Delta S = \frac{qenclosed}{\varepsilon_0}$

$$E2\pi rl = \frac{\lambda l}{\varepsilon_0}$$

$$E = \frac{\lambda}{2\pi\varepsilon_0 r} = \frac{1}{4\pi\varepsilon_0}\frac{2\lambda}{r}$$

$$E\alpha\frac{1}{r}$$

$= E\Delta S$

ΔS = Area vector

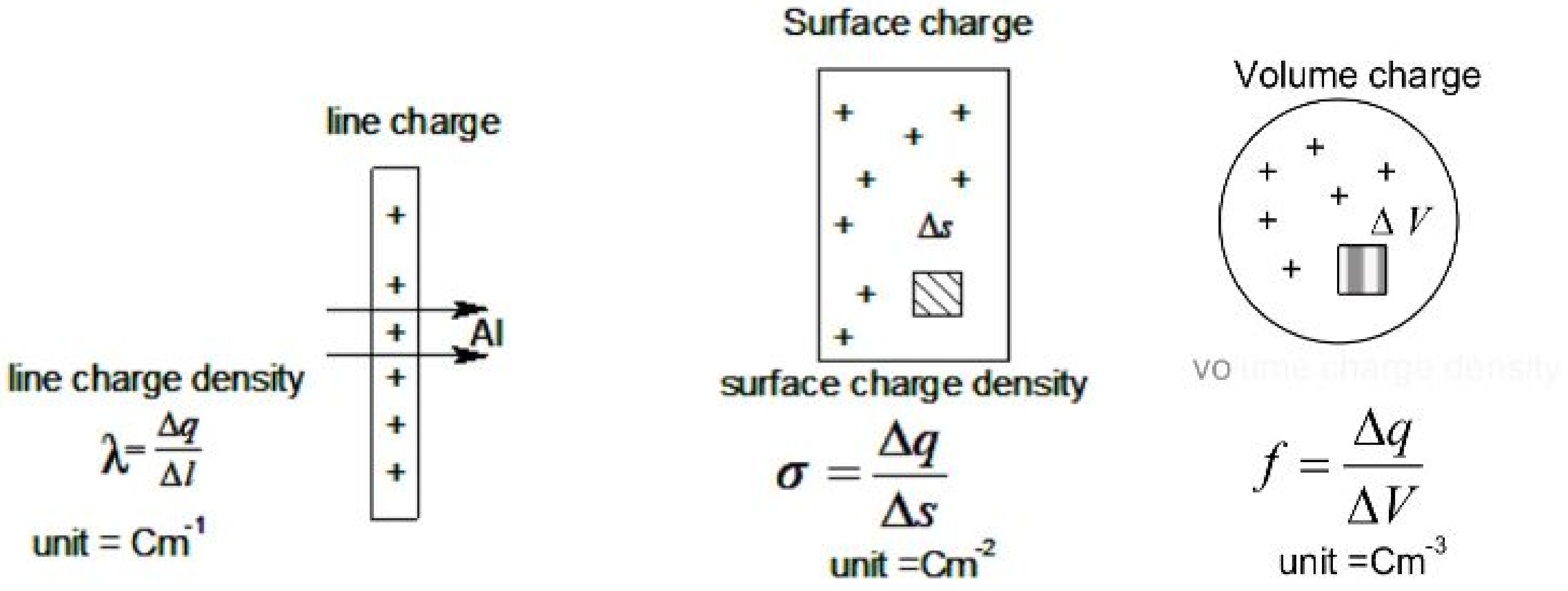
$= \Delta S n$

Direction of ΔS = Along the outward

For a closed surface

$$\phi_E = \sum_{A\Delta} E.\Delta S = \int E\,dS$$

Continous charge distribution



Gauss's Theorem in Elctrostatics

The total electric flux passing through any closed surface is equal to $\frac{1}{\varepsilon_0}$ times the charge enclosed by the surface.

$$\phi_E = \frac{1}{\varepsilon_0} \times q\,\text{enclosed}$$

$$\sum_{A\Delta} E\Delta S = \frac{q.enclosed}{\varepsilon_0}$$

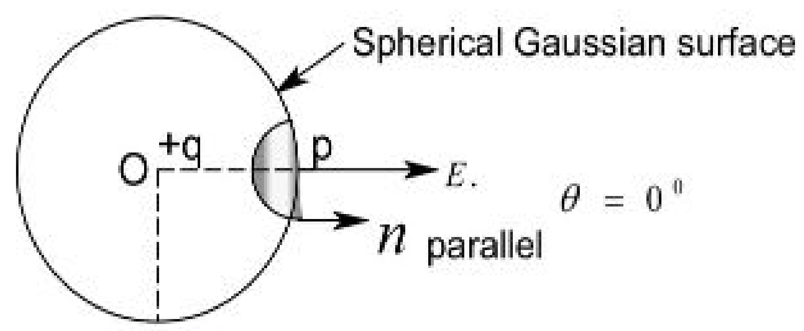
$$\int E\,ds = \frac{q.enclosed}{\varepsilon_0}$$

The closed surface in the gauss's law is known as Gaussian surface.

Proof for Gauss's Theorem

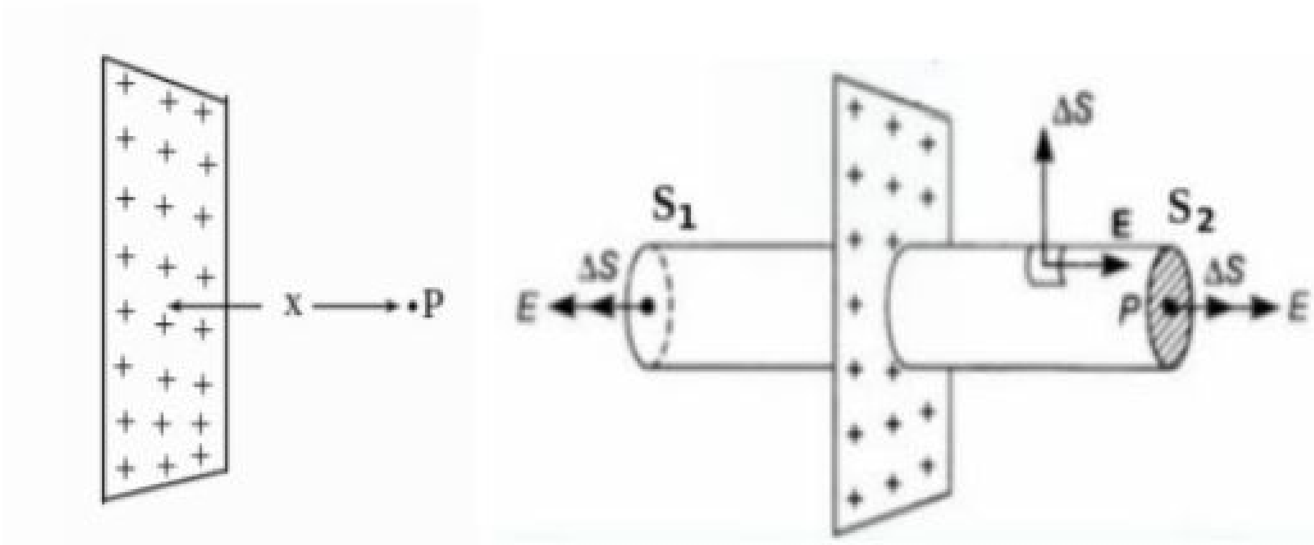
(Deriving Gauss's Law from Coulomb's Law)

- Consider a charge 'q' placed at the centre of a spherical Gaussian surface (Imaginary surface)



The small electric flux passing through the small area Δs

II) Electric field due to uniformly charged Infinite plane sheet



- Consider an infinitely along space of charge of the surface charge density $\sigma = \frac{\Delta q}{\Delta s}$
- Consider a point 'p' at a distance 'r' from the surface. The resultant electric field 'p' is horizontally outward
- Assume a cylindrical Gaussian surface passing through the sheet extending on either side

$\phi_E = \phi_{end} + \phi_{end} + \phi_{curved}$

$E\,S\cos\theta + E\,S\cos\theta + E\,S\cos 90$

$E\,S(\cos\theta + \cos\theta) + \cos 90$

$\phi_E = 2ES$ (1)

$q_{end} = \sigma S$ (2)

According to Gauss's Theorem $\phi_E = \frac{q_{end}}{\varepsilon_0}$

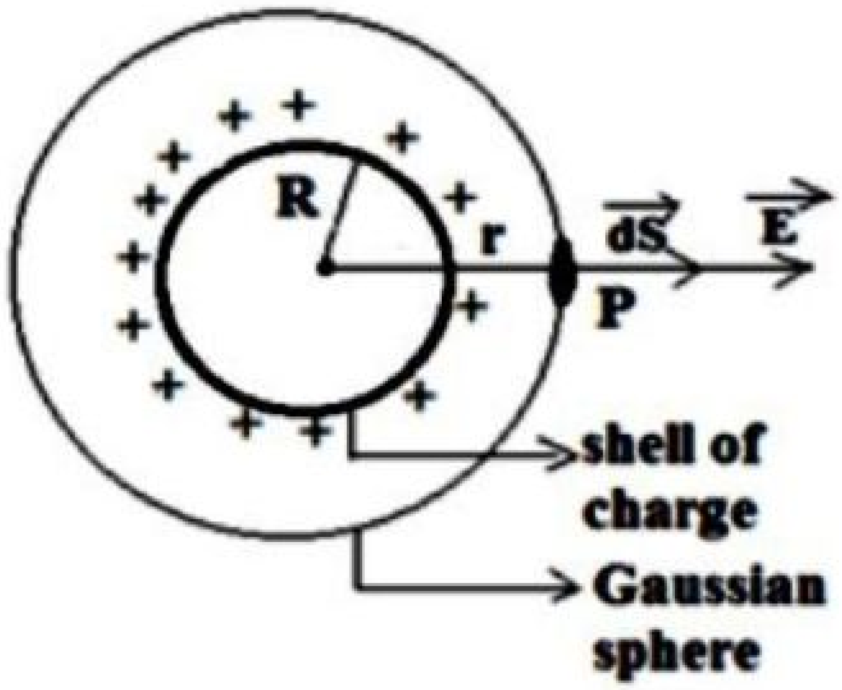
$2ES = \frac{\sigma S}{\varepsilon_0}$

$$\boxed{E = \frac{\sigma}{2\varepsilon_0}}$$

III) Electric due to uniformly charged spherical shell of charge density (σ)

Consider a shell of radius R and charge density σ. We have to find the electric field at a point distant r from the centre of this shell. For this we imagine a Gaussian sphere of radius r, concentric with the given shell of charge and passing through P.

Case(i): Electric field Outside the shell



The total Electric flux through the Gaussian sphere,

$$\oint \vec{E} \bullet \vec{dS}$$

$$= \oint EdS\cos 0 \quad (\because \ \vec{E} \parallel \vec{dS})$$

$$= \oint EdS$$

$$= E\oint dS$$

$$= E \times 4\pi r^2$$

The charge enclosed by the Gaussian sphere, $q = A\sigma = 4\pi R^2\sigma$

Applying Gauss's theorem,

$$\oint \vec{E} \bullet \vec{dS} = \frac{q}{\varepsilon_0}$$

$$E \times 4\pi r^2 = \frac{4\pi R^2\sigma}{\varepsilon_0}$$

$$E = \frac{R^2\sigma}{\varepsilon_0 r^2}$$

$$\boxed{E = \frac{R^2\sigma}{\varepsilon_0 r^2}}$$

Case(ii): Electric field on the shell

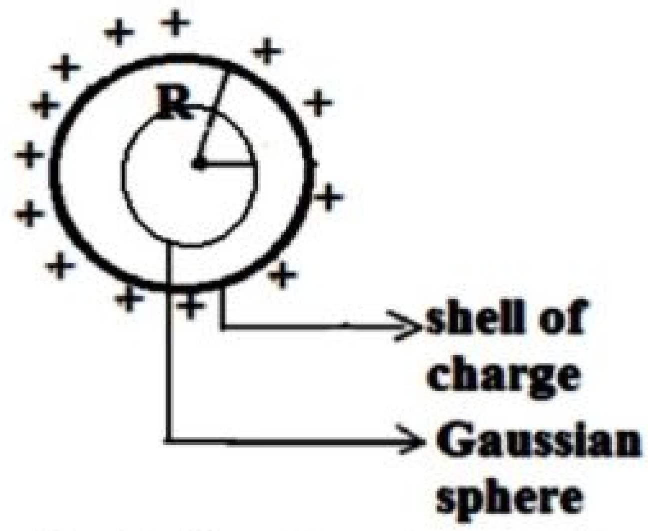
Put r=R

$$E = \frac{R^2\sigma}{\varepsilon_0 R^2} = \frac{\sigma}{\varepsilon_0}$$

$$E = \frac{\sigma}{\varepsilon_0}$$

$$\boxed{E = \frac{\sigma}{\varepsilon_0}}$$

Case(iii) Electric field inside the shell



In this case the charge enclosed by the Gaussian sphere, q = 0

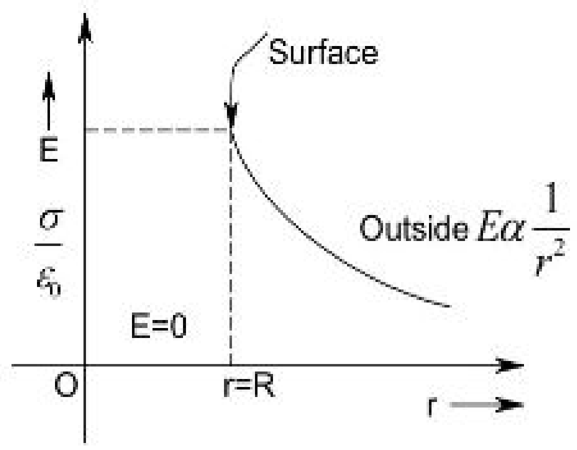
∴Substituting in Gauss's theorem

$$E \times 4\pi r^2 = \frac{0}{\varepsilon_0}$$

$\Rightarrow$ **E = 0.**

The electric field inside a spherical shell of charge is zero

Variation of E due to spherical shell with distance



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CHAPTER 2

ELECTRIC POTENTIAL AND CAPACITORS

Electric Potential (V_P)

Electrostatic potential is the work done to move a unit Positive charge from infinite to that point against electrostatic force .

Take R at ∞

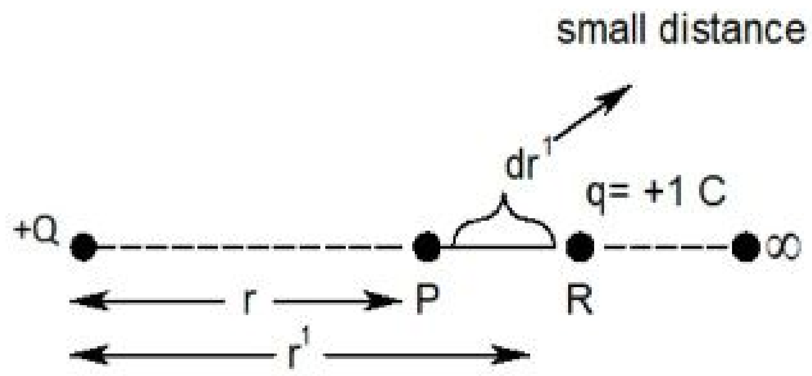
$$V_P = \frac{W_{\infty \to P}}{q}$$

$V_R = 0$ (R is at ∞)

$$V_P = -\int_{\alpha}^{P} E.dr$$

SI Unit = Volt or JC^{-1}

Electric Potential due to a Point charge



E at a distance r^1

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{(r^1)^2}$$

Electric Potential $V_P = -\int_{\alpha}^{P} E.dr^1$

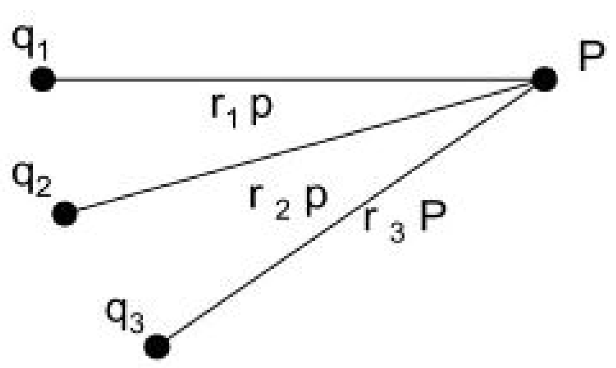
$$V_P = \frac{-Q}{4\pi\varepsilon_0}\int_{\alpha}^{P}\frac{1}{(r^1)^2}.dr^1 \quad \text{or} \quad \frac{-Q}{4\pi\varepsilon_0}\int_{\alpha}^{P}(r^1)^{-2}.dr^1$$

Rule $\Rightarrow \int x^n \quad \frac{x^{n+1}}{n+1}$ that is, $V_P = \frac{-Q}{4\pi\varepsilon_0}\left[\frac{r^{1-2+1}}{-2+1}\right]$

$= \frac{+Q}{4\pi\varepsilon_0}\left[\frac{1}{r^1}\right]_{\infty}^{r}$ $= \frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{r^1}\right]_{\infty}^{r}$ or $V_{(P)} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$

That is, $\frac{E}{V} = \frac{1}{r}$

Electric Potential due to a number of charges



$$V_{(P)} = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1}{r_1 p} + \frac{q_2}{r_2 p} + \frac{q_3}{r_3 p}\right]$$

In general $V_{(P)} = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{rip}$

Note : Potential of positive charge is positive , potential of a negative charge is negative.

Capacitors (Condensers)

Charge storing devices (electric energy storing device

Principle

A capacitor store electrical energy in the form of electric field lines . Charge on a conductor α electric potential .

q α V or $\frac{q}{v}$ = constant

Capacitance (size and shape, dielectric medium, neighboring conductor)

Metal sphere = $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$

For spherical conductor (on earth)

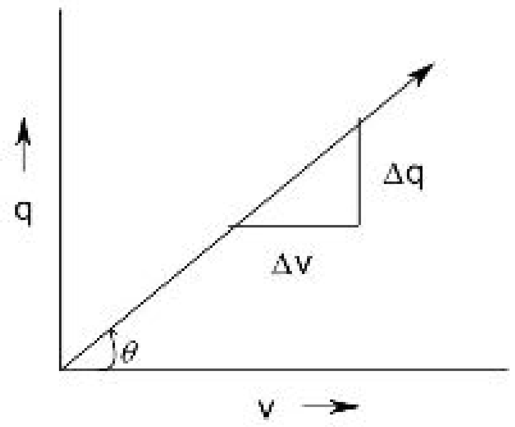
$C = \frac{q}{V} = \frac{q}{4\pi\varepsilon_0\frac{q}{R}}$

$C_{sphere} R = 4\pi\varepsilon_0$

Graph between q and V

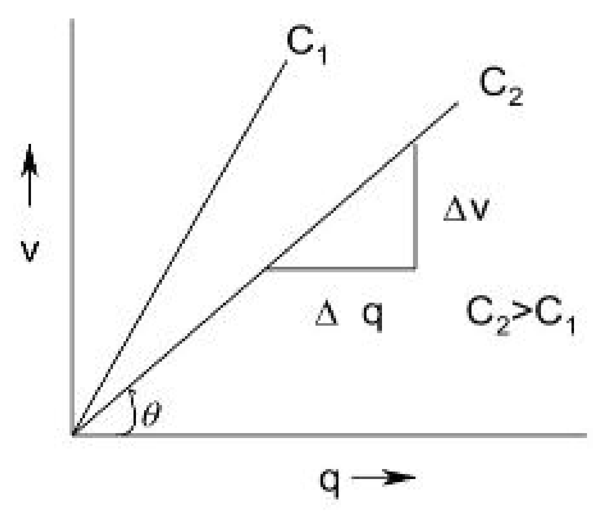
1) Slope $= \frac{\Delta q}{\Delta v} = C$

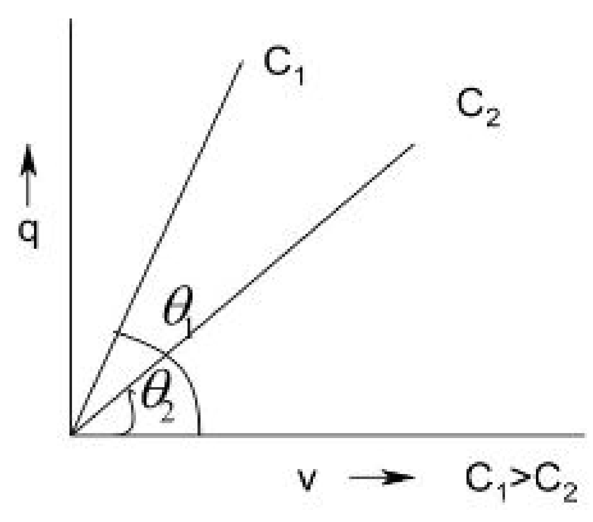
Slope = C



Area under the graph = $\frac{1}{2}Qv$ = electric energy stored by the capacitor

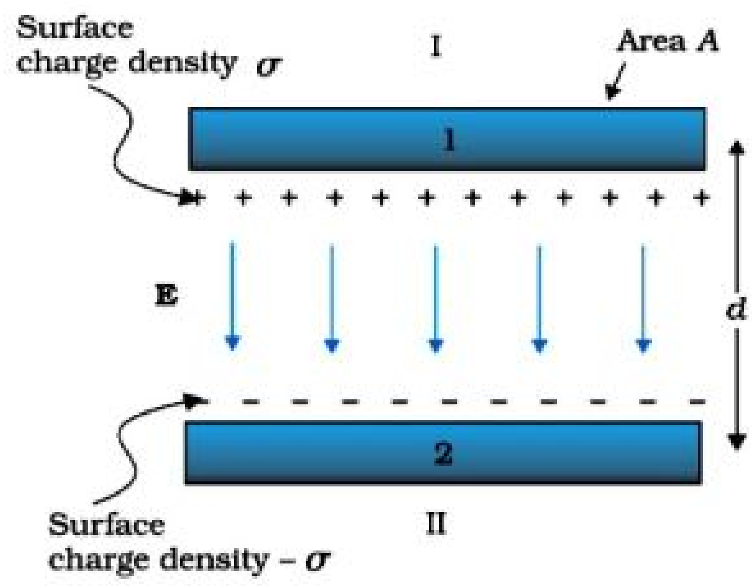
2) $\frac{1}{slope} = C$





Capacitance of a Parallel plate Capacitor

Electrical field between the plates



$$E = \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{\varepsilon_0}$$

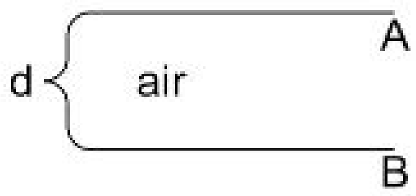
$$E = \text{since } \sigma = \frac{Q}{A} \qquad E = \frac{Q}{A\varepsilon_0}$$

Potential difference between the plates

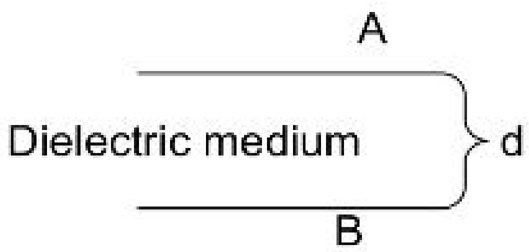
$$V = Ed \qquad E = \frac{dV}{dr} = \frac{V}{d}$$

$$V = \frac{Q d}{A\varepsilon_0}$$

Then capacitance $C = \frac{Q}{V} = \frac{Q}{\frac{Q}{A\varepsilon_0} d}$



$$C_{air} = \frac{\varepsilon_0 A}{d}$$



In a dielectric medium $C_{dielectric} = \frac{k\varepsilon_0 A}{d}$

Note :- Presence of neighboring conductor can increase the capacity of a conductor

Electric energy stored in a capacitor

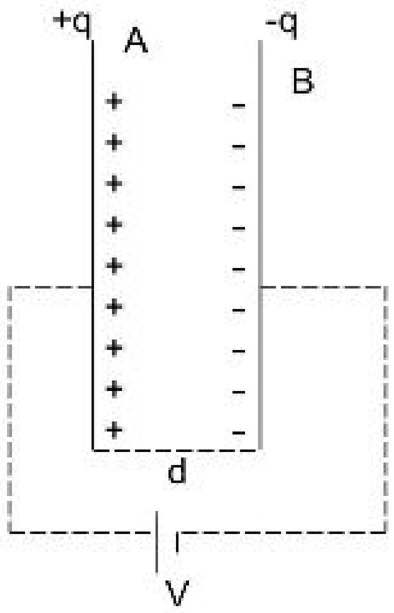
Consider a capacitor of capacitance 'C' connected to a battery of voltage 'V', Let the initial charge on the capacitor is 'q'.

The potential across the capacitor in $V = \frac{q}{c}$

Small work done to charge the capacitor from q to q + dq

$$dW = (dq)\, V$$

$$dW = \frac{q}{V} dq$$



Total work done to charge the capacitor from q = 0 to q = Q

$W = \int dW = \int \frac{1}{C} q^1 dq$

Rule $= W = \int x^n dx = \frac{x^{n+1}}{n+1}$ ie, $W = \frac{1}{C}\left[\frac{q^2}{2}\right]_0^Q$ or $W = \frac{1}{2C}\left[Q^2 - 0\right]$

This work done is stored as $U_\in$

$$U_\in = \frac{1}{2}\frac{Q^2}{C}$$

We know Q = CV

$$U_\in = \frac{1}{2}\frac{C^2V^2}{C} = \frac{1}{2}CV^2$$

Also $C = \frac{Q}{V}$

$$U_\in = \frac{1}{2}\frac{Q^2}{\frac{Q}{V}} = \frac{1}{2}QV$$

<u>Electric energy density of a parallel Plate capacitor (u_E)</u>

Electric energy density $= \frac{\text{electric energy}}{\text{volume}}$

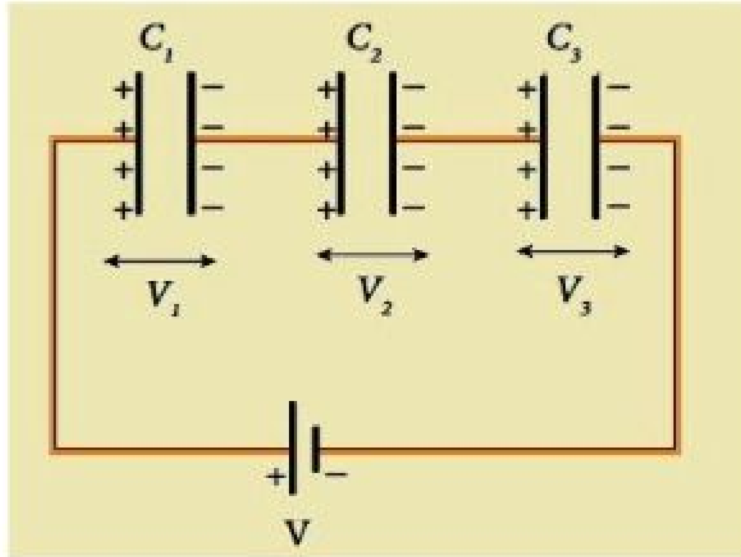
$u_E = \frac{U_E}{A \times d}$

$= \frac{\frac{1}{2}CV^2}{Ad} = \frac{\frac{1}{2}\left(\frac{\varepsilon_0 A}{d}\right)(\in d)^2}{A \times d} = u_E = \frac{1}{2}\frac{\varepsilon_0 A \in^2 d^2}{A \times d^2}$ $\quad u_E = \frac{1}{2}\varepsilon_0 \in^2$

<u>Combination of Capacitor</u>

1) **<u>Series Combination</u>**

$\Rightarrow$ charge is same



⇒ Charge is same in all capacitor and equal to total charge stored by combination

⇒ Potential may be different

$$V_1 = \frac{Q}{C_1}, V_2 = \frac{Q}{C_2} \quad V_3 = \frac{Q}{C_3}$$

Total potential $V = V_1 + V_2 + V_3$

$$V \alpha \frac{1}{C}$$

$$\frac{V_1}{V_2} = \frac{C_2}{C_1}$$

$$V = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} \qquad \text{or} \qquad V = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right) \qquad \Rightarrow C_s = \frac{Q}{V}$$

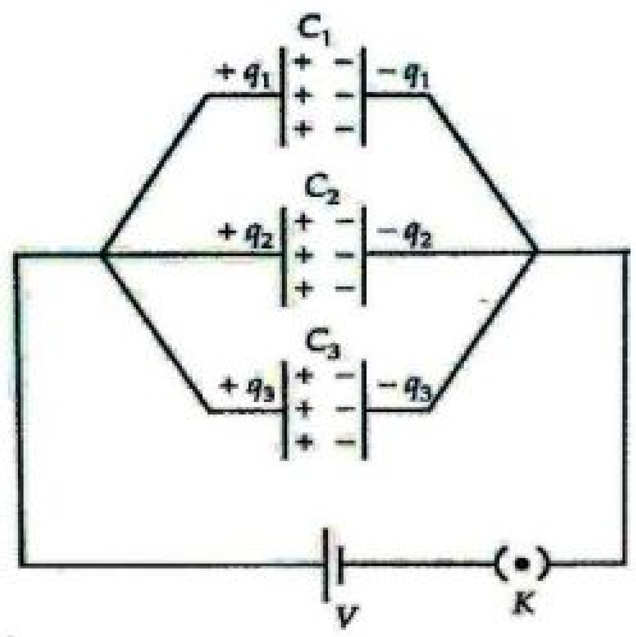
$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

C_s = Effective (equivalent) capacitance in series)

For n identical capacitors in series $C_s = \frac{C}{n}$

Parallel Combinations

⇒Potential is same in all capacitor and equal to total potential stored by combination



⇒ Charge may be different

$$Q_1 = VC_1 \quad C_1V$$

$$Q_2 = VC_2 \quad C_2V$$

$$Q_3 = VC_3 \quad C_3V$$

$$Q \alpha C$$

$$\frac{Q_1}{Q_2} = \frac{C_1}{C_2}$$

$Q_{para} = VC_1 + VC_2 \quad VC_3$

$= V(C_1 + C_2 \quad C_3)$

$$\frac{Q}{V} = C_1 + C_2 + C_3$$

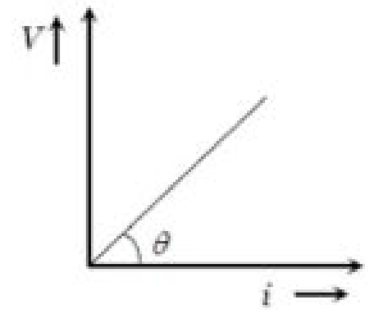
$C_P = Q/V$

C_P = Effective (equivalent) capacitance in parallel

For n identical capacitors in parallel $C_P = nC$

CHAPTER 3
CURRENT ELECTRICITY

Ohm's law -At constant temperature the current flowing through a conductor is directly proportional to potential difference between the ends of the conductor. Thus, V= IR where V- potential difference, I – current, R- resistance.



Resistance- Ability of conductor to oppose electric current. R=V/I

SI unit – ohm **(Ω)**

Its dimension is [$ML^2 T^{-3} A^{-2}$]. Reciprocal of resistance is known as conductance. Its unit is Ω^{-1} or mho or siemens **(S).**

Resistance depends on resistivity (ρ), length (ℓ) and area (A) of the conductor. $R = \rho \frac{\ell}{A}$

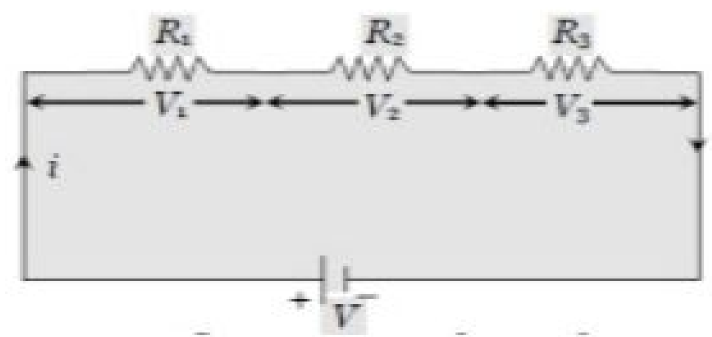
The heat energy dissipated in a current flowing conductor is given by $H= I^2 Rt$ where I- current, R – resistance, t –time.

Electrical energy It is defined as the energy generated by the movement of electrons from one point to another. Electrical energy = electrical power X time. SI unit – joule (J). Commercial unit – kilowatt hour (kWh). 1kWh = 3.6×10^6 J.

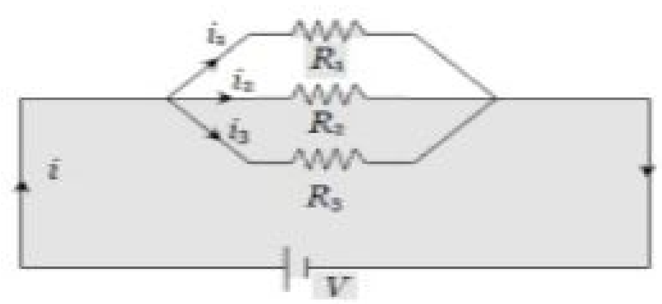
Electric power It is the energy dissipated per unit time. Power, $P= H/t$. Also, $P = VI = V^2/R$

SI unit is **watt (W).** 1 kilo watt (1kW) = 1000W. 1mega watt (MW) = 10^6W. Another unit is horse power (hp) and 1 hp = 746 W

Resistors - A resistor is an electrical component to offer resistance to the flow of electric current. Symbol is as shown here.



Resistors in series



Resistors in parallel

Symbol of a resistor

Series combination	Parallel combination
• In series connection same current pass through all resistors.	• In parallel connection current is different through each resistor.
• The applied potential is given by $V= V_1+V_2+V_3$	• The total current is $I = I_1+I_2+I_3$
• The effective resistance is $R = R_1 + R_2 + R_3$	• The reciprocal of effective resistance is $1/R_P =1/R_1 + 1/R_2 +1/R_3$
• The effective resistance increases in series combination.	• The effective resistance decreases in parallel combination.

Cell - The device which converts chemical energy into electrical energy is known as electric cell.

(1) A cell neither creates nor destroys charge but maintains the flow of charge present at various parts of the circuit by supplying energy needed for their organised motion.

(2) Cell is a source of constant emf but not constant current.

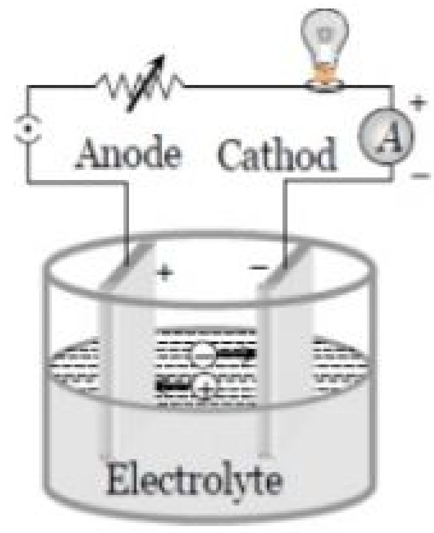
(3) Mainly cells are of two types:

(i) Primary cell: Cannot be recharged

(ii) Secondary cell: Can be recharged

(4) The direction of flow of current inside the cell is from negative to positive electrode while outside the cell is form positive to negative electrode.

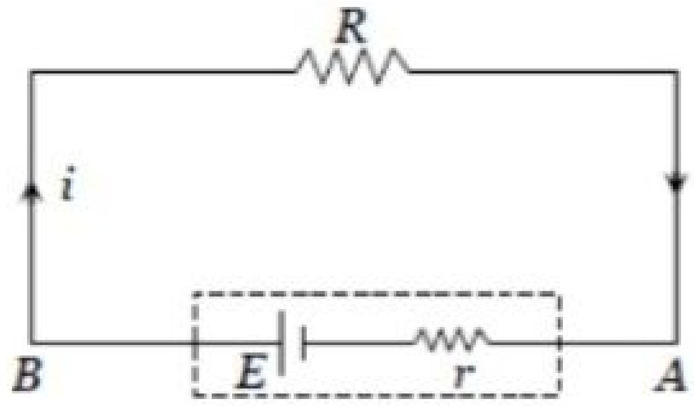
(5) A cell is said to be ideal, if it has zero internal resistance.



Emf of cell (*E*): The potential difference across the terminals of a cell when it is not given any current is called its emf. Its unit is volt (V).

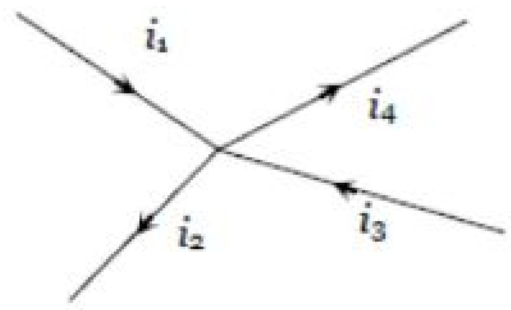
Potential difference (*V*): The energy given by the cell in the flow of unit charge in a specific part of electrical circuit is called potential difference. Its unit is also volt (V).

Terminal Voltage: The voltage across the terminals of a cell when it is supplying current to external resistance is called terminal voltage. Terminal voltage is equal to the product of current and resistance of that given part *i.e.* $V = Ir$



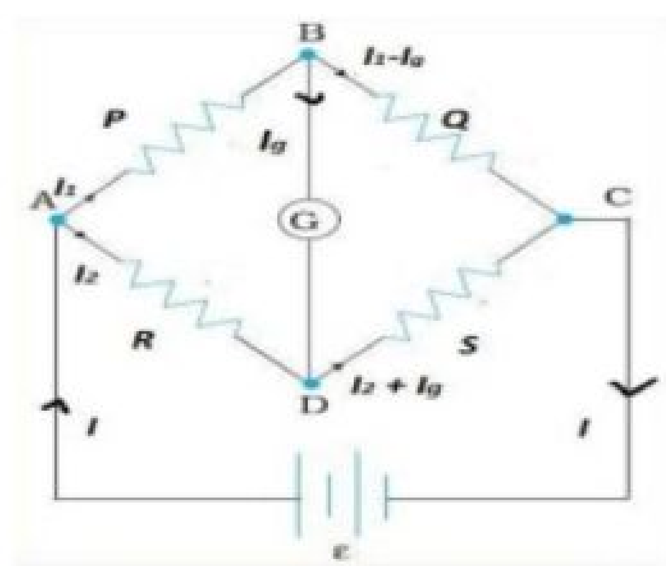
Internal resistance (*r*): In case of a cell the opposition of electrolyte to the flow of current through it is called internal resistance of the cell. The internal resistance of a cell depends on the distance between electrodes ($r \propto d$), area of electrodes [$r \propto (1/A)$] and nature, concentration ($r \propto C$) and temperature of electrolyte [$r \propto (1/\text{temp.})$]. Internal resistance is different for different types of cells and even for a given type of cell it varies from to cell.

Kirchhoff's Laws



Kirchhoff's first law: This law is also known as junction rule or current law (*KCL*). According to it the algebraic sum of currents meeting at a junction is zero *i.e.* $\sum i = 0$. This law is a statement of "*conservation of charge*" as if current reaching a junction is not equal to the current leaving the junction, charge will not be conserved. In a circuit, at any junction the sum of the currents entering the junction must equal the sum of the currents leaving the junction. $i_1 + i_3 = i_2 + i_4$

Kirchhoff's second law: This law is also known as loop rule or voltage law (KVL) and according to it "the algebraic sum of the changes in potential in complete traversal of a mesh (closed loop) is zero", *i.e.* $\sum V = 0$. This law represents "*conservation of energy*" as if the sum of potential changes around a closed loop is not zero, unlimited energy could be gained by repeatedly carrying a charge around a loop.



Wheatstone bridge: Wheatstone bridge is an arrangement of four resistance which can be used to measure the unknown resistance. The bridge is said to be balanced when deflection in galvanometer is zero *i.e.* no current flows through the galvanometer.

In the balanced condition $\frac{P}{Q} = \frac{R}{S}$

Meter bridge is an instrument based on the principle of Wheatstone bridge and is used to measure unknown resistance.

Applying voltage rule to the loop ABDA

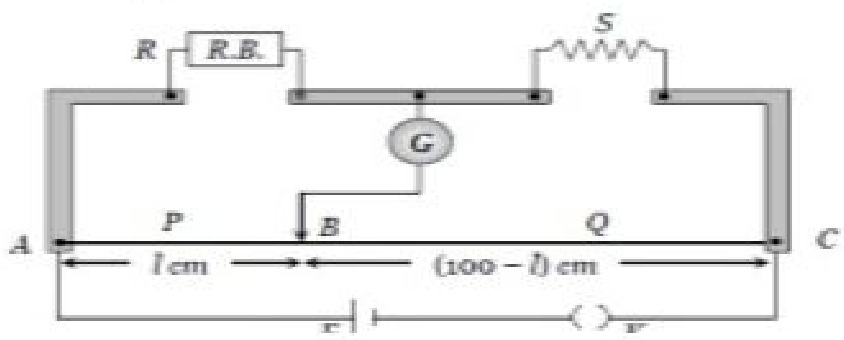
$I_1P + I_g G - I_2R = 0$

For the loop BCDB

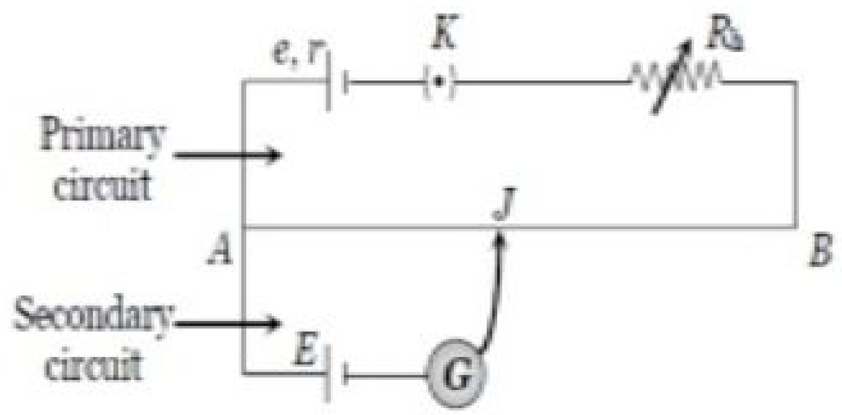
$(I_1 \quad I_g)Q-(I_2+I_g)S-I_gG=0$ Now PQR and S are so adjusted that current through galvanometer is zero ($I_g = 0$). Now the bridge is balanced.

Thus $I_1P - I_2R = 0$ and $I_1Q - I_2S = 0$ Or $I_1P = I_2R$ and $I_1Q = I_2S$

That is $\frac{P}{Q} = \frac{R}{S}$ This is the balancing condition of a Wheatstone bridge.



Meter bridge: In case of meter bridge, the resistance wire *AC* is 100 *cm* long. Varying the position of tapping point *B*, bridge is balanced (galvanometer deflection is zero). If there is no current through the galvanometer (bridge is balanced) then, $\frac{R}{S} = \frac{\ell}{100-\ell}$. If R is an unknown resistance and S is known resistance then $R = S(\frac{\ell}{100-\ell})$.



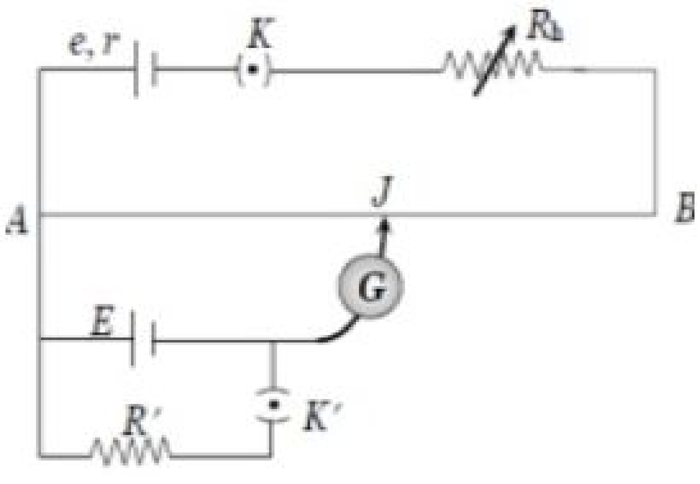
Potentiometer: Potentiometer is a device used to measure emf of a cell. It is also used to measure internal resistance of a given cell. Potentiometer is based on no deflection (null deflection) method. When the potentiometer gives zero deflection, it does not draw any current from the cell or the circuit *i.e.* potentiometer is effectively measuring the emf of the cell. The different parts are follows,
J = Jockey *K* = Key *R* = Resistance of potentiometer wire ρ = Specific resistance of wire and *Rh* = Variable resistance.

Working: When the Jockey is at the point *J* on wire, then potential difference between *A* and *J* will be $V \alpha xl$. If $V = E$ then no current will flow in galvanometer circuit this condition to known as null deflection position, length *l* is known as balancing length.ie: $\boldsymbol{E \alpha l}$

Voltmeter	Potentiometer
• Its resistance is high but finite	• Its resistance is high but infinite
• It draws some current from source of emf	• It does not draw any current from the source of known emf.
• Its sensitivity is low	• Its sensitivity is high
• It is based on deflection method	• It is based on zero deflection method

Application of Potentiometer

(1) **To determine the internal resistance of a primary cell**



(i) Initially in secondary circuit key *K′* remains open and balancing length (*l*1) is obtained. Since cell *E* is in open circuit so it's emf balances on length *l*1 *i.e.* $E = xl_1$ ……. (i)

(ii) Now key *K*' is closed so cell *E* comes in closed circuit. If the process is repeated again then potential difference *V* balances on length *l*2 *i.e.* $V = xl_2$……. (ii)

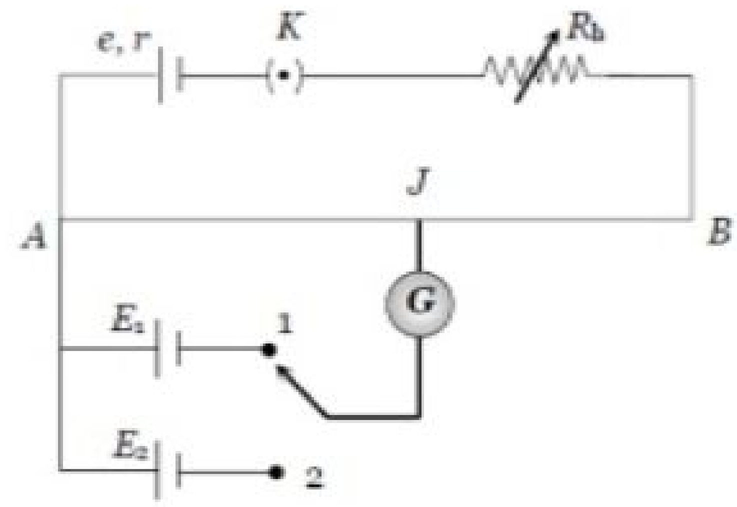
By using formula internal resistance

$r = \left(\frac{E}{V} - 1\right) R'$

or $r = \left(\frac{l1}{l2} - 1\right) R'$

(2) **Comparison of emf's of two cell**

Let l_1 and l_2 be the balancing lengths with the cells E_1 and E_2 respectively, then



$\boldsymbol{E_1 \propto l_1}$ and $\boldsymbol{E_2 \propto l_2}$

Therefore $\frac{E1}{E2} = \frac{l1}{l2}$

CHAPTER 4
MOVING CHARGES AND MAGNETISM

Source of magnetic field

A charge at rest produces electric field while a moving charge produces magnetic field in addition to electric field.

Superposition Principle

The magnetic field of several sources is the vector addition of magnetic field of individual sources.

Magnetic Lorentz force

Force on a charge moving in a magnetic field. $\mathbf{F}_{mag} = q\,(\mathbf{v}\times\mathbf{B}) = qvB\,\text{Sin}\theta$

Where, q –charge, v- velocity, B – magnetic field, θ- angle between **v** and **B**.

Special Cases:

1. **If the charge is at rest**, i.e. v = 0, then F = 0.

Thus, a stationary charge in a magnetic field does not experience any force.

2. **If θ = 0° or 180°** i.e. if the charge moves parallel or anti-parallel to the direction of the magnetic field, then F = 0.

3. **If θ = 90°** i.e. if the charge moves perpendicular to the magnetic field, then the force is maximum. $F_{max} = qvB$

4. **Force on a negative charge is opposite to that on a positive charge**

Lorentz force

Total force acting on a charge, when it is passing through a crossed electric and magnetic field.

$F_{Lorentz} = q\,\mathbf{E} + q\,(\mathbf{v} \times \mathbf{B})$

Right hand thumb rule: Grasp the current carrying conductor in the right hand with the thumb indicating the direction of current, then the closed fingers will indicate the direction of magnetic field.

Unit of Magnetic field: The SI unit of magnetic field is tesla(T). Its smaller unit is gauss. 1 gauss = 10^{-4} T. Earth's magnetic field is about 0.36 gauss or 3.6×10^{-5} T.

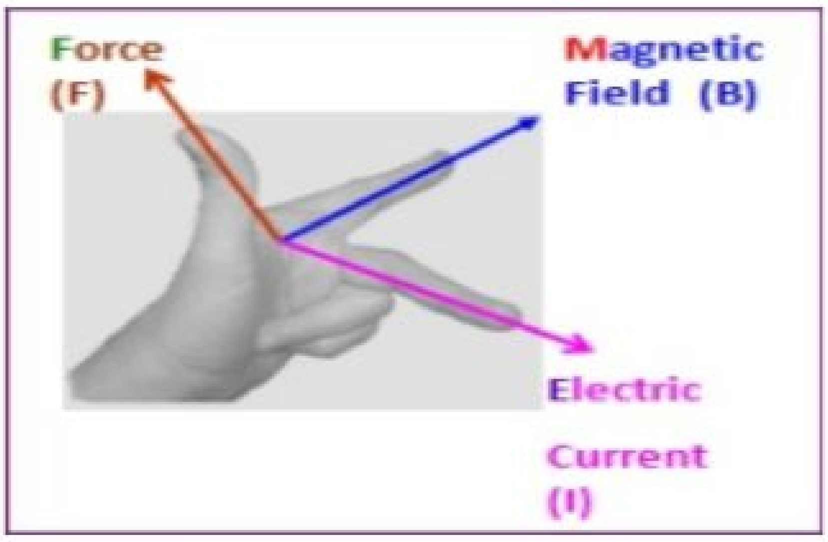
Magnetic force on a current carrying conductor

When a current carrying conductor of length *l* carrying a current I ampere is kept in a magnetic field of intensity B, then the force acting on it is given by

$$\mathbf{F} = I\,(\boldsymbol{l} \times \mathbf{B}) = IlB\,\text{Sin}\theta$$

Fleming's Left Hand Rule

Stretch out the first three fingers of the left hand in mutually perpendicular directions. If **forefinger represents field** and **central finger represents the current** then **thumb represents the direction of force**.



Magnetic Field due to a Current Element, BIOT-SAVART's LAW

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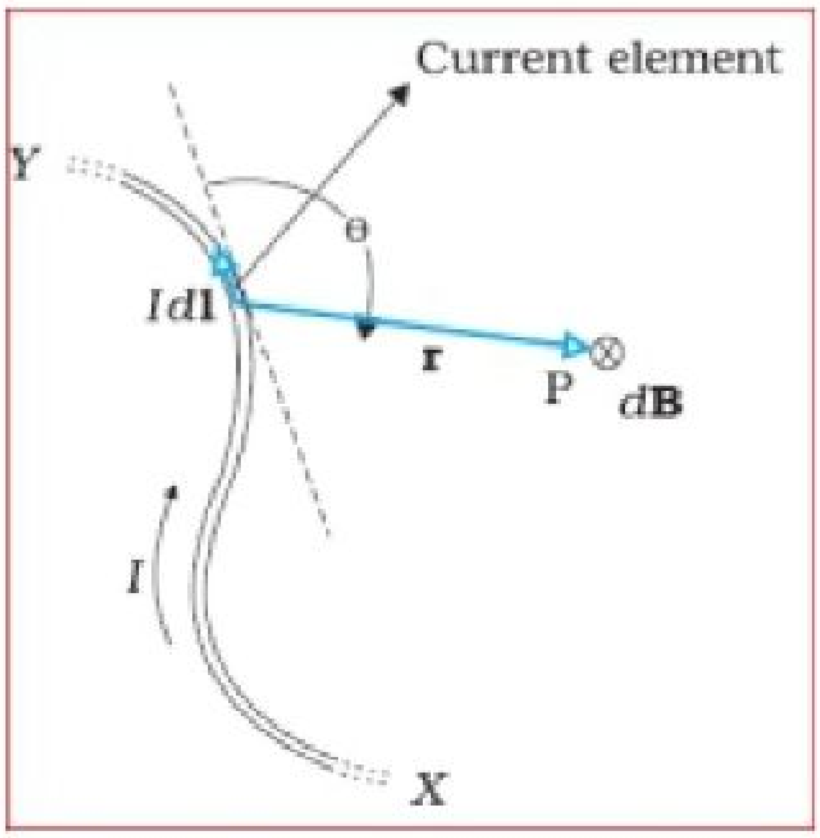


The magnetic field at a point due to the small element of a current carrying conductor is directly proportional to

1) the current flowing through the conductor (I)
2) the length of the element (dl)
3) sine of the angle (θ) between r and dl

and inversely proportional to

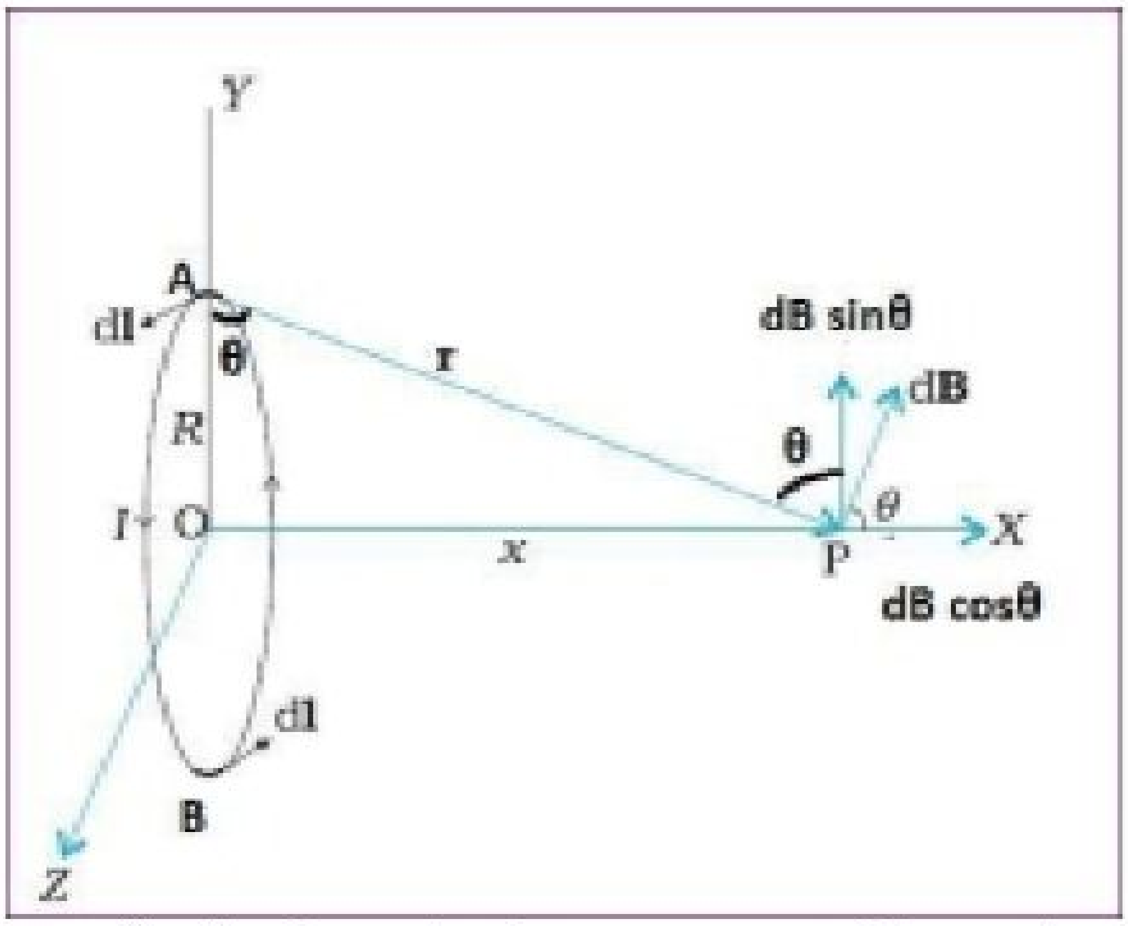
4) the square of the distance (r) of the point P from dl.

Thus the magnetic field due to a current element is

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{r^2}$$

Where $\mu_0 = 4\pi \times 10^{-7}$ Tm/A, called permeability of free space.

Magnetic Field on the Axis of a Circular Current Loop



Consider a current loop of radius R carrying I ampere current. P be a point at a distance of x from its centre O.

The magnetic field at P due to the current element dl, at A is d**B** = $\frac{\mu_0}{4\pi}\frac{IdlSin\theta}{r^2}$

Here θ = 90° and sin 90 = 1,

Hence, d**B**= $\frac{\mu_0}{4\pi}\frac{Idl}{r^2}$..........(1)

This magnetic field can be resolved into two components, dB Sinθ and dB Cosθ as shown in figure. Consider another element B, diametrically opposite to A.

Now, the vertical components cancel each other and the total magnetic field at P due to these current elements is only along horizontal ie dB = dB Cosθ.......(2)

But Cosθ = Sin(90- θ) = $\frac{R}{r}$

Therefore, (2)⇒ dB = = $\frac{\mu_0}{4\pi}\frac{Idl\,R}{r^3}$ ....(3)

But, r = $\sqrt{(x^2 + R^2)}$

(3) ⇒ dB = $\frac{\mu_0}{4\pi}\frac{Idl\,R}{(x^2+R^2)^{3/2}}$

The net contribution along *x*-direction can be obtained by integrating d*B* = d*B* cos q over the loop.

$$B = \int dB\, Cos\theta$$

$$= \int \frac{\mu_0}{4\pi}\frac{Idl\,R}{(x^2+R^2)^{3/2}}$$

$$= \frac{\mu_0}{4\pi}\frac{IR}{(x^2+R^2)^{3/2}}\int dl \;......(4)$$

But $\int dl = 2\pi R$, is the circumference.

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

$$B = \frac{\mu_0 I R^2}{2\,(x^2+R^2)^{3/2}}$$

If there are N turns, then $B = \frac{\mu_0 N I R^2}{2\,(x^2+R^2)^{3/2}}$ .... (5)

Magnetic field at the centre of the loop

If the point P is at the centre of the loop, then x = 0

$\therefore$ (5) $\Rightarrow$ $B = \frac{\mu_0 N I}{2R}$ ....(6)

Problem: A current loop of 300 turns of radius 20cm carries a current of 2A. Calculate the magnetic field produced at its centre.

Solution: Given N = 300 R = 20 cm = 0.2 m I = 2A

We have, $B = \frac{\mu_0 N I}{2R}$

$= \frac{4\pi \times 10^{-7} \times 300 \times 2}{2 \times 0.2} = 1.88 \times 10^{-3}$T

Ampere's Circuital Theorem

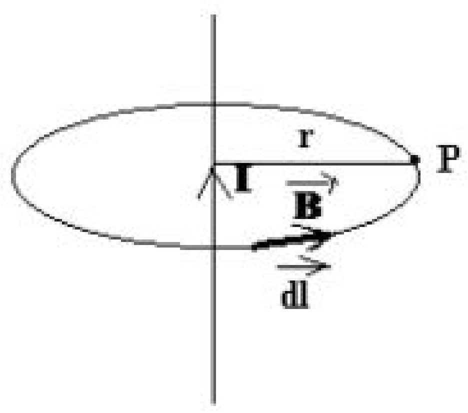
The line integral of magnetic field around a closed loop is equal to μ_0 times the total current enclosed by that loop.

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I_{encl}$$

The closed loop is called amperian loop.

Magnetic field due to a straight infinite current carrying wire

Let I be the current through an infinitely long straight conductor. In order to calculate the magnetic field at a distance r, imagine a circular amperian loop of radius r



Around the loop B and dl are in the same direction and hence $\theta = 0$

$\therefore$ B.dl = Bdl Cosθ = Bdl

$$\oint \mathbf{B} \cdot d\mathbf{l} = \oint B\, dl = \mu_0 I_{encl}$$

$$B \oint dl = \mu_0 I$$

$$B \times 2\pi r = \mu_0 I$$

$$= \frac{\mu_0 I}{2\pi r}$$

Problem: A long straight wire carries a current of 3A. What is the field B at a point 10cm from the wire?

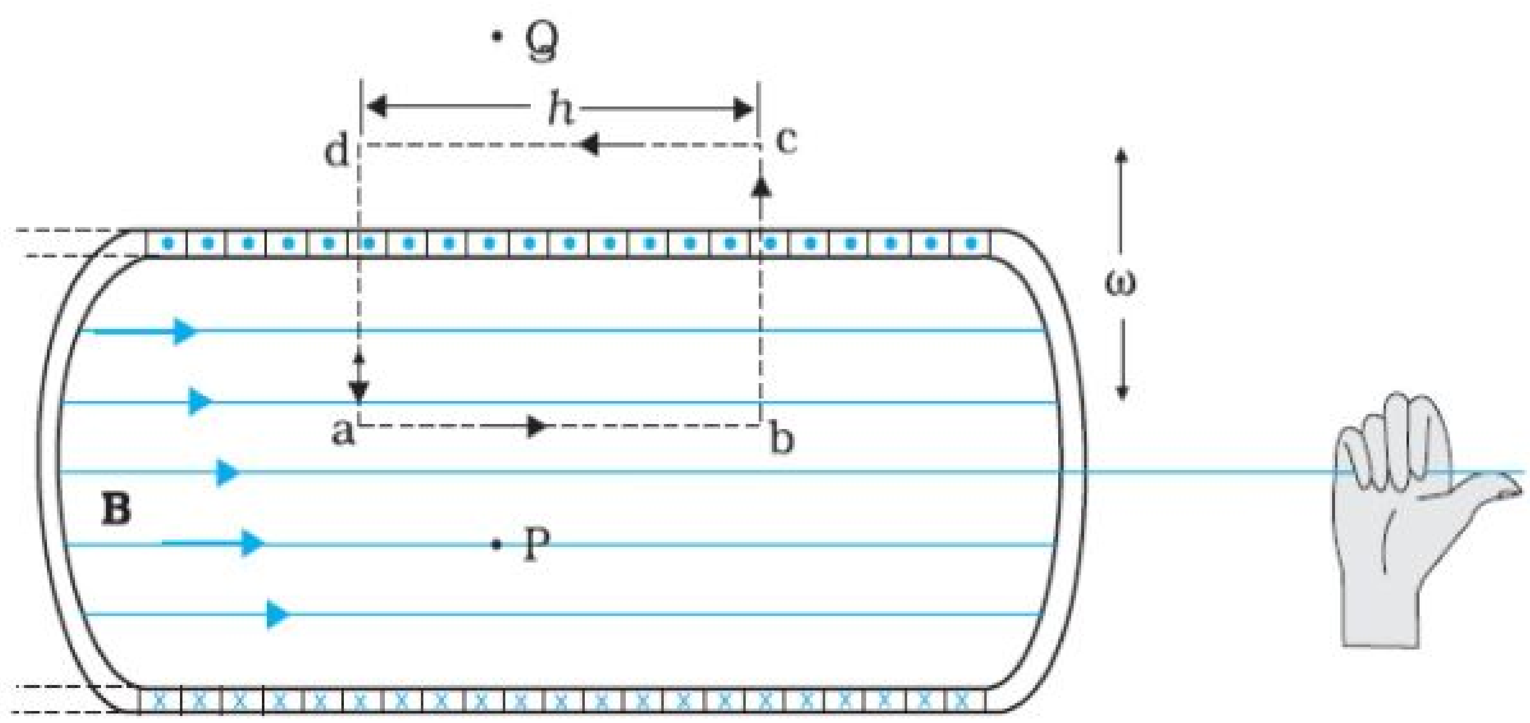
Solution: Given I = 3A r = 10cm = 0.1m

$$\text{We have, } \mathbf{B} = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} \times 3}{2\pi \times 0.1}$$

$$\mathbf{B = 6 \times 10^{-6}}\ \mathrm{T}$$

Magnetic Field due to a Solenoid

A solenoid is an insulated copper wire closely wound in the form of a helix. Since they are wound closely, each turn are assumed to be circular. The cross sectional view of a solenoid is given below.



The magnetic field of a very long solenoid. We consider a rectangular Amperian loop abcd to determine the field.

Imagine a rectangular amperian loop abcd of side h. Let n be the number of turns per unit length. According to Ampere's circuital theorem,

$$\mathbf{B}\oint \boldsymbol{dl} = \mu_0 I_{encl}$$

$$\mathbf{B}\oint \boldsymbol{dl} = \int_a^b B.dl + \int_b^c B.dl + \int_c^d B.dl + \int_d^a B.dl \quad ....(1)$$

The sides bc and da are perpendicular, $\int_b^c B.dl = \int_d^a B.dl = 0$ and since the side cd is outside the solenoid, $\int_c^d B.dl = 0$

$$\therefore (1) \Rightarrow \mathbf{B}\oint \boldsymbol{dl} = \int_a^b B.dl = \mu_0 I_{encl} \quad ....(2)$$

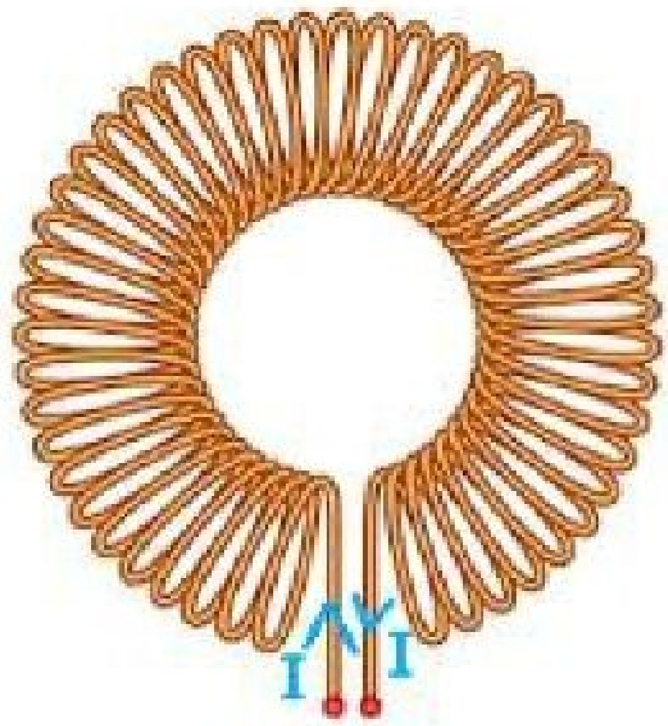
But $\oint \boldsymbol{dl}$ = h and I_{encl} = nhI

$$(2) \Rightarrow B\,h = \mu_0\, nhI$$

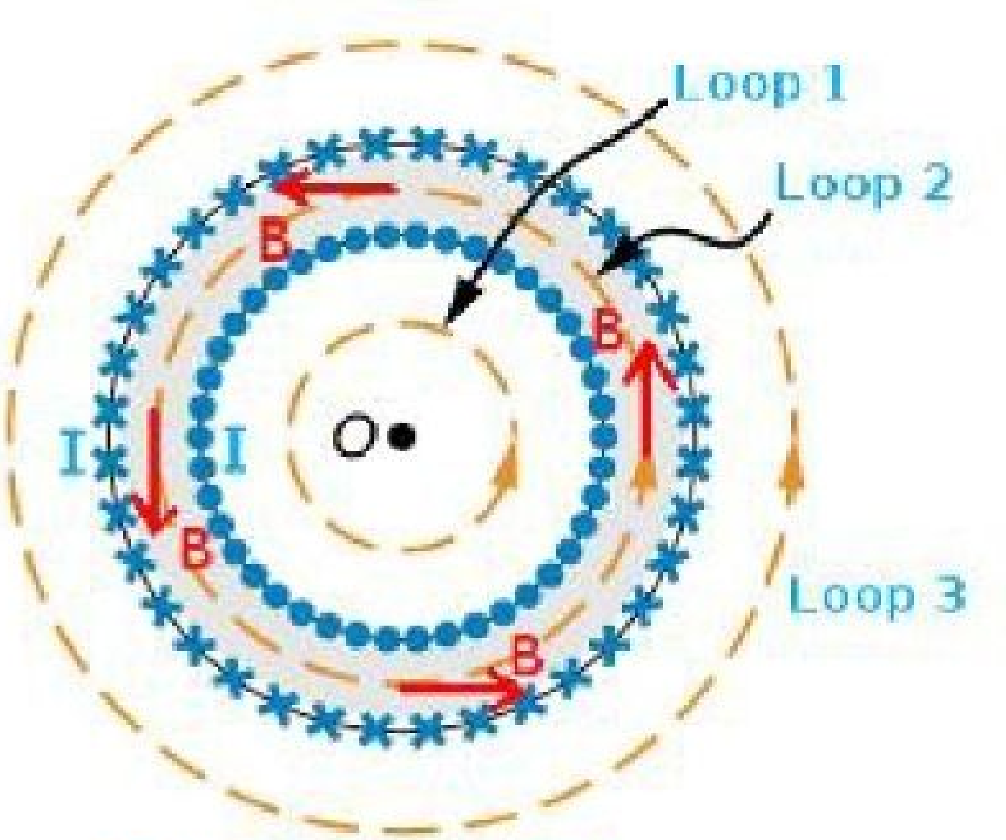
$\therefore \qquad B = \mu_0 nI$

Magnetic Field due to a Toroid

Toroid is an endless solenoid.



Toroid



Toroid (top view)

Consider a toroid of mean radius r and N turns, carrying a current of I. Imagine 3 amperian loops as shown in figure.

Loop 1 is well inside the toroid and encloses no current. Hence $B_1 = 0$.

Loop 3 is outside and loop 2 is at the centre. The circular areas bounded by loops 2 and 3 both cut the toroid so that each turn of current carrying wire is cut once by the loop 2 and twice by the loop 3.

Hence enclosed current by the loop 3 is also zero. Therefore $B_3 = 0$

But for the loop 2, $\quad \mathbf{B}\oint \boldsymbol{dl} = \mu_0\, I_{encl}$ ………………..(1)

Here $\oint \boldsymbol{dl} = 2\pi r$ and $I_{encl} = NI$

$$\therefore (1) \Rightarrow B\, 2\pi r = \mu_0\, NI$$

$$B = \frac{\mu_0\, NI}{2\pi r} = \mu_0\, n\, I$$

where $n = \frac{N}{2\pi r}$, is the number of turns per unit length.

Problem: A solenoid of length 0.5 m has a radius of 1 cm and is made up of 500 turns. It carries a current of 5 A. What is the magnitude of the magnetic field inside the solenoid?

Solution: Given $\quad l = 0.5$ m $\quad r = 1$ cm $= 0.01$ m $\quad N = 500 \quad I = 5$ A

The number of turns per unit length is, $n = \frac{N}{l} = \frac{500}{0.5} = 1000$ turns/m

The length $l = 0.5$ m and radius $r = 0.01$ m. Thus, $l/a = 50$ i.e., $l >> a$.

Hence, we can use the *long* solenoid formula

$B = \mu_0 n\, I$

$= 4\pi \times 10^{-7} \times 1000 \times 5$
$= 6.28 \times 10^{-3}$ T

Factors affecting the magnetic field produced by a solenoid or toroid

1. Number of turns per unit length
2. Medium inside the solenoid or toroid
3. Current

CHAPTER 5

MAGNETISM AND MATTER

Gauss's Theorem in magnetism.

Gauss's theorem states that the surface integral of magnetic field over a closed surface is zero.

$$\oint B \bullet dS = 0$$

Earth's magnetic field.

Source of Earth's Magnetism – Dynamo Effect

Earth's magnetism is due to the electric currents produced by the motion of metallic fluids such as molten metallic iron and nickel in the outer core of earth. This is known as **Dynamo Effect**.

(a) Geographic meridian: *The vertical plane passing through the geographic north – south direction is called geographic meridian.*

(b) Magnetic meridian*: The vertical plane passing through the north – south direction as indicated by the freely suspended magnet is called magnetic meridian.*

Magnetic elements of earth:

The earth's magnetic field at a particular place can be specified by three quantities namely declination, dip or inclination and horizontal intensity. These three quantities are together called magnetic elements.

1) Magnetic declination

Declination at a place is the angle between magnetic meridian and geographical meridian at that place.

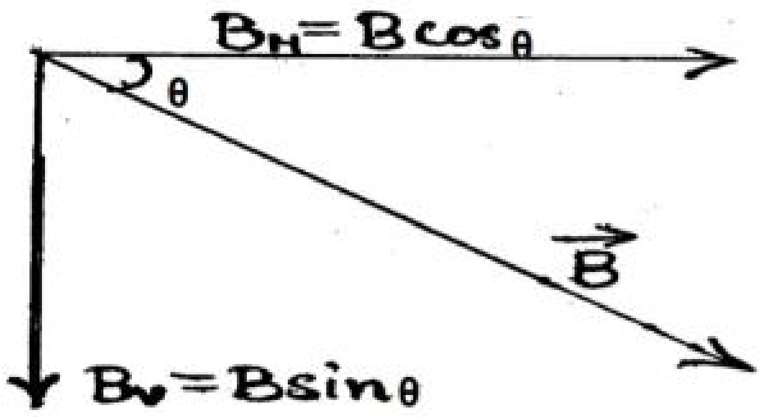
2) Dip or inclination (θ)

It is the angle which the earth's magnetic field B at a particular place makes with the horizontal line.

3) Horizontal component of earth's magnetic field (Horizontal intensity) (B_H)

The earth's magnetic field B can be resolved into two components –

B_V in the vertical direction and B_H in horizontal direction



Now from fig; $B_H = B\cos\theta$ and $B_v = B\sin\theta$

$\tan\theta = \frac{B_V}{B_H}$ or $\theta = \tan^{-1}\left(\frac{B_V}{B_H}\right)$

Also from the figure,

$B_V{}^2 + B_H{}^2 = B^2 \sin^2\theta + B^2 \cos^2\theta$

$$= B^2(\sin^2\theta + \cos^2\theta)$$

$$= B^2$$

or

$$B = \sqrt{B_V{}^2 + B_H{}^2}$$

At equator, angle of dip, $\theta = 0$. $\therefore$ Horizontal intensity B_H is maximum.

At poles, angle of dip, $\theta = 90$. $\therefore$ Horizontal intensity B_H is zero and B_V. is maximum.

Magnetic properties of materials :

1) Magnetising field (H)

When a magnetic material is placed in a magnetic field, it becomes magnetized. The ability of the applied field to magnetise the substance is measured by the quantity - magnetising field denoted by the letter H.

2) Permeability (μ)

The ratio of magnetic flux density B in a material to the magnetising field is called the absolute permeability (μ) of the medium.

$$\mu = \frac{B}{H}$$

Relative permeability :

Relative permeability of medium is the ratio of permeability of a medium (μ) to the permeability of air or vacuum (μ_0)

$$\mu_r = \frac{\mu}{\mu_0}$$

Also $\mu_r = (1+\chi)$

3) Intensity of magnetization (M)

Intensity of magnetization is defined as the magnetic moment developed per unit volume of the specimen when subjected to a magnetic field.

$$M = \frac{m}{V}$$

4) Susceptibility (χ)

Magnetic susceptibility is the ratio of intensity of magnetization produced in a material to the magnetizing field.

$$\chi = \frac{M}{H}$$

Relation connecting B, H and M:

$$\mathbf{B = \mu_0 (H+M)}$$

Magnetic Flux :

I t is the number of magnetic field lines passing normally through a surface.

It's unit is weber (Wb)

CHAPTER 6

ELECTROMAGNETIC INDUCTION

Magnetic flux

Magnetic flux is the total number of magnetic field lines passing perpendicular to the given surface area.

$$Magnetic\ flux, \qquad \phi = \vec{B} \cdot \vec{A}$$

$$In\ scalar\ form, \qquad \phi = BA\ Cos\ \theta$$

Here B is the magnetic field, A is the area and θ is the angle by which the area vector makes with the direction of magnetic field. The SI unit of magnetic flux is ***weber*** and the C.G.S unit is Maxwell.

Faraday's laws of electromagnetic induction

First law

Whenever the magnetic flux linked with a circuit changes, an emf is induced in the circuit. This induced emf lasts so long as the magnetic flux changes.

Second law

The magnitude of the induced emf in the circuit is directly proportional to the rate of change of magnetic flux linked with that circuit.

Mathematically, if $d\phi$ is the change in magnetic flux in a time dt seconds,

$$then, induced\ emf, \qquad \epsilon \propto \frac{d\phi}{dt}$$

$$or \qquad \epsilon = k\frac{d\phi}{dt}$$

Here k is the proportionality constant. The unit of magnetic flux is so chosen that the constant k is equal to one.

$$so, induced\ emf \quad \epsilon = -\frac{d\phi}{dt}$$

Motional emf

The emf induced by the motion of a conductor in a magnetic field is called motional emf.

Expression of motional emf

3. Induction furnace
4. Electric power meters

AC generator

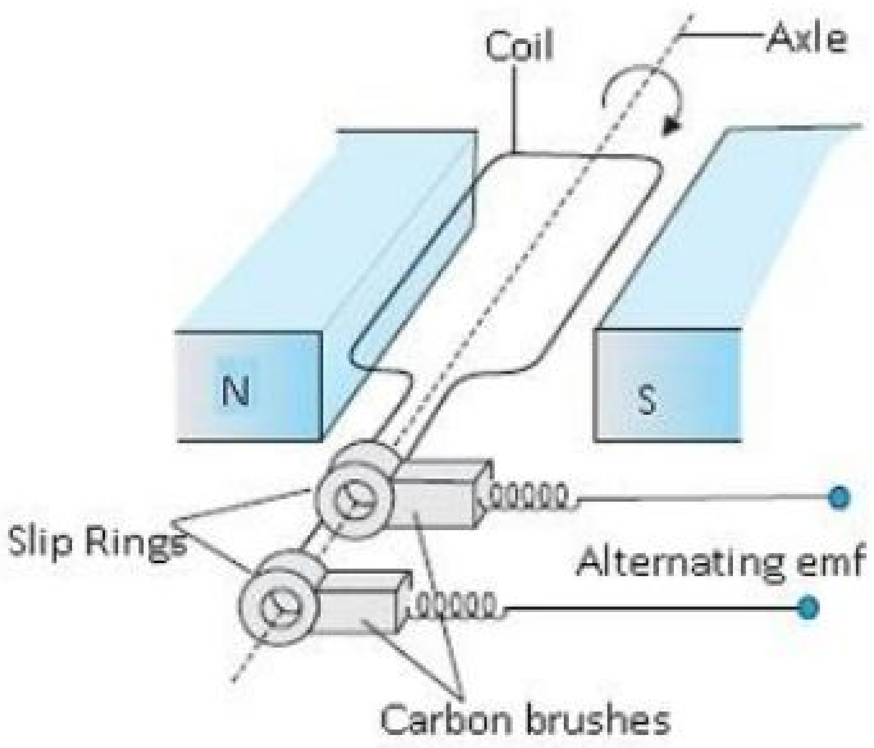
AC generator is a device, which converts mechanical energy into electrical energy.

Principle

It is based on the principle of electromagnetic induction.

Construction

- An AC Generator consists of a coil mounted on a rotor shaft.
- The axis of rotation of the coil is perpendicular to the direction of the magnetic field.
- The coil (called armature) is mechanically rotated in the uniform magnetic field by some external means.
- The ends of the coil are connected to an external circuit by means of slip rings and brushes.



Theory

Let ω be the angular velocity of the coil. Then the angle between the magnetic field and normal to the coil,

$$\theta = \omega t$$

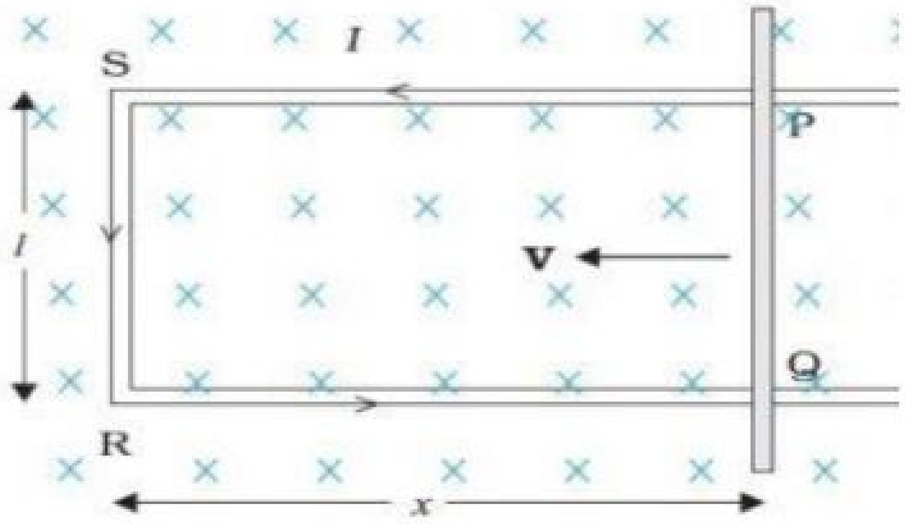
The magnetic flux linked with the coil at any instant is

$$\phi = BANcos\ \omega t \qquad or \qquad \phi = \phi_o cos\ \omega t$$

Here A is the area and N is the number of turns of the coil. As the coil rotates, the flux linked with the coil changes and an emf is induced in the coil.

$$induced\ emf, \quad \epsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(BANcos\ \omega t)$$

$$ie \qquad \epsilon = BAN\omega\ sin\ \omega t \qquad or \qquad \epsilon = \epsilon_o\ sin\ \omega t$$



The straight conductor PQ is moved towards the left with a constant velocity $\vec{v}$ perpendicular to a uniform magnetic field $\vec{B}$. PQRS forms a closed circuit enclosing an area that changes as PQ moves.

Let the length $RQ = x$ & $RS = l$.The magnetic flux linked with loop PQRS will be,

$$\phi = BA \cos\cos\theta$$

$$but \;\; A = lx \;\; and \;\; \theta = 0^o$$

$$\therefore \phi = Blx$$

Since x is changing with time the rate of change of flux will induce an emf given by,

$$\epsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(Blx) = -Bl\frac{dx}{dt}$$

$$But \;\; \frac{dx}{dt} = -v, \;\; the\ velocity\ of\ the\ rod\ PQ$$

$$\therefore \;\; \epsilon = -Bl(-v) = Blv.$$

The energy is conserved in the motional emf.

Eddy currents

Whenever the magnetic flux linked with a metal block changes, induced currents are produced. The induced currents flow in closed paths. Such currents are called eddy currents.

- The direction of the induced emf is given by Lenz's law.
- Eddy currents are undesirable in electrical devices like transformers; electric motors etc since they heat up the core and dissipate electrical energy in the form of heat
- . Eddy currents are minimized by using laminated metal plates instead of a single metal block.

Applications of eddy currents

1. Magnetic braking in trains
2. Electromagnetic damping

Here $\epsilon_o = BAN\omega$ is called peak value of induced emf.

Working

When the armature coil is mechanically rotated in a uniform magnetic field, the magnetic flux through the coil changes and hence an emf is induced in the coil.

The ends of the coil are connected to the external circuit by means of slip rings and brushes.

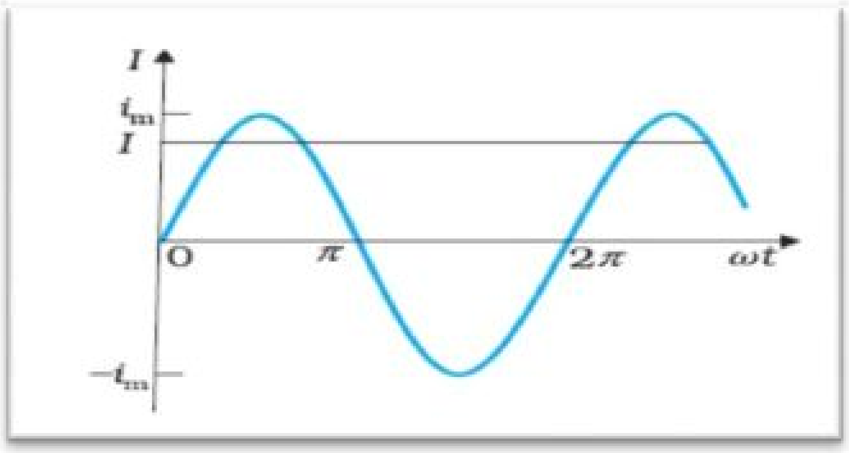
The frequency of rotation is 50 Hz in India.

CHAPTER 7
A.C.

AC Voltage and AC Current

A voltage that varies like a sine function with time is called alternating voltage (ac voltage). It is a current whose magnitude changes with time and direction reverses.

Advantages of AC: It can be,



$ easily stepped up or stepped down using transformer
$ regulated using choke coil without loss of energy
$ easily converted in to dc
$ transmitted over distant places
$ produced and transmitted more economically

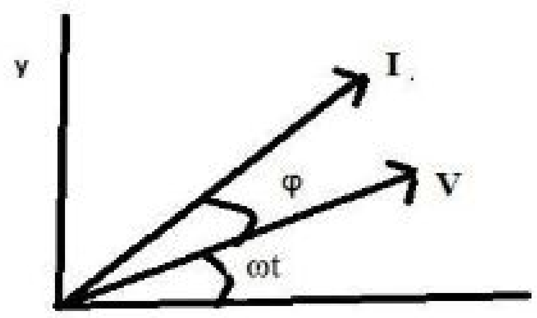
Disadvantages of ac: It cannot be,

$ used for electroplating
$ stored for longer time

RMS Value (effective current)

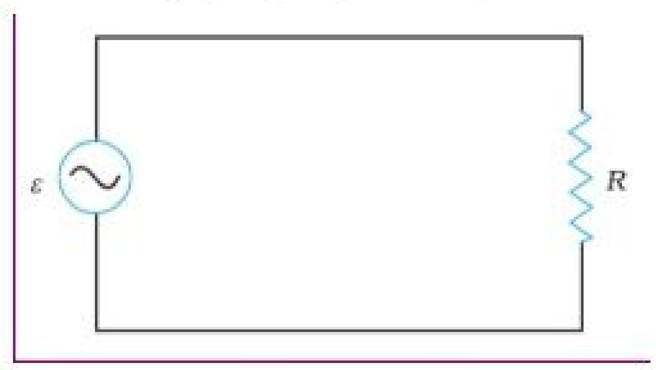
r.m.s. value of a.c. is the d.c. equivalent which produces the same amount of heat energy in same time as that of an a.c. It is denoted by I_{rms} or I.

Relation between r.m.s. value and peak value of current is $I_{rms} = \frac{I_m}{\sqrt{2}}$. Similarly, for voltage, is $V_{rms} = \frac{V_m}{\sqrt{2}}$



Phasors: A phasor is a vector which rotates about the origin with angular speed ω. The vertical components of phasors V and I represent the sinusoidally varying quantities v and i. The magnitudes of phasors V and I represent the peak values v_m and i_m.

AC through a Resistor



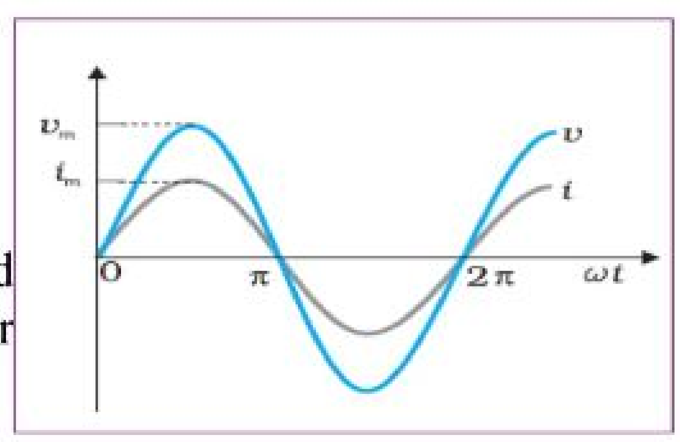
The ac voltage applied to the resistor is $v = v_m \sin \omega t$

But V=IR. Therefore, $v_m \sin \omega t = iR$

$$i = \frac{V_m}{R} \sin \omega t$$

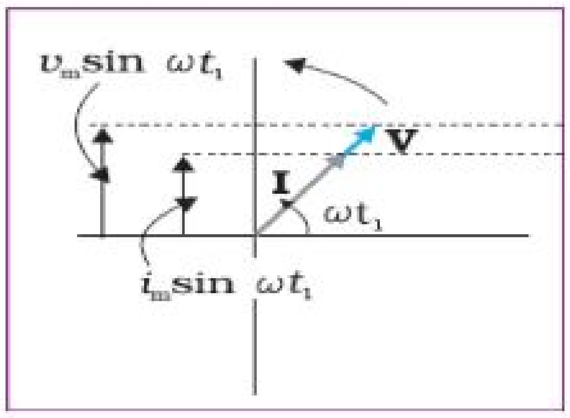
Since R is a constant, we can write this equation as $i = i_m \sin \omega t$

Where peak value of current is $i_m = \frac{V_m}{R}$



When $v = v_m \sin \omega t$, we get $i = i_m \sin \omega t$. Thus, when ac is passed through a resistor the voltage and current are in phase with each other as shown above.

Phasor diagram: A phasor is a vector which is rotating in the anti-clockwise direction with a uniform velocity. The magnitude of the vector is represented by the length of the phasor.



Instantaneous power

The power at a particular time is called instantaneous power. It is a function of sin ωt.

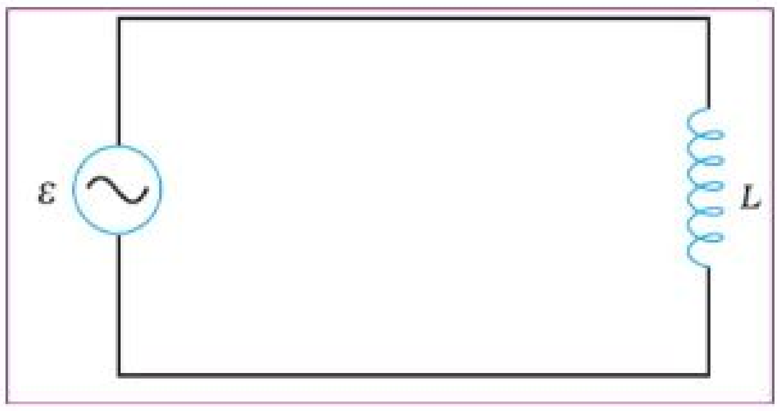
Since, $i = i_m \sin \omega t$ the instantaneous power dissipated in the resistor is $p = i^2 R = i_m^2 R \sin^2 \omega t$

Average power: It is the average value of power over a cycle and is given by

$$\overline{p} = \langle i^2 R \rangle = \langle i_m^2 R \sin^2 \omega t \rangle$$

In terms of r.m.s value $P = \overline{p} = \frac{1}{2} i_m^2 R = I^2 R$ Or $P = V^2 / R = IV \quad (\text{since } V = IR)$

AC through an inductor



Let the voltage across the source be $v = v_m \sin \omega t$

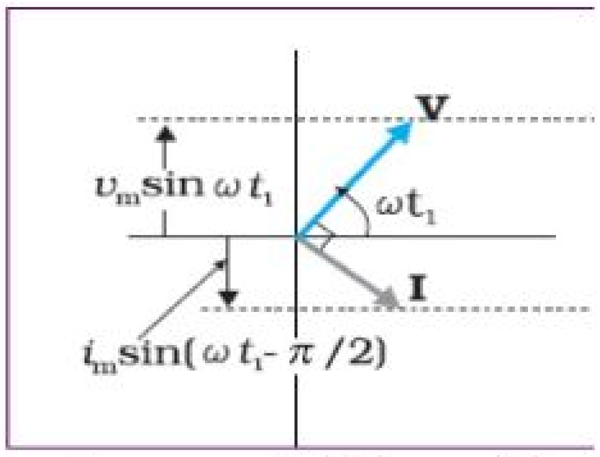
We have $v = L\frac{di}{dt}$

or $v - L\frac{di}{dt} = 0$ $\quad \frac{di}{dt} = \frac{v}{L} = \frac{v_m \sin \omega t}{L}$

Where L is the self-inductance. Thus $\frac{di}{dt} = \frac{v}{L} = \frac{v_m \sin \omega t}{L}$

Integrating, $\int \frac{di}{dt} dt = \frac{v_m}{L} \int \sin(\omega t) dt$

$$i = i_m \sin\left(\omega t - \frac{\pi}{2}\right)$$



Phasor diagram of AC through Inductor

Thus, when $v = v_m \sin \omega t$, we get $i = i_m \sin (\omega t - \frac{\pi}{2})$. That is, for inductor current lags behind the voltage by $\frac{\pi}{2}$

Here, $i_m = \frac{v_m}{\omega L}$ and $i_m = \frac{v_m}{X_L}$ X_L is called inductive reactance. It is defined as the resistance offered by the inductor to an ac through it. Its SI unit is ohm (Ω).

AC through a Capacitor

Let the applied voltage be $v = v_m \sin \omega t$

The instantaneous voltage v across the capacitor is $v = \frac{q}{C}$

Where q is the charge on the capacitor.

That is,

$$v_m \sin \omega t = \frac{q}{C} \quad \text{or } q = v_m C \sin \omega t \quad \text{But } i = \frac{dq}{dt}$$

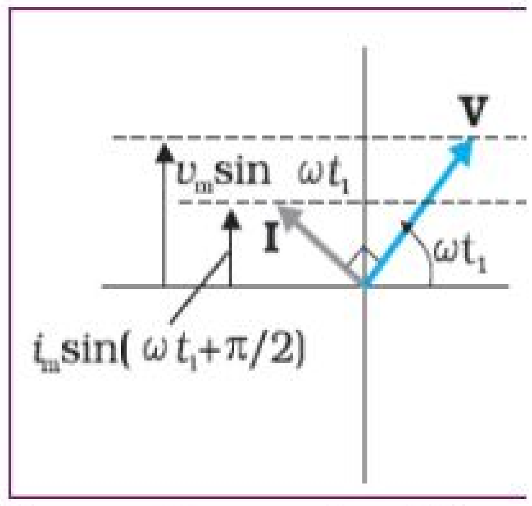
Therefore

$$i = \frac{d}{dt}(v_m C \sin \omega t) = \omega C v_m \cos(\omega t)$$

Or

$$i = i_m \sin\left(\omega t + \frac{\pi}{2}\right)$$

Thus, when $v = v_m \sin \omega t$, we get $i = i_m \sin (\omega t + \frac{\pi}{2})$. That is, for a capacitor current leads the voltage by $\frac{\pi}{2}$



Phasor diagram for AC through capacitor

Here, $i_m = \frac{v_m}{(1/\omega C)}$ Also, $i_m = \frac{v_m}{X_C}$

- Xc is called capacitive reactance. It is the resistance offered by the capacitor to an ac current through it. The dimension of capacitive reactance is the same as that of resistance and its SI unit is ohm (Ω).

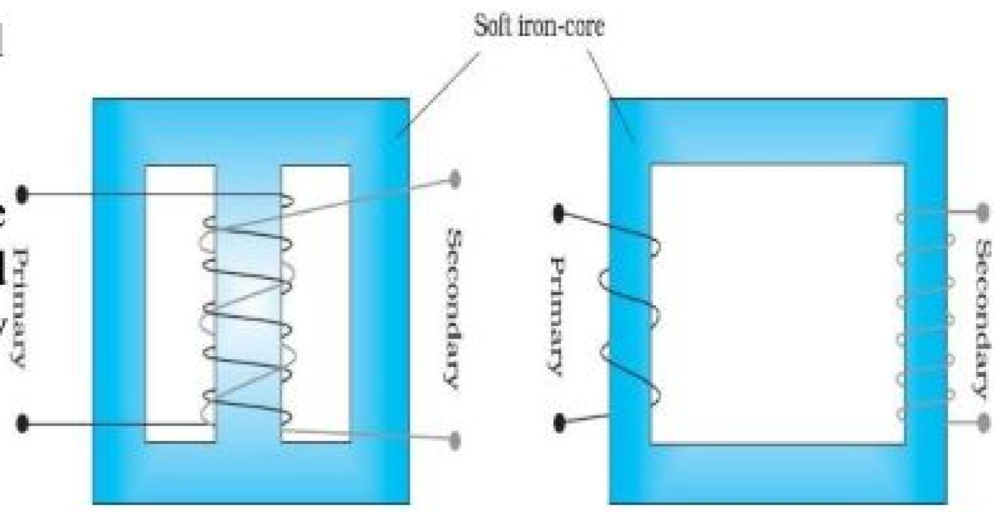
Transformer

It is a device used to change alternating voltage. It works using the principle of mutual induction. It works only in ac.

The primary coil with N_p turns is called the **input coil** and the secondary coil with N_s turns is called the **output coil** of the transformer.

Let φ be the flux in each turn in the core at time t due to current in the primary when a voltage v_p is applied to it. The induced emf or voltage ε_s in the secondary with N_s turns is

$$\varepsilon_s = -N_s \frac{d\phi}{dt}$$



The alternating flux φ also induces an emf, called back emf in the primary.

$$\varepsilon_p = -N_p \frac{d\phi}{dt}$$

Assuming $\varepsilon_p = v_p$ and $\varepsilon_s = v_s$

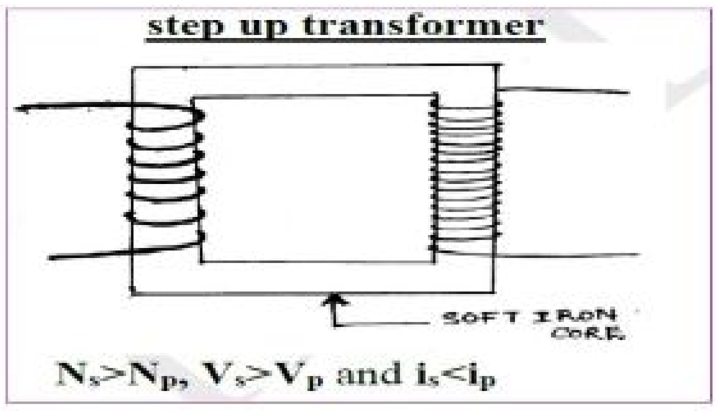
$$v_s = -N_s \frac{d\phi}{dt} \quad \text{and} \quad v_p = -N_p \frac{d\phi}{dt}$$

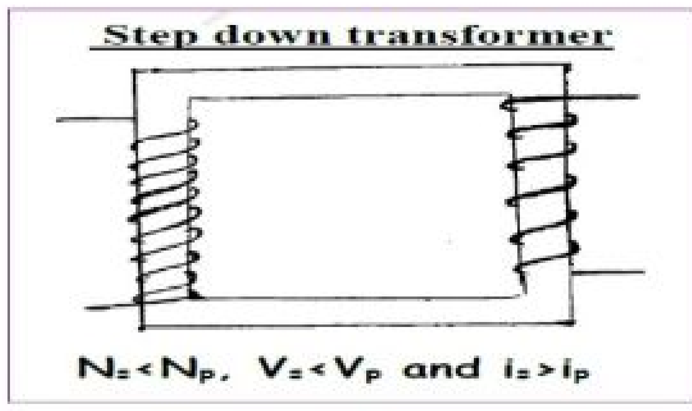
That is, $\frac{v_s}{v_p} = \frac{N_s}{N_p}$

An ideal transformer is one for which input and output powers are equal. That is, $i_p v_p = i_s v_s$

Thus, we get $\frac{i_p}{i_s} = \frac{v_s}{v_p} = \frac{N_s}{N_p}$ This is called transformer turn ratio.

The following are the two types of transformers.





If the secondary coil has a greater number of turns than the primary ($N_S > N_P$), then voltage is stepped up ($V_S > V_P$). This type of arrangement is called a step-up transformer.
If the secondary coil has a smaller number of turns than the primary ($N_S < N_P$), then voltage is stepped down ($V_S > V_P$). This type of arrangement is called a step-down transformer.
The efficiency of a transformer is given by $\eta = (output\ power)/(input\ power)$

Energy loss in transformers

1) Copper Loss: As the current flows through the primary and secondary copper wires, electric energy is wasted in the form of heat. This is minimized by using thick wire.
2) Eddy current Loss (Iron Loss): The eddy currents produced in the soft iron core of the transformer produce heating. Thus, electric energy is wasted in the form of heat. The effect is reduced by having a laminated core.
3) Magnetic flux leakage: The entire magnetic flux produced by the primary coil may not be available to the secondary coil. Thus, some energy is wasted. It can be reduced by winding the primary and secondary coils one over the other.
4) Hysteresis Loss: Since the soft iron core is subjected to continuous cycles of magnetization, the core gets heated due to hysteresis. It can be minimized by using a magnetic material which has a low hysteresis loss.

Uses of a transformer

The large-scale transmission and distribution of electrical energy over long distances is done with the use of transformers.
The voltage output of the generator is stepped- up. It is then transmitted over long distances to an area sub-station near the consumers. There the voltage is stepped down.
It is further stepped down at distributing sub- stations and utility poles before a power supply of 240 V reaches our homes.

CHAPTER 8

ELECTROMAGNETIC WAVES

In 1820 Oersted found electric field can cause magnetic field.

In 1831 Faraday found magnetic field can cause electric field.

In 1864 Maxwell proposed the existence of electromagnetic wave.

In 1885 Hertz produced electromagnetic wave.

Displacement Current

Maxwell proposed the concept of displacement current to explain the magnetic field produced in between the plates of a parallel plate capacitor, where there is no conduction current.

According to Maxwell, the magnetic field in between the plates of a capacitor is due to the changing electric flux. Hence, he gave correction to Ampere's Circuital theorem.

Total current is the sum of conduction current and displacement current.

$$\text{ie} \quad i = i_c + i_d$$

But $i_d = \epsilon_0 \frac{d\phi_E}{dt}$, called displacement current.

$$\text{ie} \quad i = i_c + \epsilon_0 \frac{d\phi_E}{dt}$$

Thus, Maxwell corrected Ampere's law as,

$$\oint B.\, dl = \mu_0 i = \mu_0 (i_c + \epsilon_0 \frac{d\phi_E}{dt})$$

Maxwell's Equations

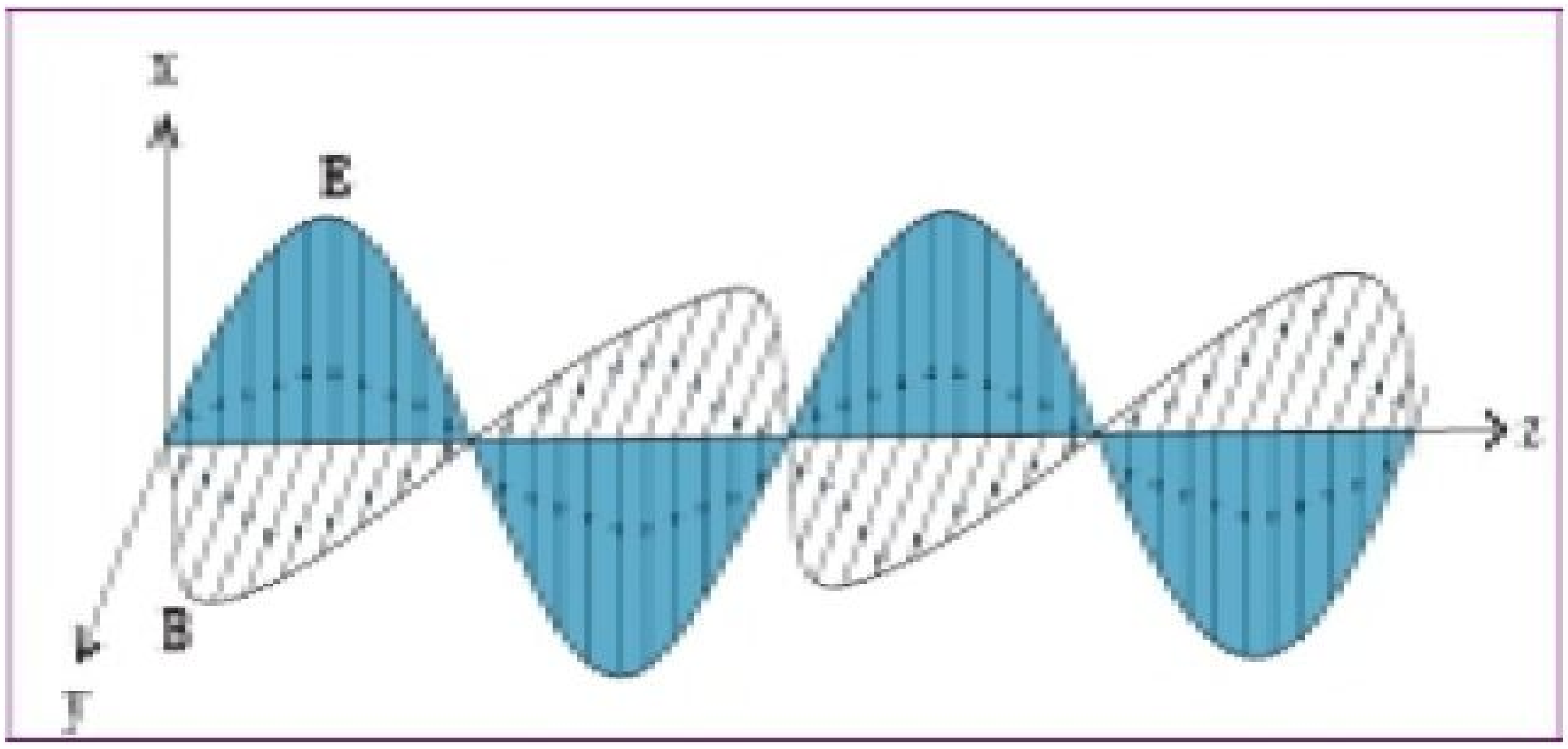
$\oint \mathbf{E.\, dA} = Q/\epsilon_0$	Gauss's law for electricity
$\oint \mathbf{B.\, dA = 0}$	Gauss's law for magnetism
$\oint \mathbf{E.\, dl} = -\frac{d\phi_B}{dt}$	Faraday's law
$\oint \mathbf{B.\, dl} = \mu_0 (i_c + \epsilon_0 \frac{d\phi_E}{dt})$	Ampere– Maxwell law

Electromagnetic Waves

The periodic change in electric and magnetic fields that can propagate through air or vacuum with the velocity of light.

The fields are represented as

$$E_x = E_0 \sin(kz - \omega t)$$
$$B_y = B_0 \sin(kz - \omega t)$$



The **direction** of electromagnetic wave is **mutually perpendicular** to both **E** and **B**.

Properties of EM waves

- They are self-sustaining oscillations of electric and magnetic fields in free space, vacuum.
- Shows transverse wave nature.
- No material medium is needed for its propagation.
- EM waves are not deflected in electric field and magnetic field.
- The velocity of em waves in any media is given by

$$v = \frac{1}{\sqrt{\mu\varepsilon}}$$

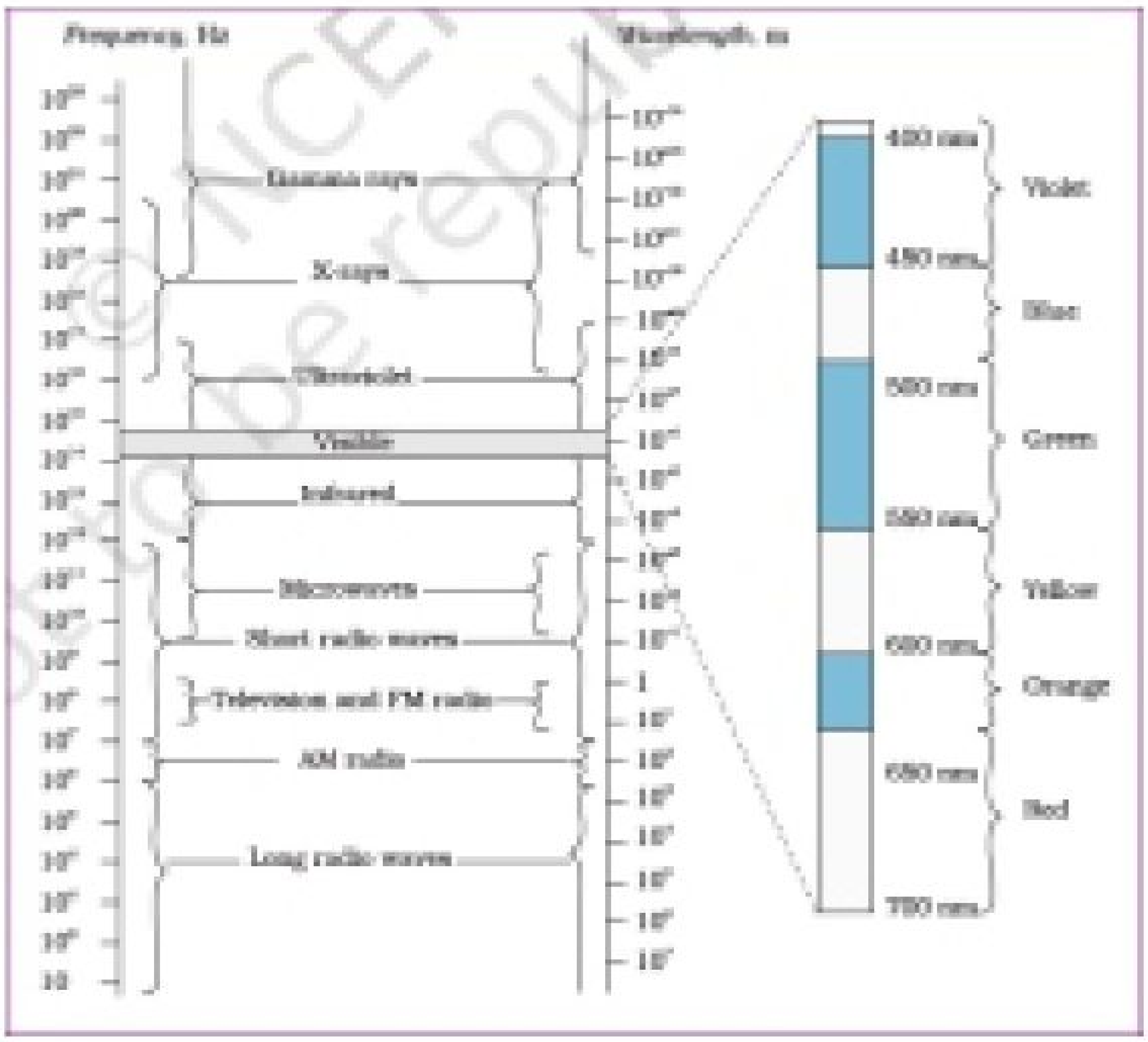
- EM waves are polarized.
- Electromagnetic waves carry energy and momentum like other waves.

Electromagnetic Spectrum

The arrangement of electromagnetic waves according to their wavelength or frequency

In the increasing order of wavelength they may be arranged as Gamma rays, X rays, UV, Visible, IR, Micro waves and Radio waves.

Frequency range and Wavelength range of em waves

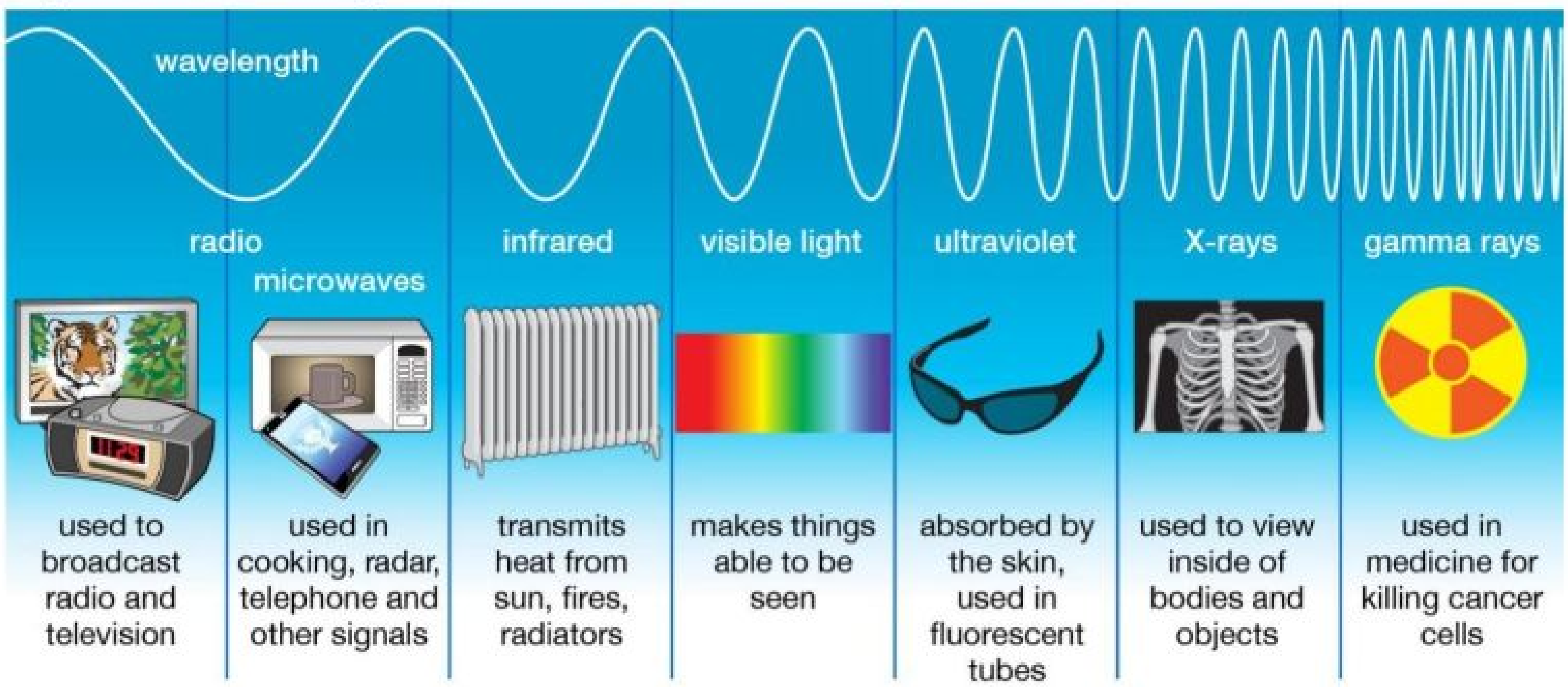


Production and Detection of electromagnetic waves

Type	Wavelength range	Production	Detection
Radio	> 0.1 m	Rapid acceleration and decelerations of electrons in aerials	Receiver's aerials
Microwave	0.1m to 1 mm	Klystron valve or magnetron valve	Point contact diodes
Infra-red	1mm 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 level	The eye Photocells Photographic film
Ultraviolet	400 nm to 1nm	Inner shell electrons in atoms moving from one energy level to a lower level	Photocells Photographic film
X-rays	1nm to 10^{-3} nm	X-ray tubes or inner shell electrons	Photographic film Geiger tubes Ionisation chamber
Gamma rays	$<10^{-3}$ nm	Radioactive decay of the nucleus	-do-

Uses of electromagnetic waves

Types of Electromagnetic Radiation



CHAPTER 9
RAY OPTICS

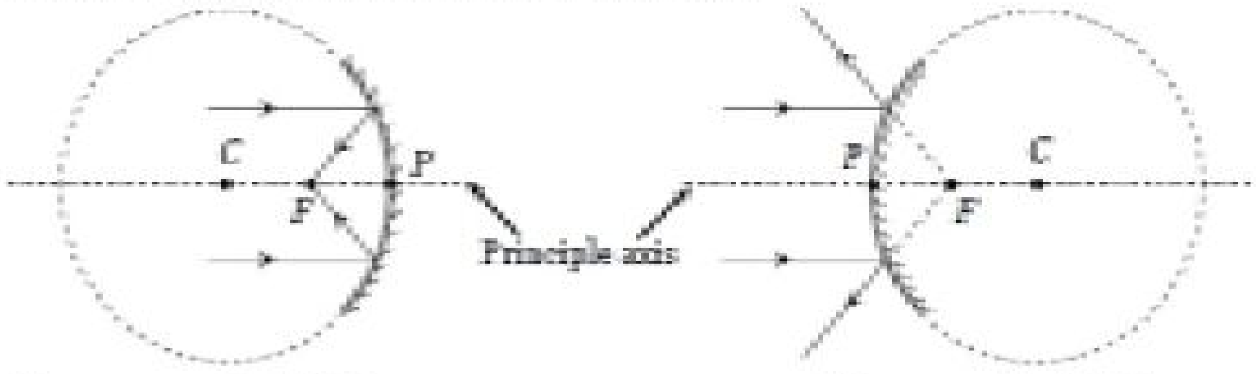
Reflection of light: When a ray of light, after incident on a boundary, is coming back into the same media, then this phenomenon is called reflection of light. A convex or concave mirror can be assumed to be a part of spherical surface.

A concave mirror converges light rays and a convex mirror diverges light rays.

(i) Pole (P)**:** Midpoint of the mirror

(ii) Centre of curvature (C): Centre of the sphere of which the mirror is a part.

(iii) Radius of curvature (R): Distance between pole and centre of curvature.
($R_{concave} = -ve$, $R_{convex} = +ve$, $R_{plane} = \alpha$)



Converges the light rays   Diverges the light rays

(iv) Principle axis: A line passing through *P* and *C*.

(v) Focus (F): An image point on principle axis for which object is at infinity.

(vi) Focal length (f): Distance between *P* and *F*.

Relation between *f* and *R:* f = 2R   Note: ($f_{concave} = -ve$, $f_{convex} = +ve$, $f_{plane} = \alpha$)

(viii) Power: The converging or diverging ability of mirror

(ix) Aperture: Effective diameter of light reflecting area.

Intensity of image α Area α $(\text{Aperture})^2$

(x) Focal plane: A plane passing from focus and perpendicular to principle axis.

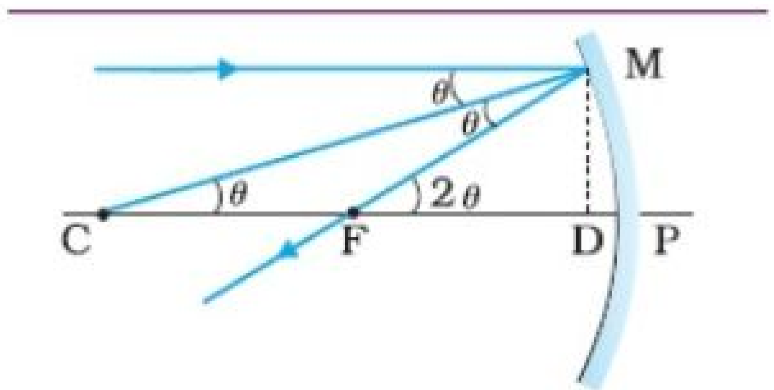
<u>Relation between focal length and radius of curvature</u>

From the diagram

$\angle MCP = \theta$ and $\angle MFP = 2\theta$

Now,

$$\tan\theta = \frac{MD}{CD} \text{ and } \tan 2\theta = \frac{MD}{FD}$$



For small θ, tan θ ≈ θ,   and   tan 2θ ≈ 2θ.

$$\frac{MD}{FD} = 2\,\frac{MD}{CD}$$

$$\text{or, } FD = \frac{CD}{2}$$

For small θ, the point D is very close to the point P. Therefore, FD = *f* and *CD* = *R*.

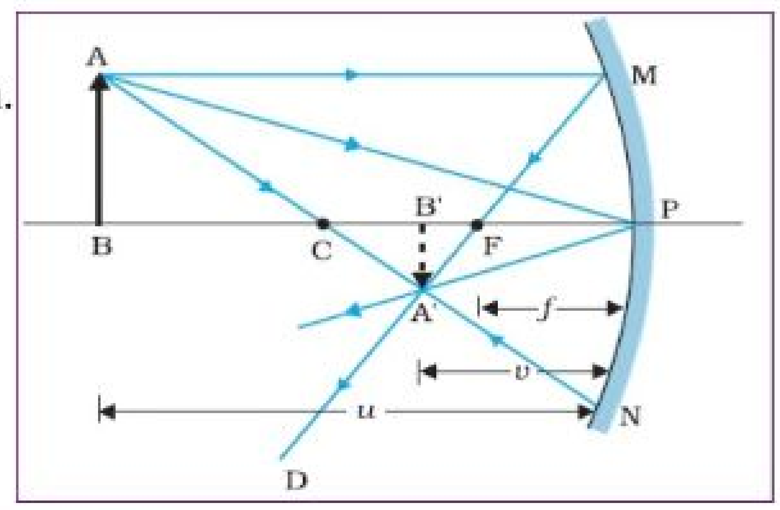
Thus,

$$f = R/2$$

Mirror equation and magnification:

The relation connecting the object distance (u), image distance (v) and the focal length (f) is called mirror equation.

The two right-angled triangles A′B′F and MPF are similar. Therefore,



Therefore,
$$\frac{B'A'}{PM}=\frac{B'F}{FP}$$
$$\text{or } \frac{B'A'}{BA}=\frac{B'F}{FP} \quad (\because PM = AB)$$

(Since $\angle APB = \angle A'PB'$, the right angled triangles A′B′P and ABP are also similar.)

That is
$$\frac{B'A'}{BA}=\frac{B'P}{BP}$$

Comparing the equations, $\frac{B'F}{FP}=\frac{B'P-FP}{FP}=\frac{B'P}{BP}$, But $B'P = -v$, $FP = -f$, $BP = -u$

Thus we get
$$\frac{-v+f}{-f}=\frac{-v}{-u}$$
$$\text{or } \frac{v-f}{f}=\frac{v}{u}$$

Therefore
$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

This equation is known as mirror equation.
Here, u = Distance of object from pole, v = distance of image from pole and f = Focal length

Magnification (or linear magnification) is defined as the ratio of size of the image to the size of the object.
Magnification = $\frac{\text{Size of image}}{\text{Size of object}}$ or $m = \frac{I}{O}$.
Also, $m = \frac{-v}{u}$

Similarly, areal magnification is defined as the ratio of area of the image to the area of the object.

Object position	Image position	Size of image	Nature of image
At infinity	Focus (F)	Point sized	Real
Beyond C	Between F and C	Small	Real and inverted
At C	At C	Same as that of the object	Real and inverted
Between C and F	Behind C	Enlarged	Real and inverted
At F	At infinity	Highly enlarged	Real and inverted
Between F and P	Behind mirror	Enlarged	Virtual and erect

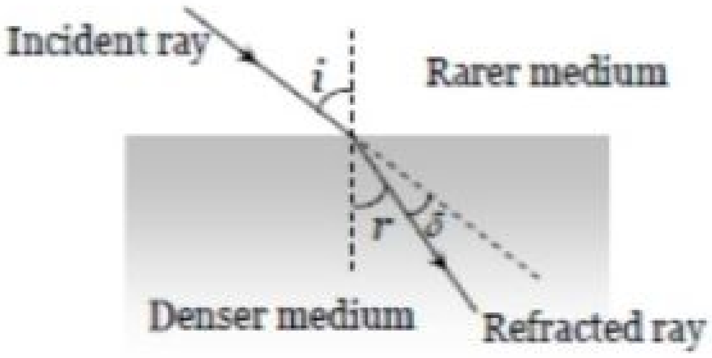
A convex mirror always forms a virtual and diminished image irrespective of the position of the object.

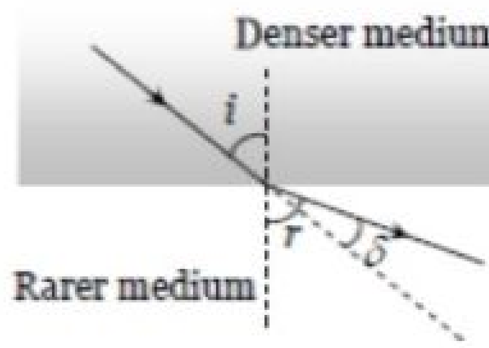
Uses of mirrors

(i) **Concave mirror:** Used as a shaving mirror, In search light, in cinema projector, in telescope, by E.N.T. specialists etc.

(ii) **Convex mirror:** In road lamps, side mirror in vehicles *etc.*

Refraction of light: The bending of the ray of light passing from one medium to the other medium is called refraction. Refractive index of a medium is that characteristic which decides speed of light in it. It is a scalar, unitless and dimensionless quantity. The medium with a higher refractive index is called denser medium and a medium with lower refractive index is called rarer medium.





Laws of Refraction:

First law: The incident ray, the refracted ray and the normal to the interface at the point of incidence, all lie in the same plane.

Second law or Snell's law: The ratio of sine of the angle of incidence to the angle of refraction (r) is a constant.

That is $\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$ (n_2 - refractive index of second medium, n_1 - refractive index of first medium)

Dependence of Refractive index

(i) Nature of the media of incidence and refraction.

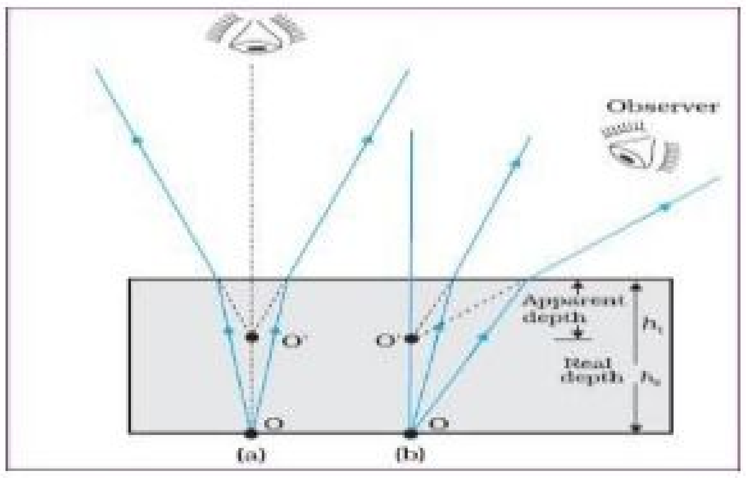
(ii) Colour of light or wavelength of light.

(iii) Temperature of the media: Refractive index decreases with the increase in temperature.

Applications of refraction:

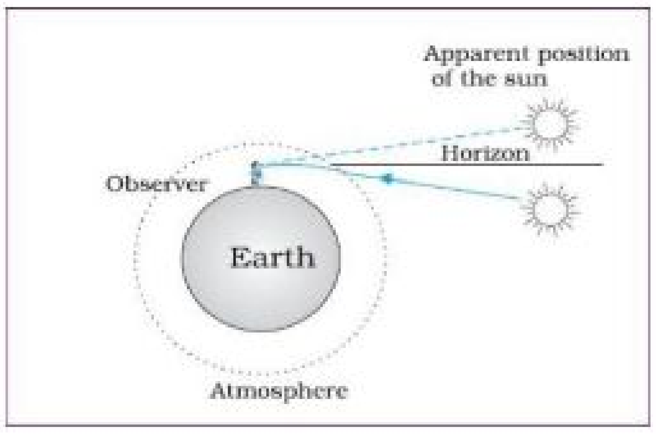
1.Apparent depth: If object and observer are situated in different medium then due to refraction, object appears to be displaced from its real position. If an object in a denser medium is viewed from a rarer medium the image appears to be raised towards the surface.

Refractive index of the medium, n = $\frac{Real\ Depth}{Apparent\ Depth}$



2. Apparent position of sun: A ray of light travelling from sun to earth is travelling from rarer to denser medium. So, it bends towards the observer and he see the shifted position of the sun.

Thus, we see the sun at an apparent position raised above the horizon. This is the reason for early sunrise and delayed sunset.



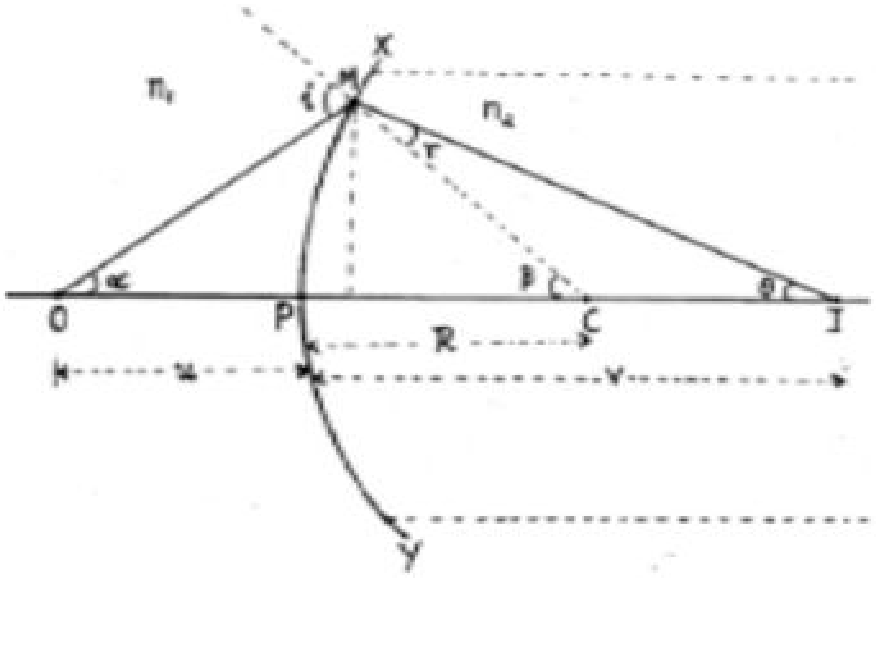
Refraction at spherical surfaces

If n_1 is the refractive index of first medium and n_2 the refractive index of second medium, then

From triangle OMP, $\tan\alpha \approx \alpha = \frac{PM}{PO}$

From triangle PCM, $\tan\beta \approx \beta = \frac{PM}{PC}$

From triangle PMI, $\tan\theta \approx \theta = \frac{PM}{PI}$



From triangle OMC, Exterior angle = sum of interior angles. Thus,

$$i = \alpha + \beta = \frac{PM}{PO} + \frac{PM}{PC} \quad \ldots\ldots\ldots\ldots (1)$$

From triangle IMC

$$\beta = r + \theta$$
$$\Rightarrow r = \beta - \theta = \frac{PM}{PC} - \frac{PM}{PI} \quad \ldots\ldots\ldots (2)$$

By Snell's law $\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$

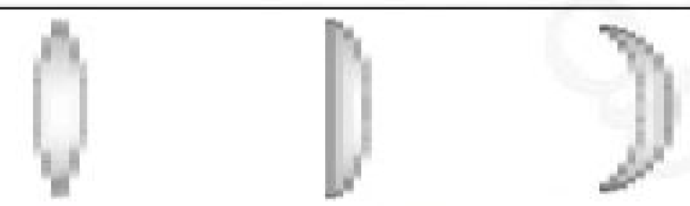
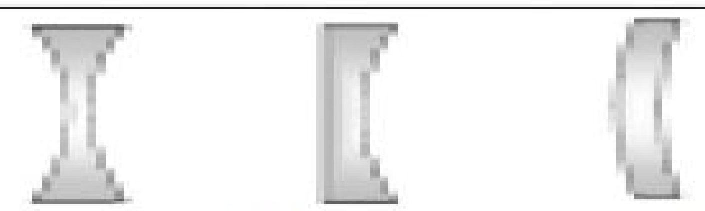
If i and r are small, $\frac{i}{r} = \frac{n_2}{n_1}$ or $n_1 i = n_2 r$

Substituting for i and r $n_1\left(\frac{PM}{PO} + \frac{PM}{PC}\right) = n_2\left(\frac{PM}{PC} - \frac{PM}{PI}\right)$ or $\frac{n_1}{PO} + \frac{n_1}{PC} = \frac{n_2}{PC} - \frac{n_2}{PI}$

Therefore $\frac{n_1}{PO} + \frac{n_2}{PI} = \frac{n_2 - n_1}{PC} \quad \ldots\ldots\ldots\ldots (3)$ But PO = -u , PI = v , PC =R

Thus equation (3) becomes $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$ This is the equation of refraction at convex surface.

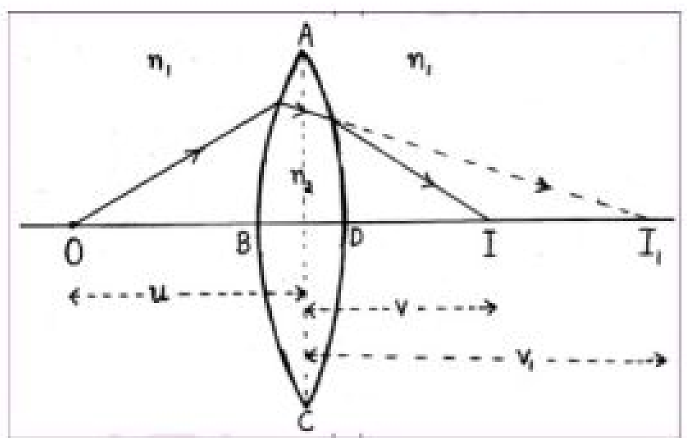
Refraction by a lens: Lens is a transparent medium bounded by two refracting surfaces, such that at least one surface is spherical.

Convex lens (Converges the light rays)	Concave lens (Diverges the light rays)
	
Double convex Plano convex Concavo convex	Double concave Plano concave Convexo-concave
Thick at middle	Thin at middle
It forms real and virtual images both	It forms only virtual images

Lens maker's formula

For the curved surface ABC,

$$\frac{n_2}{v_1} - \frac{n_1}{u} = \frac{n_2 - n_1}{R_1} \quad \ldots\ldots\ldots\ldots (1)$$



For the curved surface ADC,

$$\therefore \frac{n_1}{v} - \frac{n_2}{v_1} = \frac{n_1 - n_2}{R_2} \quad \ldots\ldots\ldots (2)$$

$$\frac{n_1}{v} - \frac{n_2}{v_1} = \frac{-(n_2 - n_1)}{R_2} \quad \ldots\ldots\ldots (3)$$

where **R_2 is** the radius of curvature of ADC

Now, adding equation 1 and 2, we get

$$\frac{n_1}{v} - \frac{n_1}{u} = (n_2 - n_1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

Dividing the above equation by n_1,

$$\frac{1}{v} - \frac{1}{u} = \left(\frac{n_2 - n_1}{n_1}\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$\frac{1}{v} - \frac{1}{u} = \left(\frac{n_2}{n_1} - 1\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$\frac{1}{v} - \frac{1}{u} = (n_{21} - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \text{.......(4)}$$

If the object is at infinity, the image is formed at the principal focus. Thus, if u=infinity and v = f, equation 4 becomes

$$\frac{1}{f} - \frac{1}{\infty} = (n_{21} - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

Thus, the lens maker's formula is given by

$$\therefore \frac{1}{f} = (n_{21} - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \text{............(5)}$$

Now, comparing equations 4 and 5, we may write,

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

This is known as thin lens formula. The formula is valid for both convex as well as concave lenses and for both real and virtual images.

Linear magnification (m)

It is defined as the ratio of the size of the image to that of the object. $m = \frac{I}{O} = \frac{v}{u}$

The value of m is negative for real images and positive for virtual images.

Power of a lens (P)

Power of a lens is the reciprocal of focal length. Power of a lens is a measure of the convergence or divergence when light falls on it. The SI unit for power of a lens is diopter (D). Power of a lens is positive for a converging lens and negative for a diverging lens.

$$P = \frac{1}{f}$$

If several thin lenses of focal length f_1, f_2, f_3,... are in contact, the effective focal length of their combination f, is given by

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + \dots$$

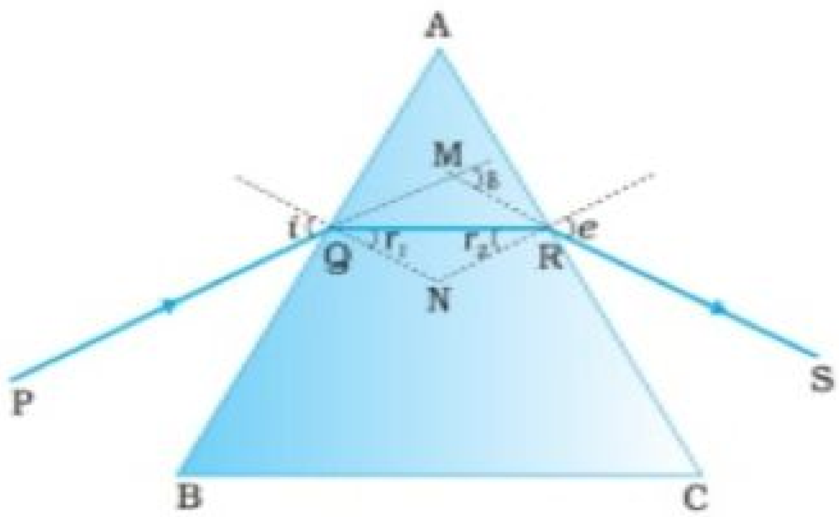
Thus, the power P is given by

$$P = P_1 + P_2 + P_3 + \dots$$

The total magnification m is

$$m = m_1\, m_2\, m_3\, \dots$$

Refraction through a Prism: Prism is a transparent medium bounded by refracting surfaces, such that the incident surface and emergent surface are plane and non-parallel.



From the figure, the sum of the other angles of the quadrilateral AQNR is 180^0.

$$\angle A + \angle QNR = 180^\circ$$

From the triangle QNR $$r_1 + r_2 + \angle QNR = 180^\circ$$

Comparing these two equations $$r_1 + r_2 = A$$

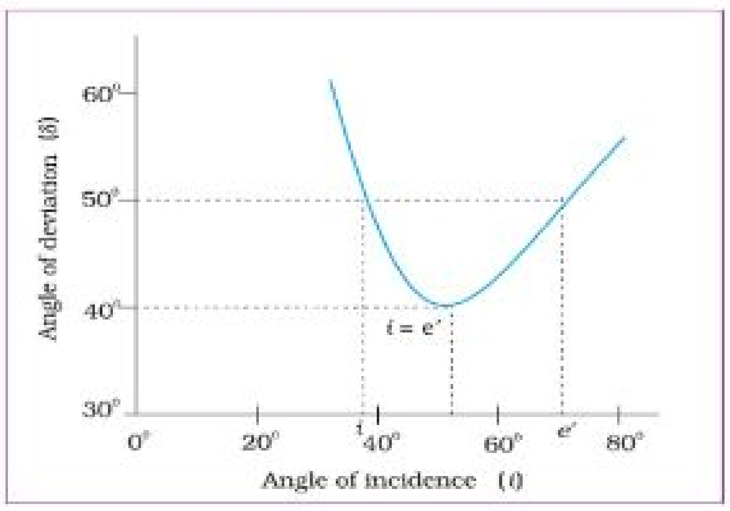
We know, exterior angle = sum of interior angles, thus $d = (i - r_1) + (e - r_2)$ or $d = (i + e - A)$

At the minimum deviation, d=D, i =e, $r_1 = r_2$, therefore

$$2r = A \text{ or } r = \frac{A}{2}$$ and $$D = 2i - A, \text{ or } i = (A + D)/2$$

Thus, Snell's law becomes,

Refractive index, $$n_{21} = \frac{\sin[(A + D_m)/2]}{\sin[A/2]}$$



i-d curve of a prism

Dispersion by Prism: The phenomenon of splitting of light into its component colors is known as dispersion. The pattern of color components of light is called the spectrum of light. Dispersion takes place because the refractive index of medium for different wavelengths (colors) is different. When white light is passed through a prism, it splits into its seven component colors (VIBGYOR).

The medium in which the different colors of light travel with different velocities is called a dispersive medium. Eg: Glass

The medium in which all colors travel with the same speed is called non- dispersive medium. Eg:- vacuum

CHAPTER 10

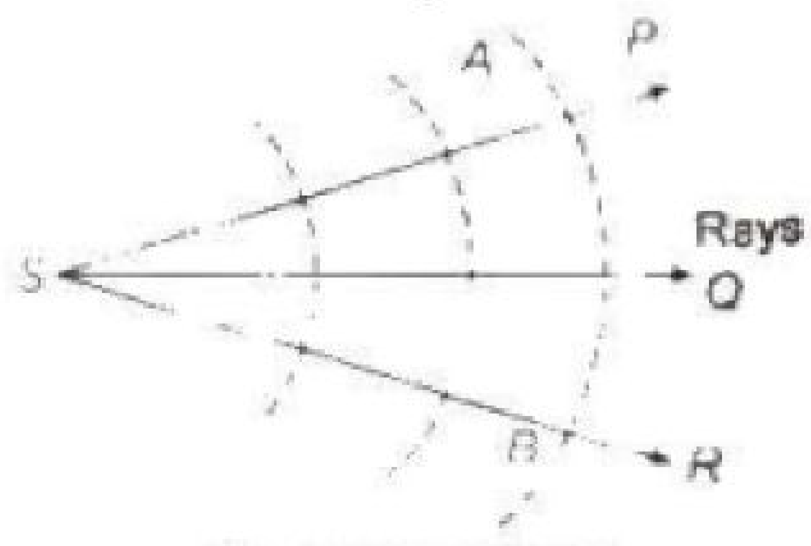
WAVE OPTICS

Wave Theory of light:

In 1678, a Dutch Physicist and astronomer, Christian Huygens put forward the wave theory of light. According to this theory, *light is propagated in the form of waves through an all-pervading hypothetical medium called ether. These waves carry energy and produce the sensation of vision on falling on the eye.* The phenomenon like interference, diffraction and polarisation are well explained using this concept.

Wave front:

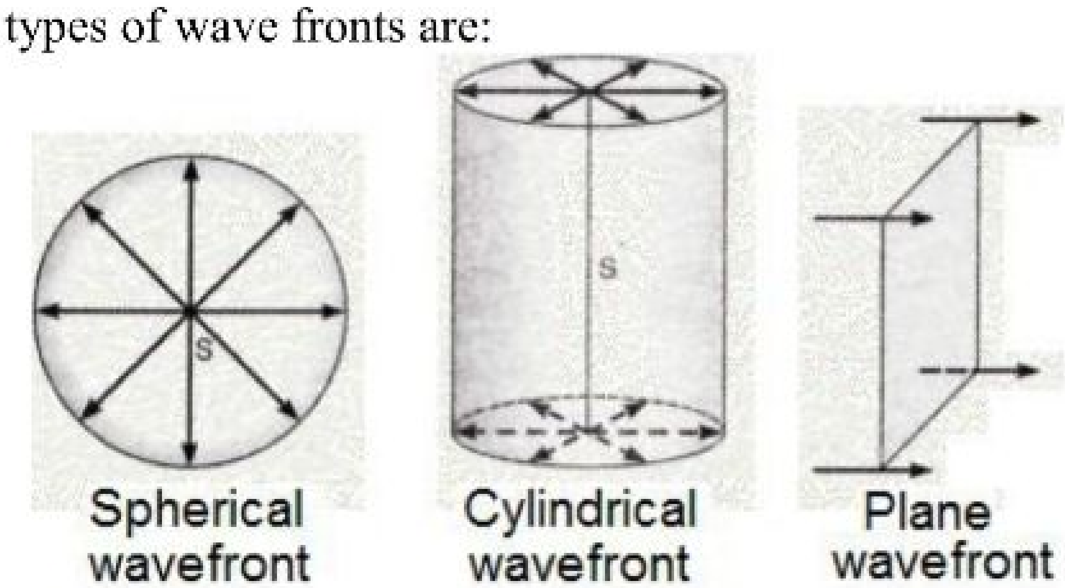
According to Huygenes theory, light travels in the form of waves. During the wave propagation, all particles of the medium which are located at the same distance from the source receive the disturbance simultaneously and vibrate in the same phase.



S = source of light
AB = wavefront and SP SQ
and SR are rays of light

The wavefront is defined as the locus of all points which have the same phase of vibration.

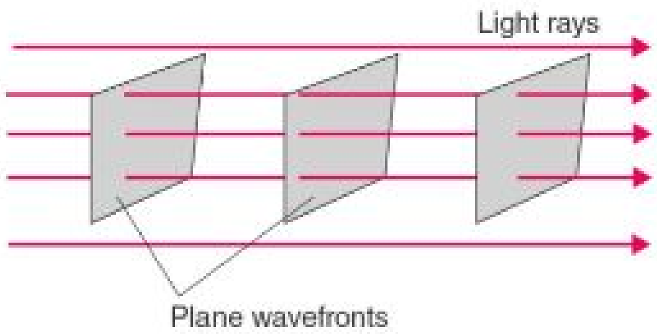
The common types of wave fronts are:



(i) **Spherical wavefront**: The wavefront near a point source is a spherical wavefront. This is because at a particular instant all the disturbances from a point source of light reach on the surface of a sphere and will be in the same phase of vibration.

(ii) **Cylindrical wavefront**: If a source of light is linear in shape (eg: slit) and is very near, the wavefront is cylindrical. This is because, all the points equidistant from a linear source lie on the surface of a cylinder.

(iii) **Plane wavefront:** If the source of light is at infinity, we will get plane wavefront.



Any line perpendicular to a wavefront is called ray of light.

Huygen's Principle:

Huygen's Principle states that:

(1) Every point on a given wavefront can be considered as a source of secondary waves, called wavelets.

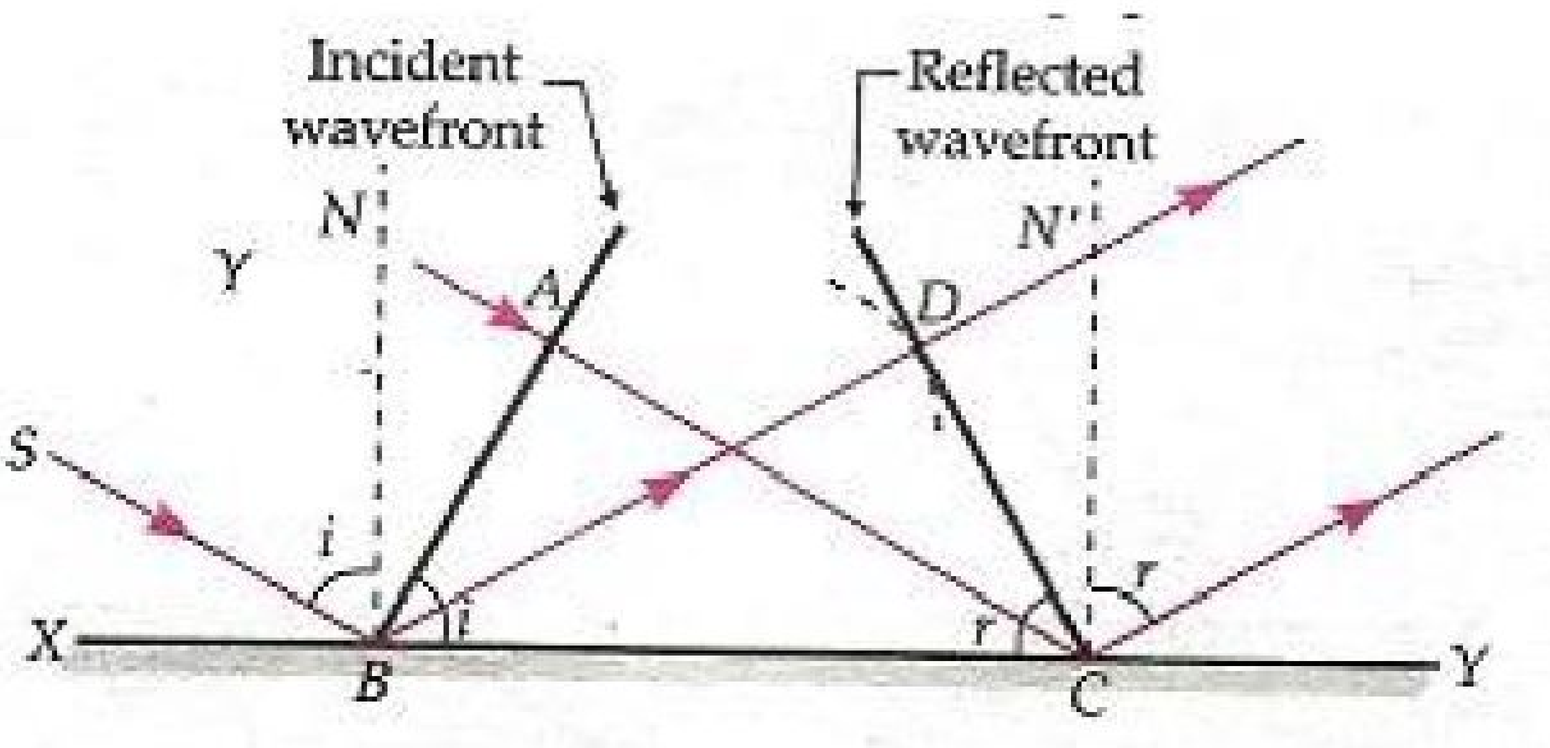
(2) The secondary wavelets spread in all directions with the velocity of light.

(3) The new wavefront at any instant is the envelop of these wavelets in the forward direction.

Reflection of a plane wavefront at a plane surface:

Let XY be a plane reflecting surface and AB be the incident plane wavefront. All the particles on AB will be vibrating in phase. Let **i** be the angle of incidence. By the time the disturbance at A reaches C, the secondary waves from the point B will travel a distance BD = AC. With the point B as centre and AC as radius, construct a sphere.

Draw tangent CD to the sphere. Then CD is the reflected wavefront.



In the triangles BAC and BDC, BC is common. BD = AC and

∠BAC = ∠BDC = 90^0

Therefore, the triangles are congruent.

∠ABC =∠BCD

i.e, **i = r.**

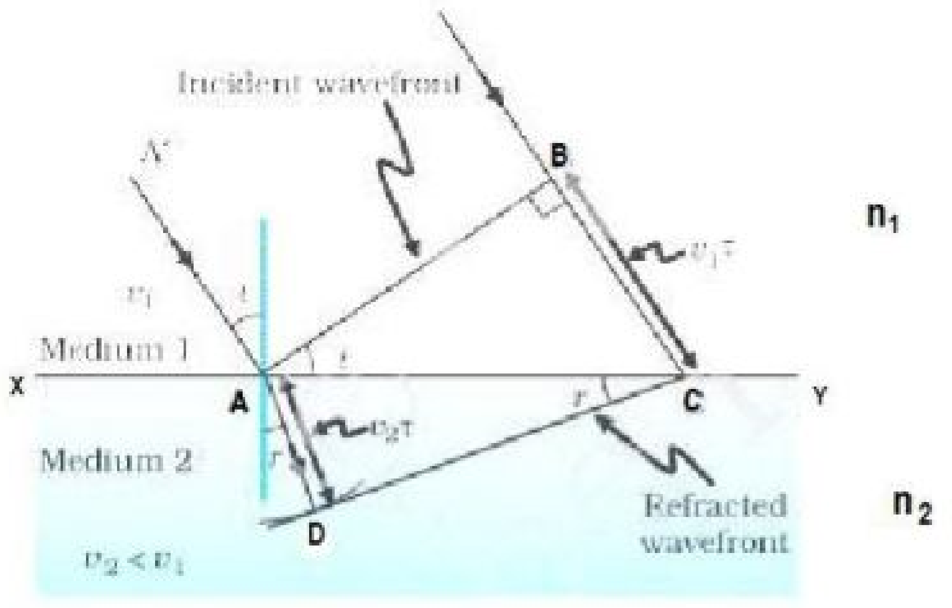
Thus

The **angle of incidence is equal to the angle of reflection**.

Also **the incident ray, reflected ray and the normal to the surface at the point of incidence all lie in the same plane**.

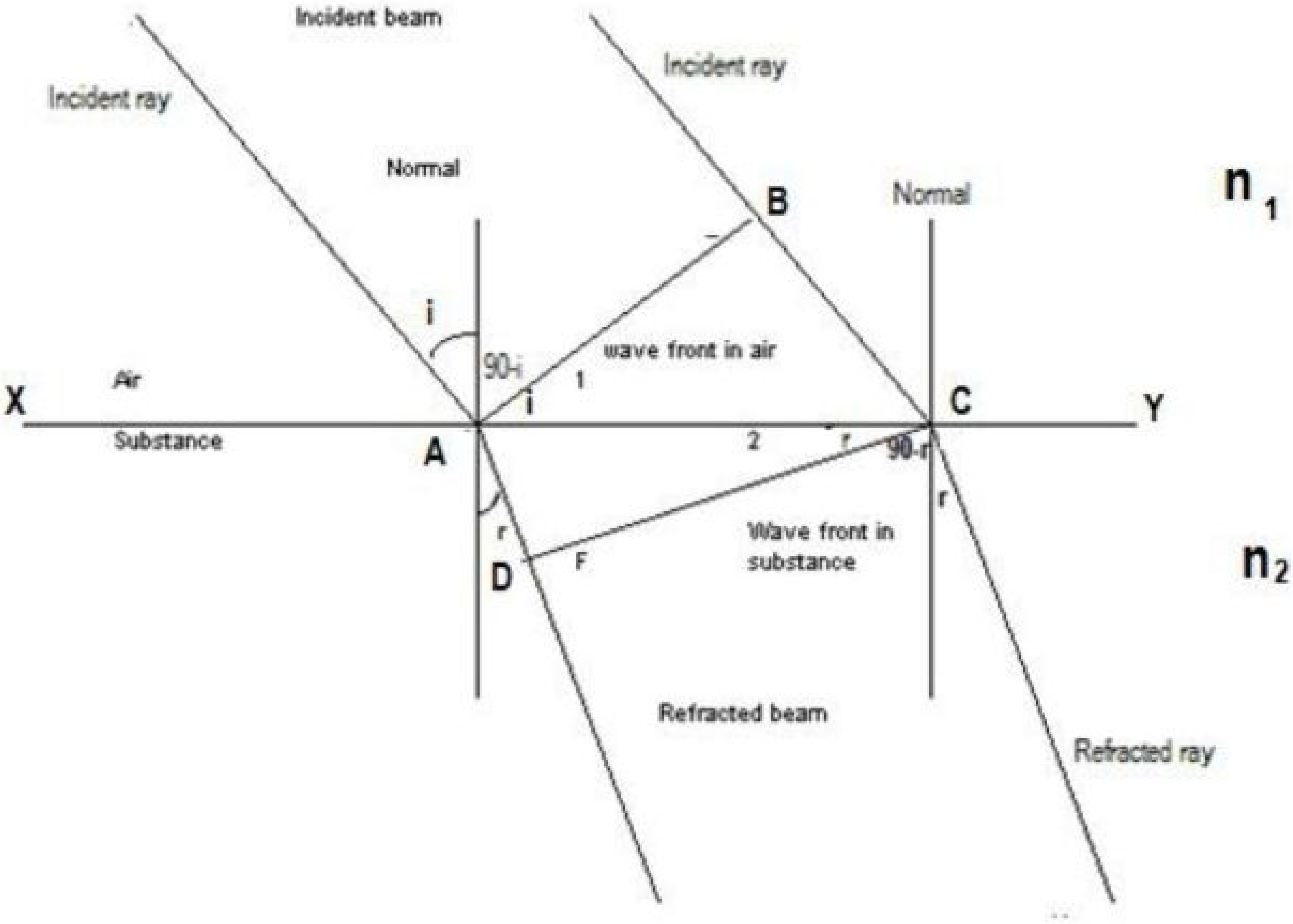
These are the laws of reflection.

Refraction of a plane wavefront at a plane surface:



Let XY be a plane refracting surface separating two media having refractive indices $\mathbf{n_1}$ and $\mathbf{n_2}$ respectively (n2 > n1). Let **c1** and **c2** be the velocity of light in medium 1 and medium 2.

Let AB be an incident plane wavefront. By the time the disturbance at B reaches C secondary waves from A must have travelled a distance c_2t in medium 2, where t is the time taken by the wave to reach from B to C. Now with A as Centre and c_2t as radius draw a sphere. Then draw tangent CD to the sphere. Then CD will give the refracted wavefront.



Now in right angled triangle ABC, sin i = $\frac{BC}{AC}$

From right angled triangle ADC sin r = $\frac{AD}{AC}$

$\therefore \frac{\sin i}{\sin r} = \frac{BC/AC}{AD/AC} = \frac{BC}{AD}$

But BC = c_1 x t and AD = c_2 x t

$\therefore \frac{\sin i}{\sin r} = \frac{c_1 t}{c_2 t} = \frac{c_1}{c_2}$

We know n = $\frac{c}{v}$ or $n_1 = = \frac{c}{c_1}$ and $n_2 = = \frac{c}{c_2}$

Or $c_1 = \frac{c}{n_1}$ and $c_2 = \frac{c}{n_2}$

$\therefore \frac{\sin i}{\sin r} = \frac{c_1}{c_2} = \frac{c/n_1}{c/n_2} = \frac{c}{n_1} \text{ x } \frac{n_2}{c} = \frac{n_2}{n_1}$

$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = n$

This is **Snell's law in refraction**.
Now **the incident ray, refracted ray and the normal are in the same plane**.
Thus both laws of refraction are proved.

Polarisation:

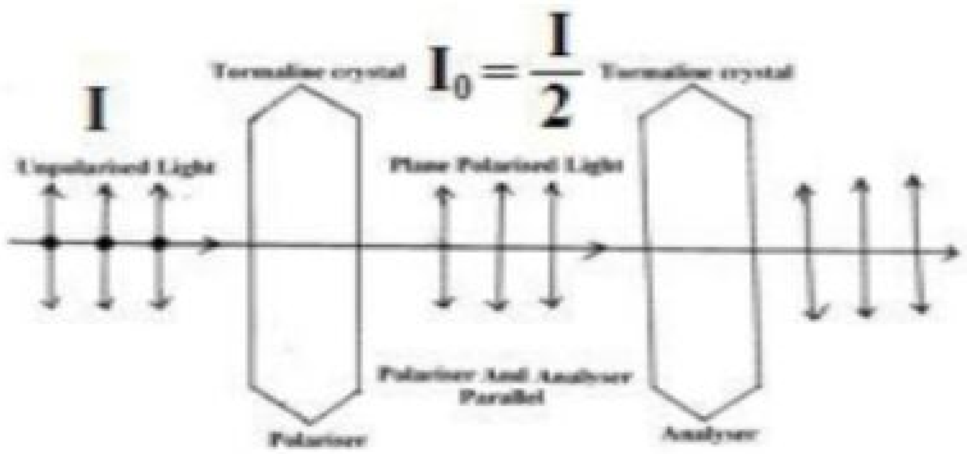
According to electromagnetic theory, light is the propagation of mutually perpendicular vibrating electric and magnetic fields.

The electric field functions as light vector. When light is passed through certain crystals like tourmaline, the vibrations of electric field vector are restricted. This property exhibited by light is known as **polarisation**.

Light having electric field vector vibrations confined to a single plane and in a particular direction is known as linearly polarised or plane polarised light.

Polarisation is exhibited by transverse waves only. Thus polarisation proves the light is transverse in nature.

Demonstration



Polarisation can be demonstrated using a tourmaline crystal. Light from a source is allowed to pass through a tourmaline crystal. The vibrations parallel to the optical axis will pass through it and other vibrations are absorbed by the crystal.

The crystal is called **polarisor** or **polaroid,** since the emergent light is polarised. To test whether the emergent light is polarised or not, a second tourmaline crystal is used.

Keeping the first crystal fixed, the second one is rotated about the incident ray as axis. Then it is found that the intensity of emergent light from second crystal varies between maximum and minimum (zero).

The intensity of transmitted light is maximum when the polarising directions are parallel and intensity falls to zero when the polarising directions become perpendicular to each other.

The light coming out of first polaroid has acquired a property which the incident light did not have (i.e. the intensity is reduced to half). This property is called polarisation of light.

The second crystal is called **analyser or detector**.

The plane in which the vibrations of electric field vector are confined is known as plane of vibration and the plane perpendicular to the plane of vibration is known as plane of polarisation.

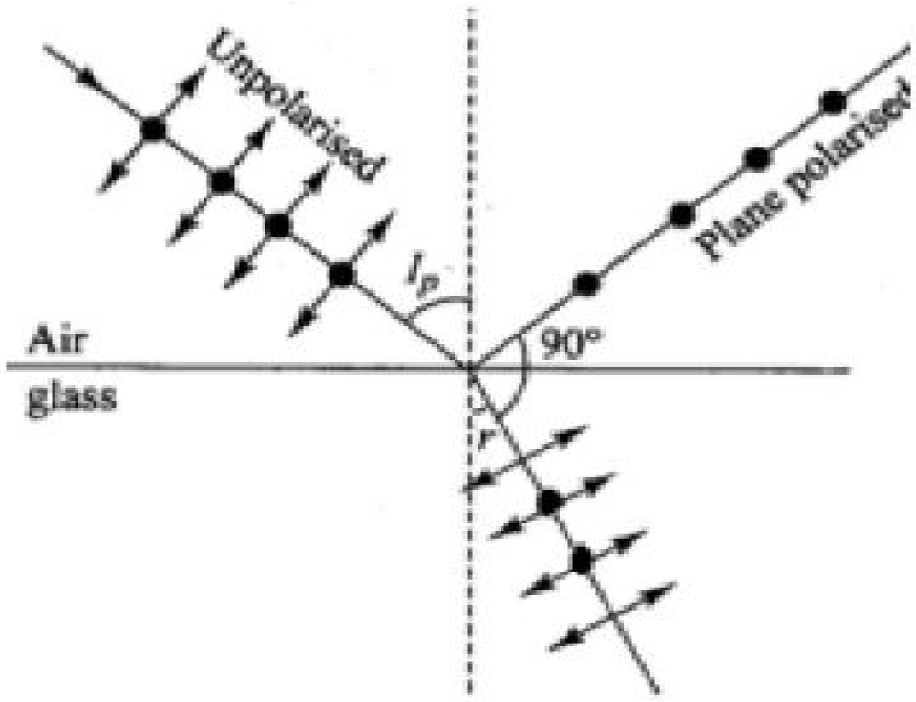
Malus's law:

Malus's law states that when a beam of plane polarised light of intensity I_0 is incident on the analyser, then the intensity I of the emergent light is directly proportional to square of the cosine of the angle (θ) between the polariser and analyser.

Intensity of light coming out of the analyser is

$$I = I_0 \cos^2\theta$$

Polarisation by reflection



Malus in 1808 found that when light gets reflected from a transparent medium, the reflected light is partially polarised. At a particular angle of incidence, the reflected light is fully polarised.

This particular angle is known as **polarising angle** or **angle of polarisation** or **Brewster angle (θ)** for that medium.

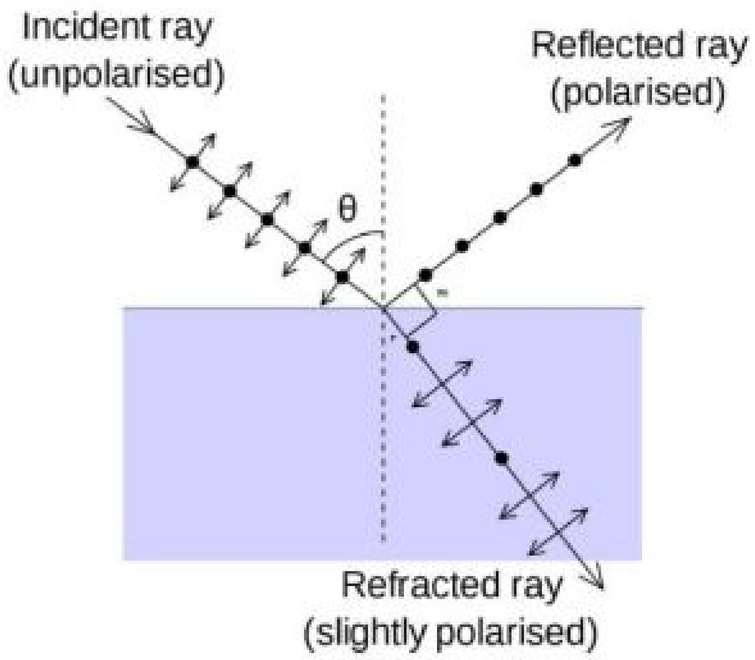
When light is incident at polarising angle, the reflected and refracted rays are mutually perpendicular.

i.e. $r + \theta = 90^0$; r = angle of refraction and θ= polarising angle.

Brewster's law

Brewster's law states that "*the tangent of the polarising angle is equal to the refractive index of the medium on which light is incident*"

If θ is the polarising angle and n is the refractive index of the medium, then **$\tan\theta = n$**. This is Brewster's law



Proof :

By Snell's law of refraction,

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = n$$

where n is the refractive index of the refracting medium.

From the figure . $i = \theta$

Also $r + \theta = 90$ $r = 90 - \theta$

$$\frac{\sin \theta}{\sin (90 - \theta)} = n$$

But $\sin (90 - \theta) = \cos\theta$

$$\therefore \frac{\sin \theta}{\cos \theta} = n$$

$$\mathbf{\tan \theta = n}$$

This is Brewster's law

Uses of plane polarised light

(i) To project stereoscopic pictures on a screen.
(ii) If polarised light is used in optical instruments, it becomes polarised instrument.
(iii) It is used in liquid crystal display (LCD).
(iv) Sun glasses.

Polaroid

Polaroid is a polariser in the form of a large film (sheet). When unpolarised light is passes through a polaroid, we get polarised light.

Uses: (i) In polarising optical instruments.
(ii) In order to improve colour contrast in old oil paintings, polaroids are used.
(iii) Used to produce and view 3D films.
(iv) In aeroplanes, polaroid glasses are used to control light coming in.
(v) In sun glasses
(vi) In wind glass of vehicles to avoid glare.

CHAPTER 11
DUAL NATURE OF RADIATION & MATTER

Work function (ϕ_0).

Work function is minimum external energy required to remove an electron from a metal.

Photoelectric effect

Emitting of electrons from the metal surface when an electromagnetic radiation with suitable frequency is falling on it is called photo electric effect

Planck's quantum theory

According to quantum theory the radiation has particle nature; it is made up of large number of small packets of energy called light quanta or photons.

Properties of photons

1. Travels in straight line in the speed of light
2. Photons are electrically neutral so they are not deflected by electric or magnetic field.
3. Rest mass of photon is zero; they possess mass by its motion.
4. Energy of each photon is given by $E = h\nu$
   h – Planck's constant h=6.63×10^{-34} Js
   ν – Frequency of light

Einstein's Photoelectric Equation

- Einstein explained photoelectric emission with the help of Planck's quantum theory.
- According Einstein's photoelectric equation, the energy of the falling photon ($h\nu$) can be used in two parts
  1. Work To liberate the electron from the metal surface (as Work function Φ_0)
  2. To give maximum kinetic energy KE_{max} to the emitted photoelectrons.

According to Einstein's photoelectric equation

$$h\nu = \phi_o + KE_{\max}$$

CHAPTER12

ATOMS

BOHR MODEL OF THE HYDROGEN ATOM

Postulates:

1. ***An electron in an atom could revolve in certain stable orbits without the emission of radiant energy.***

2. ***The electrons can orbit only those orbits for which the angular momentum is an integral multiple h/2π.***

$$ie, \quad angular\ momentum, L = mvr = \frac{nh}{2\pi}$$

Here n is called the principal quantum number and it has the integral values 1,2,3….

3. ***When an electron jumps from higher energy orbit to lower energy orbit, a photon is emitted having energy equal to the energy difference between the initial and final states.***

If E_i and E_f are the energies associated with the orbits of principal quantum numbers n_i and n_f respectively ($n_i > n_f$), then the amount of energy radiated in the form of photon is,

$$h\nu = E_i - E_f$$

Here ν is the frequency of the photon.

Bohr's theory of hydrogen atom

In a hydrogen atom, an electron having negative charge revolves around the nucleus in a circular path of radius r.

The electrostatic force between nucleus and electron is given by,

$$F_e = \frac{1}{4\pi\varepsilon_o}\frac{e.e}{r^2} = \frac{1}{4\pi\varepsilon_o}\frac{e^2}{r^2}$$

This force provides the necessary centripetal force required for the circular motion,

$$centripetal\ force, F_c = \frac{mv^2}{r}$$

Expression for Velocity of electrons in an orbit

For a stable orbit in a hydrogen atom,

$$F_c = F_e$$

$$ie \quad \frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_o}\frac{e^2}{r^2} \qquad or$$

$$mv^2 = \frac{1}{4\pi\varepsilon_o}\frac{e^2}{r} \qquad \cdots\cdots\cdots \; (1)$$

According to Bohr's third postulate

$$angular\ momentum, L = mvr = \frac{nh}{2\pi} \cdots\cdots\cdots (2)$$

$$\frac{(1)}{(2)} \Rightarrow \qquad \frac{mv^2}{mvr} = \frac{\frac{1}{4\pi\varepsilon_o}\frac{e^2}{r}}{\frac{nh}{2\pi}} \quad or \quad \frac{v}{r} = \frac{2\pi}{nh}\frac{1}{4\pi\varepsilon_o}\frac{e^2}{r}$$

$$or \qquad v = \frac{1}{n}\frac{e^2}{4\pi\varepsilon_o}\frac{1}{\left(\frac{h}{2\pi}\right)}$$

<u>Expression for radius</u>

We have $v = \frac{nh}{2\pi mr}$

$$mv^2 = \frac{1}{4\pi\varepsilon_o}\frac{e^2}{r}$$

therefore $\qquad m\left(\frac{nh}{2\pi mr}\right)^2 = \frac{1}{4\pi\varepsilon_o}\frac{e^2}{r}$

$$\frac{mn^2h^2}{4\pi^2m^2r^2} = \frac{1}{4\pi\varepsilon_o}\frac{e^2}{r}$$

$$\frac{n^2h^2}{4\pi^2mr} = \frac{e^2}{4\pi\varepsilon_o}$$

thus $\qquad r = \frac{n^2h^2}{4\pi^2m}\frac{4\pi\varepsilon_o}{e^2}$

$$or \qquad r_n = \left(\frac{n^2}{m}\right)\left(\frac{h}{2\pi}\right)^2\left(\frac{4\pi\varepsilon_o}{e^2}\right)$$

$$ie \qquad r_n \propto n^2$$

The radii of the stationary orbits are in the ratio, $1^2:2^2:3^2:\ldots$ or 1: 4: 9: …..

The stationary orbits are not equally spaced.

For n = 1, $r_1 = \frac{h^2\varepsilon_0}{\pi m e^2}$=$a_0$, is called **Bohr radius**. (i e. radius of the lowest orbit)

a_0=5.29 X 10^{-11}m

Thus the radius of n[th] orbit becomes r_n=a_0n^2

Energy of an electron in an orbit

The total energy of the electron is the sum of its kinetic energy and potential energy.

$$kinetic\ energy, K = \frac{1}{2}mv^2$$

we have $$mv^2 = \frac{1}{4\pi\varepsilon_o}\frac{e^2}{r}$$

$$K = \frac{1}{2}mv^2$$

$$\therefore\ K = \frac{1}{2}\frac{1}{4\pi\varepsilon_o}\frac{e^2}{r} = \frac{e^2}{8\pi\varepsilon_o r}$$

$$Potential\ energy, U = -\frac{1}{4\pi\varepsilon_o}\frac{e^2}{r} = -\frac{e^2}{4\pi\varepsilon_o r}$$

$$Total\ energy, E = K + U = \frac{e^2}{8\pi\varepsilon_o r} - \frac{e^2}{4\pi\varepsilon_o r}$$

$$\therefore E = -\frac{e^2}{8\pi\varepsilon_o r}$$

$$For\ the\ n^{th} orbit, E_n = -\frac{e^2}{8\pi\varepsilon_o r_n}$$

Substituting , $$r_n = \left(\frac{n^2}{m}\right)\left(\frac{h}{2\pi}\right)^2\left(\frac{4\pi\varepsilon_o}{e^2}\right)$$

$$E_n = -\frac{e^2}{8\pi\varepsilon_o}\frac{m}{n^2}\left(\frac{2\pi}{h}\right)^2\frac{e^2}{4\pi\varepsilon_o} = -\frac{me^4}{8n^2\varepsilon_o^2h^2}$$

Substituting the values of m, h, e, ε_o etc

$$E_n = -\frac{2.18 \times 10^{-18}}{n^2}J = -\frac{13.6\ eV}{n^2}$$

The total energy of the electron is negative. This implies the fact that the electron is bound to the nucleus. Since the principal quantum number n has the values 1, 2, 3… the electron in the hydrogen atom can have only the following values of energy.

$$For\ n = 1, \qquad E_1 = -\frac{13.6}{1^2} eV = -13.6\ eV$$

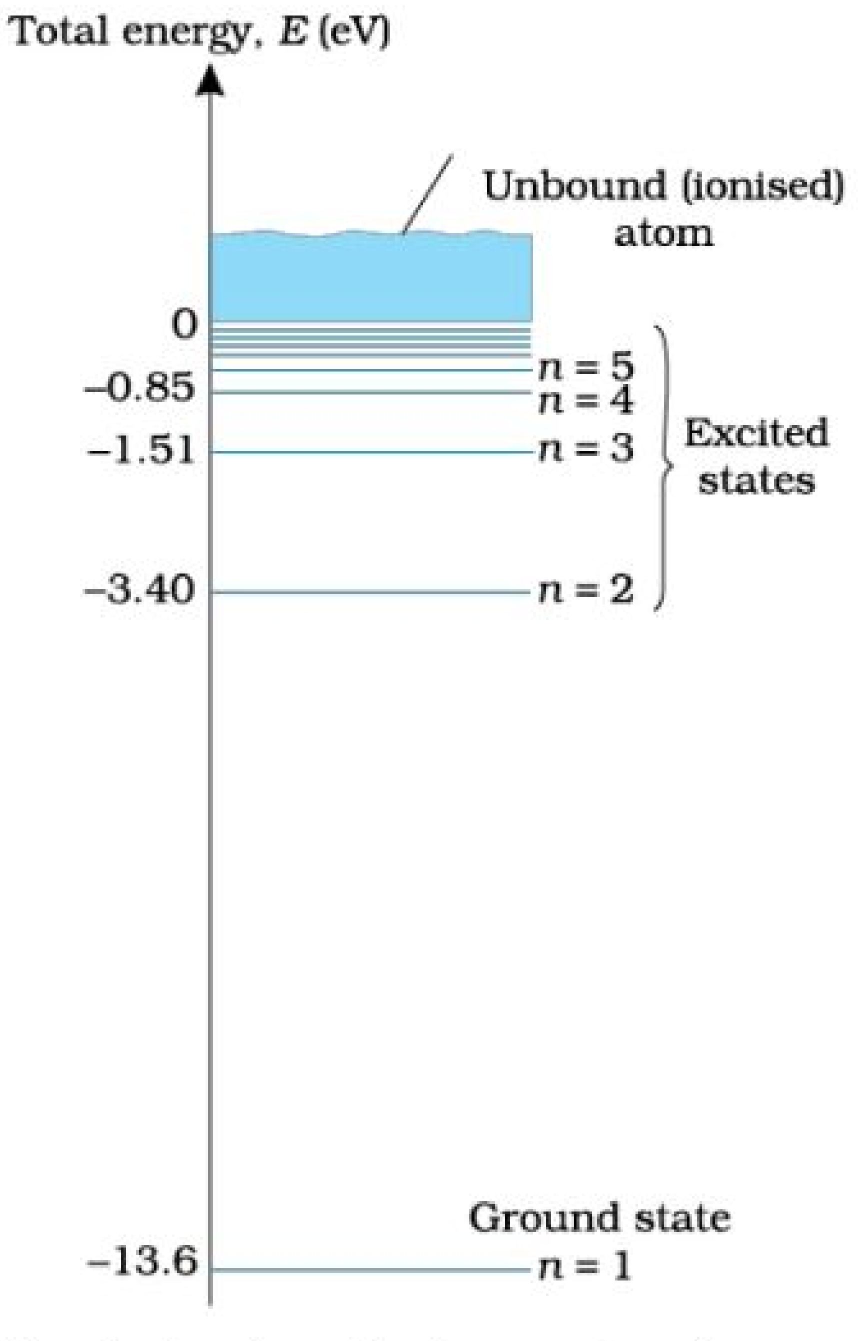
$$For\ n = 2, \qquad E_2 = -\frac{13.6}{2^2} eV = -3.4\ eV$$

$$For\ n = 3, \qquad E_3 = -\frac{13.6}{3^2} eV = -1.51\ eV$$

.

$For\ n = \infty, \quad E_\infty = 0$,i.e When $n = \infty$ the electron is completely free from the attractive force of the nucleus of the atom.

Energy level diagram of hydrogen atom



Spectral series of hydrogen atom (expression for wavelength and wavenumber)

According to Bohr's postulate if an electron makes transition from a higher energy level with quantum number n_i to a lower energy level of quantum number n_f, energy is radiated in the form of photon of frequency ν, such that

$$h\nu_{if} = E_{n_i} - E_{n_f}$$

$$= \left(-\frac{me^4}{8n_i^2\varepsilon_o^2h^2}\right) - \left(-\frac{me^4}{8n_f^2\varepsilon_o^2h^2}\right)$$

$$h\nu_{if} = \frac{me^4}{8\varepsilon_o^2h^2}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$\nu_{if} = \frac{me^4}{8\varepsilon_o^2h^3}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$but\ c = \nu\lambda, \quad \therefore \nu_{if} = \frac{c}{\lambda_{if}}$$

$$\therefore \frac{c}{\lambda_{if}} = \frac{me^4}{8\varepsilon_o^2h^3}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$or \qquad \frac{1}{\lambda_{if}} = \frac{me^4}{8\varepsilon_o^2h^3c}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$\frac{1}{\lambda_{if}} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

Here $R = \frac{me^4}{8\varepsilon_o^2h^3c}$ is called Rydberg constant.

Its value is $1.097 \times 10^7\ m^{-1}$.

$$since\ \frac{1}{\lambda} = \underline{\nu}, the\ wave\ number$$

$$\underline{\nu}_{if} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

Spectral series of hydrogen atom

The hydrogen spectrum consists of a number of series and each series consists of a number of lines. A series is due to the transition to a particular energy state from higher energy states. The important series are given below,

1. Lyman series

This series is in the ultraviolet region and is due to the transition of an electron to the first orbit from some higher state. Hence $n_f = 1$ and $n_i = 2, 3, 4 \dots \dots$

2. Balmer series

This series is in the visible region and is due to the transition of an electron to the second orbit from some higher state. Hence $n_f = 2$ and $n_i = 3, 4, 5 \dots \dots$

3. Paschen series

This series is in the infrared region and is due to the transition of an electron to the third orbit from some higher state. Hence $n_f = 3$ and $n_i = 4, 5, 6 \dots \dots$

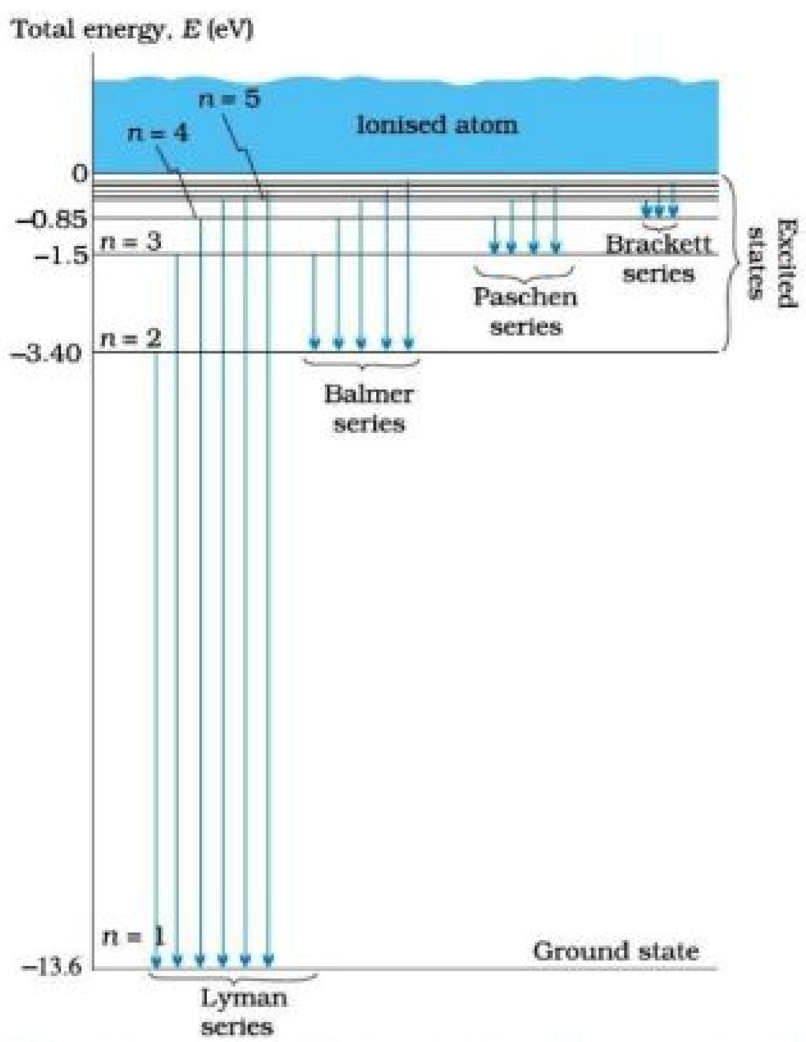
4. Bracket series

This series is in the infrared region and is due to the transition of an electron to the fourth orbit from some higher state. Hence $n_f = 4$ and $n_i = 5, 6, 7 \dots \dots$

5. Pfund series

This series is in the infrared region and is due to the transition of an electron to the fifth orbit from some higher state. Hence $n_f = 5$ and $n_i = 6, 7, 8 \dots \dots$

Line spectra of Hydrogen atom



Line spectra originate in transitions between energy levels.

de-Broglie's explanation of Bohr's second postulate of quantization

de-Broglie treated the electron as a wave of wavelength,

$$\lambda = \frac{h}{mv}$$

Here m is the mass and v is the velocity of the electron.

According to de-Broglie an electron orbit would be stable only if it contained an integral multiple of electron wavelength. If r is the radius of the electron orbit and λ, the de-Broglie wavelength, then the circumference,

$$2\pi r = n\lambda \quad or \quad 2\pi r = \frac{nh}{mv}$$

Here, n = 1, 2, 3………. This equation can be rewritten as

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

$$But, \qquad mvr = L = angular\ momentum\ of\ electron$$

$$\therefore \quad L = n\left(\frac{h}{2\pi}\right)$$

ie the angular momentum is the integral multiple of $\frac{h}{2\pi}$.

Limitations of Bohr's atomic model

- The Bohr model is applicable to hydrogenic atoms. It cannot explain the spectra of complex atoms having more than one electron.
- Bohr's model does not explain the fine structure of spectral lines of the Balmer series.
- Bohr's model does not explain the relative intensities of spectral lines.

CHAPTER 13

NUCLEI

Atomic mass unit (u)

Atomic mass unit is defined as the $1/12^{th}$ mass of the carbon-12 atom.

$$ie \quad 1u = \frac{mass\ of\ C-12\ atom}{12} = \frac{1.9926 \times 10^{-26} kg}{12}$$

$$1u = 1.66 \times 10^{-27} kg$$

Energy equivalent of 1u

According to Einstein's equation of mass energy,

$$E = mc^2$$

$$Here\ m = 1u = 1.66 \times 10^{-27} kg\ \ and\ \ c = 3 \times 10^8\ m/s$$

$$\therefore E = 1.66 \times 10^{-27} \times (3 \times 10^8)^2 = 1.484 \times 10^{-10}\ J$$

In electron volts

$$1u = 931\ MeV$$

Protons

Proton is a constituent of the nucleus. It is a positively charged particle. The magnitude of the charge on a proton is $1.6 \times 10^{-19} C$. Its mass is $1.6726 \times 10^{-27} kg$. The number of protons in the nucleus is called **atomic number (Z)** of the atom.

Neutrons

Neutron is a constituent of the nucleus. It is a neutral particle. The mass of the neutron is about $1.6748 \times 10^{-27} kg$. Inside the nucleus neutron is stable.

Mass number (A)

The total number of protons and neutrons is called mass number.

Binding energy

Binding energy is the energy required to hold the nucleons together.

$$Binding\ Energy, \quad E_b = \Delta M\ c^2$$

If the mass defect is in atomic mass unit, then binding energy in MeV is

$$Binding\ Energy, \quad E_b = \Delta M \times 931\ MeV$$

Binding energy per nucleon

It is the average energy required to extract one nucleon from the nucleus.

$$Binding\ energy\ per\ nucleon, E_{bn} = \frac{E_b}{A}$$

The higher value of binding energy per nucleon indicates the comparatively greater stability of the nucleus.

Radioactivity

Radioactivity is the phenomenon of spontaneous disintegration of the nucleus of an atom with the emission of one or more penetrating radiations like α-particles, β-particles or γ-particles.

Law of radioactive decay

The number of nuclei undergoing the decay per unit time is proportional to the total number of nuclei in the sample. Let N be the number of atoms present in a radioactive substance any instant t. Let dN be the number that disintegrates in a short interval dt.

Then, the rate of disintegration $-\frac{dN}{dt}$ is proportional to N, that is

$$-\frac{dN}{dt} = \lambda N \qquad \ldots\ldots\ldots(1)$$

Here λ is called decay constant or disintegration constant. From the above equation we have

$$\frac{dN}{N} = -\lambda\, dt$$

Integrating,

$$\int_{N_o}^{N} \frac{dN}{N} = -\lambda \int_{t_o}^{t} dt$$

$$[ln\, ln\, N\,]_{N_o}^{N} = -\lambda [t]_{t_o}^{t}$$

$$ln\, ln\, N \; - ln\, ln\, N_o \; = -\lambda[t - t_o] \qquad \ldots\ldots\ldots(2)$$

Setting $t_o = 0$ and rearranging

$$ln\, ln\, \frac{N}{N_o} = -\lambda t$$

Which gives

$$N = N_o\, e^{-\lambda t}$$

Activity of a substance

The rate of decay of a radioactive substance is called the activity (R) of the substance.

$$activity, R = -\frac{dN}{dt}$$

We have

$$N = N_o\, e^{-\lambda t}$$

Differentiating

$$\frac{dN}{dt} = -N_o \lambda\, e^{-\lambda t}$$

$$R = R_o\, e^{-\lambda t}$$

Here $R_o = \lambda N_o$ is the decay rate at $t = 0$.

The decay rate R at a certain time t and the number of undecayed nuclei N at the same time are related by

$$R = \lambda N$$

The SI unit of activity is becquerel (Bq).

1 becquerel = 1 disintegration per second.

Another unit of activity is curie (Ci) $1\ Ci = 3.7\ \times 10^{10}\ Bq$

Half life ($T_{½}$)

Half-life of a radionuclide is the time taken by it to reduce half of its initial value.

$$T_{\frac{1}{2}} = \frac{0.693}{\lambda}$$

Mean life or average life (τ)

Mean life is defined as the time taken by the radio nuclei to reduce $\frac{1}{e^{th}}$ of its initial value.

$$\tau = \frac{1}{\lambda}$$

Relation between T½ and τ

We have

$$T_{\frac{1}{2}} = \frac{0.693}{\lambda}$$

$$\tau = \frac{1}{\lambda}$$

Comparing

$$T_{\frac{1}{2}} = 0.693\ \tau$$

Alpha particles

- Alpha particles are positively charged particles.
- These particles have been identified as helium nuclei.
- They are deflected by electric and magnetic fields.
- They can affect photographic plates.

Alpha decay

Alpha decay is a process in which an unstable nucleus transforms itself into a new nucleus by emitting an alpha particle.

An example of alpha decay is the decay of uranium to thorium.

$$U_{92}^{238} \rightarrow Th_{90}^{234} + He_2^4$$

In α-decay, the mass number of the product nucleus (daughter nucleus) is four less than the decaying nucleus (parent nucleus), while the atomic number decreases by two. In general

$$X_Z^A \rightarrow X_{Z-2}^{A-4} + He_2^4$$

The disintegration energy or the Q value of a nuclear reaction is the difference between the initial mass energy and the total mass energy of the decay products. For α-decay

$$Q = (m_X - m_Y - m_{He})c^2$$

Q is also the net kinetic energy gained in the process.

Beta decay

In β-decay a nucleus spontaneously emits an electron (β^- decay) or a positron (β^-).

An example of β^- decay is

$$P_{15}^{32} \rightarrow S_{16}^{32} + e^- + \underline{\nu}$$

and that of β^+ decay is

$$Na_{11}^{22} \rightarrow Ne_{10}^{22} + e^+ + \nu$$

Here ν & $\underline{\nu}$ are neutrino and antineutrino respectively.

The basic nuclear process underlying β^- decay is the conversion of neutron to proton.

$$n \rightarrow p + e^- + \underline{\nu}$$

while for β^+ decay, it is the conversion of proton into neutron.

$p \rightarrow n + e^+ + \nu$, this reaction *is possible only inside the nucleus, since proton has smaller mass than neutron*

In both β^- and β^+ decay, the mass number A remains unchanged. In β^- decay, the atomic number Z of the nucleus is increased by one, while in β^+ decay, Z is decreased by one.

Neutrinos

Neutrinos are neutral particles with very small (possibly, even zero) mass compared to electrons. They have only weak interaction with other particles.

Gamma decay

Like an atom, a nucleus also has discrete energy levels. The difference in energy levels is of the order of MeV. When a nucleus in an excited state spontaneously decays to its ground state, a photon is emitted with energy equal to the difference in the two energy levels of the nucleus. This is called gamma decay.

Nuclear energy

Nuclear reaction is the source of nuclear energy. Two type of nuclear reactions are nuclear fission and nuclear fusion

Nuclear fission

Nuclear fission is the process in which a heavy nucleus splits up into two stable nuclei of comparable mass with release of large amounts of energy.

An example of fission is

$U_{92}^{235} \rightarrow Th_{90}^{234} + He_2^4$

The energy released in the fission reaction of nuclei like uranium is of the order of 200 MeV per fissioning nucleus.

Estimation of energy released per fission

Let us take a nucleus with A=240 breaking in to two fragment each of A=120. Then,

E_{bn} for A=240 nucleons is about 7.6 MeV

E_{bn} for A=120 fragments nuclei is about 8.5 MeV

Gain in binding energy for nucleon is about 0.9 MeV

Hence the total gain in binding energy is 240×0.9 MeV or 216 MeV.

Chain reaction

Nuclear chain reactions are series of nuclear fissions, each initiated by a neutron produced in a preceding fission.

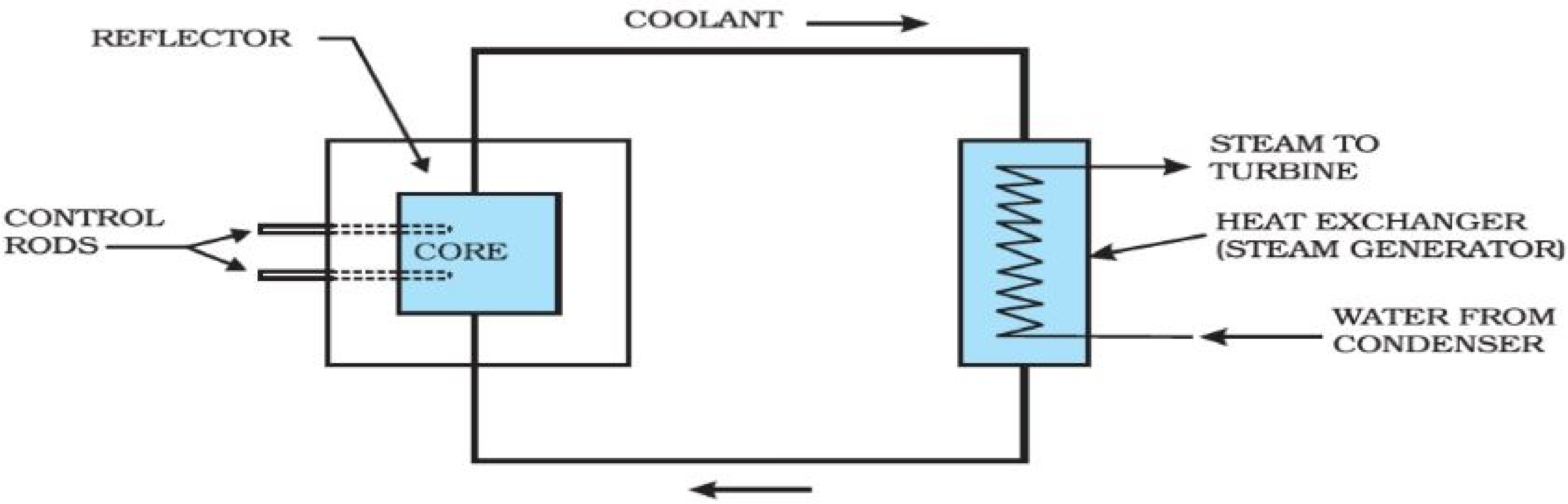
Controlled chain reaction is the principle of nuclear reactor.

If the chain reaction is uncontrolled, it leads to explosion

Nuclear reactor

A nuclear reactor works on the principle of a controlled chain reaction.

schematic diagram of a nuclear reactor



Important terms

Moderators

The light nuclei used to slow down the fast neutrons are called moderators. The commonly used moderators are water, heavy water (D_2O) and graphite.

Control rods

The reaction rate is controlled through control rods made out of neutron absorbing material such as cadmium.

Safety rods

Reactors are provided with safety rods which, when required, can be inserted into the reactor and multiplication factor can be reduced rapidly to less than unity.

Multiplication factor (K)

It is the ratio of the number of fissions produced by a given generation of neutrons to the number of fissions of the preceding generation.

It is the measure of growth rate of the neutrons in the reactor.

For $K=1$ the operation of the reactor is said to be critical (steady power operation).

If K becomes greater than one, the reactor will become supercritical and even explode.

Disadvantages of nuclear reactor

Nuclear reactors generate considerable radioactive and hazardous waste products.

Nuclear fusion

It is the process of combining or fusing two lighter nuclei into a stable and heavier nucleus.

The binding energy per nucleon of the fused heavier nuclei is more than the binding energy per nucleon of the lighter nuclei.

This implies energy would be released in this process.

Examples

$$ {}_1^1H + {}_1^1H \rightarrow {}_1^2H + e^+ + \nu + 0.42 \text{ MeV} \qquad \text{(i)} $$
$$ e^+ + e^- \rightarrow \gamma + \gamma + 1.02 \text{ MeV} \qquad \text{(ii)} $$
$$ {}_1^2H + {}_1^1H \rightarrow {}_2^3He + \gamma + 5.49 \text{ MeV} \qquad \text{(iii)} $$
$$ {}_2^3H + {}_2^3H \rightarrow {}_2^4He + {}_1^1H + {}_1^1H + 12.86 \text{ MeV} \qquad \text{(iv)} $$

The energy liberated by the sun and other stars is due to the nuclear fusion reactions occurring at very high stellar temperatures of 30 million kelvins.

Such processes are called thermonuclear reactions because they are temperature dependent.

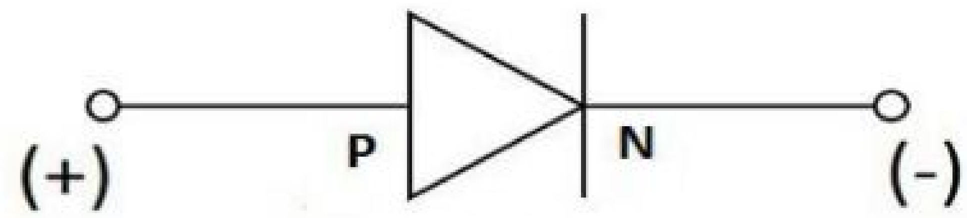
CHAPTER 14
SEMICONDUCTOR ELECTRONICS

p-n junction (diode)

A p-n junction consists layers of p-type and n-type semiconductors joined together.

n-type semiconductor made by adding pentavalent impurity atoms such as Arsenic, Phosphorous etc to a pure semiconductor. Hence its majority carriers are electrons (-ve)

p-type semiconductor made by adding trivalent impurity such as boron to a pure semiconductor crystal. Hence its majority carriers are holes (+ve)



Symbol of a Diode

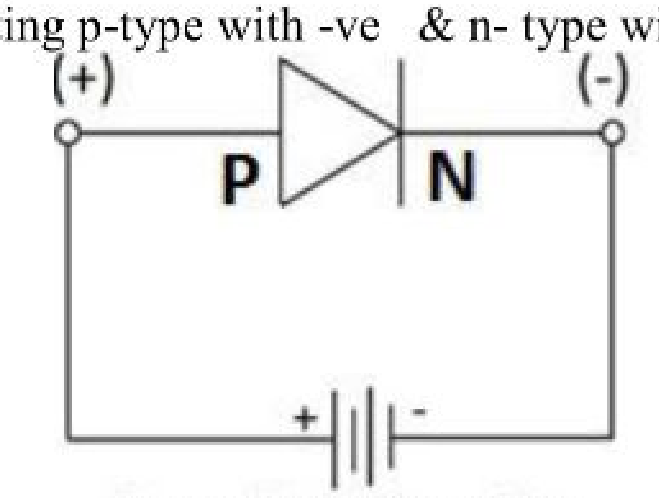
A p-n junction diode can be connected to a circuit in two ways

Forward bias

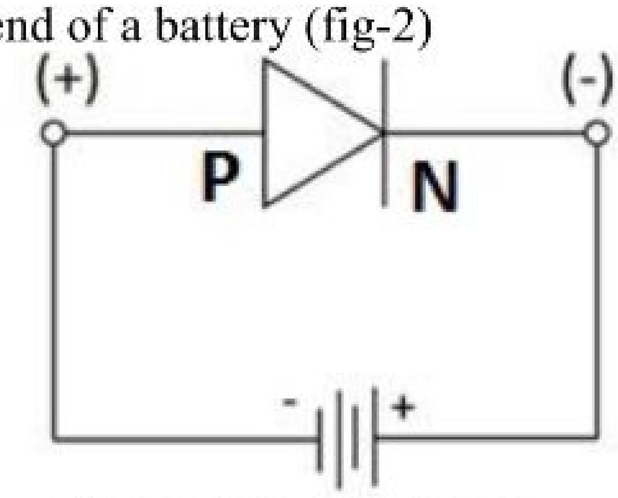
Connecting p-type with +ve & n- type with -ve end of a battery (fig-1)

Reverse bias

Connecting p-type with -ve & n- type with +ve end of a battery (fig-2)



Forward biased Connection
(fig-1)



Reverse biased Connection
(fig-2)

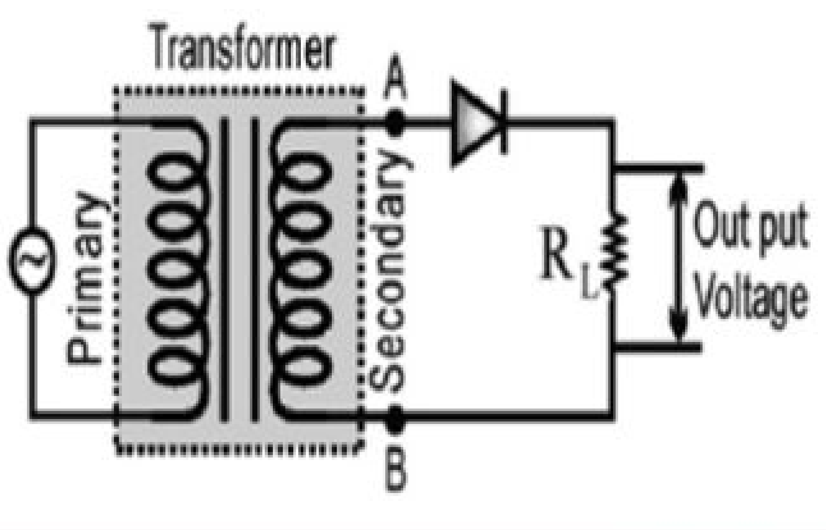
The property of allowing current during forward biasing and blocking it in reverse biasing, is the reason for
p-n junction to use as a rectifier.

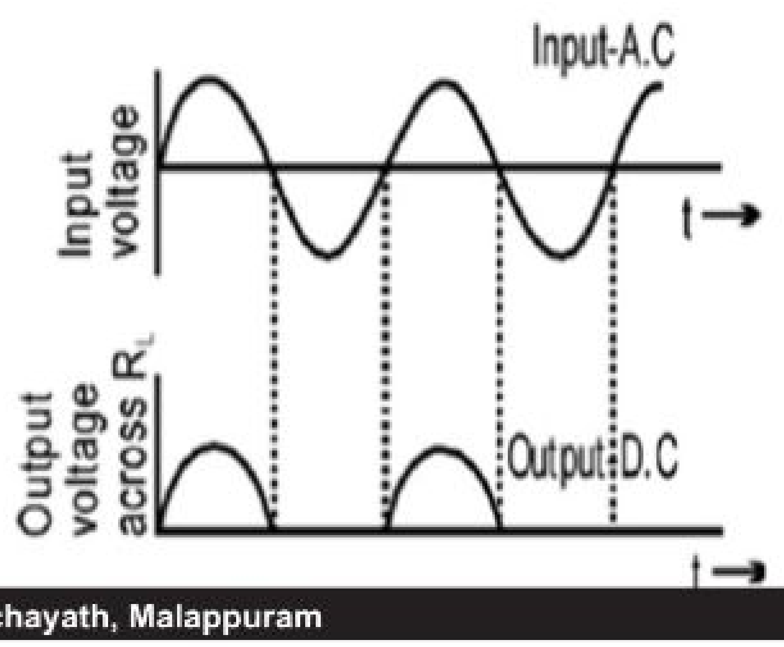
Rectifier

A device which converts ac into dc is known as a rectifier. There are two types of rectifiers.

1.Diode as a half wave rectifier

A half wave rectifier converts only one half of the given ac input into dc output. A single p-n junction diode is used in circuit as shown in figure.

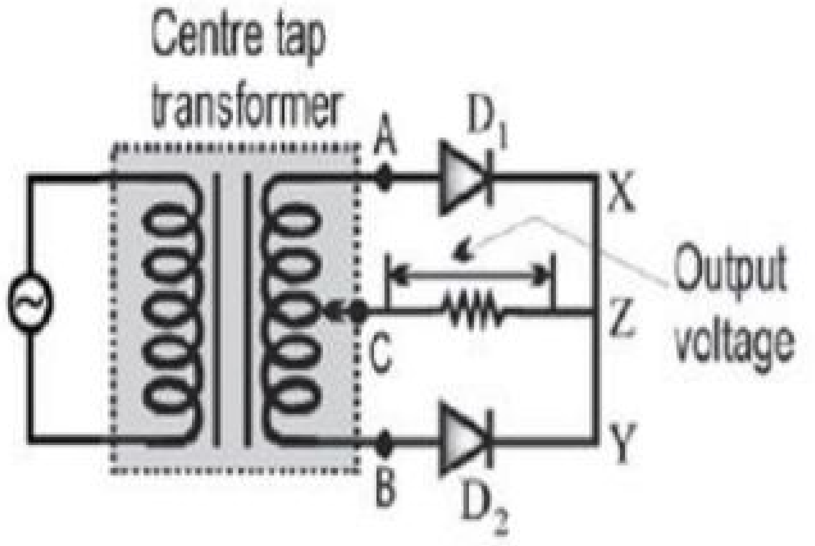


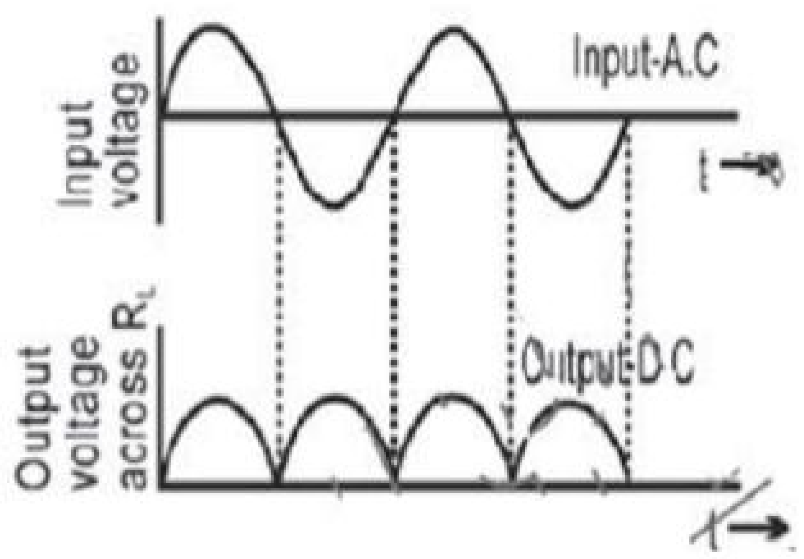


Diode conducts only during alternate half cycle of the input ac voltage. As a result, the output voltage is as shown in graph without any change in polarity.

2. Diode as full wave rectifier

A full wave rectifier converts both half of the given ac input into dc output. Two p-n junction diodes are used in circuit as shown in figure.





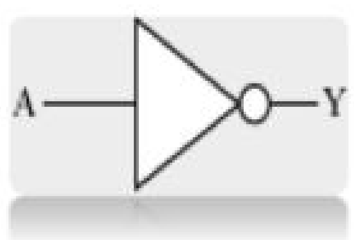
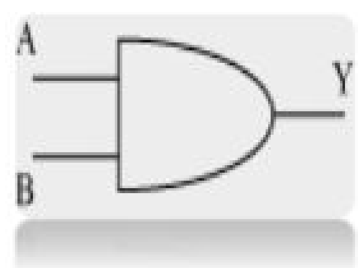
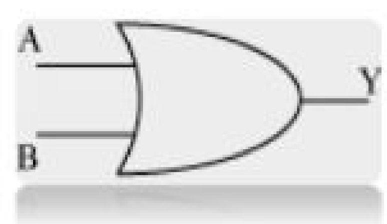
During the first half cycle of input, let A is positive while B is negative. Now D_1 is forward biased and conducts. During second half cycle, D_2 is positive and it conducts. Since the current through the load resistor in both half cycles are alike, a fluctuating positive output will be present as in figure.

Logic Gates

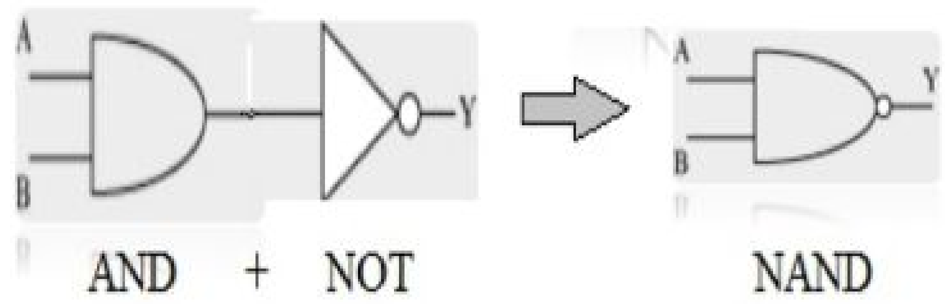
Logic gate is a digital circuit that follows a certain logical relationship between the input and output voltage based on some mathematical equations called Boolean algebra

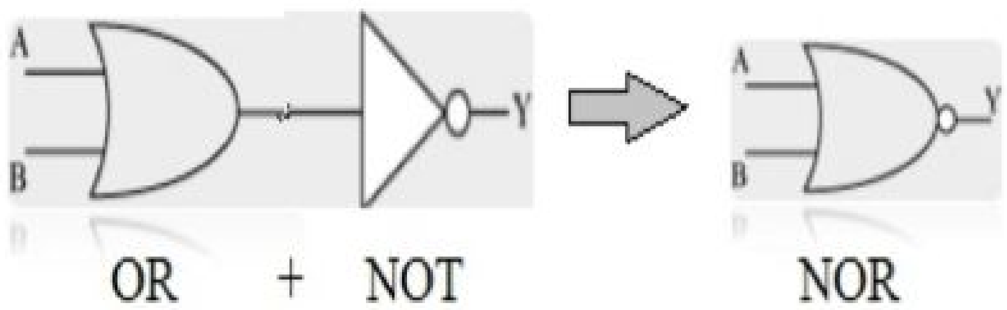
Possible input and output are 0[OFF] & 1 [ON] only

3 Basic or fundamental gates are NOT, AND and OR GATES

	1- NOT		**2- AND**			**3- OR**		
symbol								
Boolean expression	**$Y=\bar{A}$**		**Y=A.B**			**Y=A+B**		
Truth table	**input**	**output**	**Input**		**output**	**input**		**output**
	A	**$Y=\bar{A}$**	A	B	**Y=A.B**	A	B	**Y=A+B**
			0	0	0	0	0	1
	0	1	0	1	0	0	1	1
	1	0	1	0	0	1	0	1
			1	1	1	1	1	0

1.NAND (Combination of AND & NOT)





Boolean expression $Y=\bar{A}+\bar{B}$

Truth table

Input				output
A	B	$\bar{A}$	$\bar{B}$	$Y=\bar{A}+\bar{B}$
0	0	1	1	1
0	1	1	0	1
1	0	0	1	1
1	1	0	0	0

2.NOR (Combination of OR & NOT

Boolean expression $Y=\bar{A}.\bar{B}$

Truth table

Input				output
A	B	$\bar{A}$	$\bar{B}$	$Y=\bar{A}.\bar{B}$
0	0	1	1	1
0	1	1	0	0
1	0	0	1	0
1	1	0	0	0

Note:-

NAND & NOR gate is called universal gates because all other basic gates can be made by using them.