

PHYSICS

MINIMUM LEVEL MATERIAL

for

CLASS – XII

2017 – 18



Project Planned By

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PREFACE

It gives me great pleasure in presenting the Minimum Level Study Material in Physics for Class XII. It is in accordance with the latest CBSE syllabus of the session 2017-18.

I am extremely thankful to Honourable Shri D. Manivannan, Deputy Commissioner, KVS RO Hyderabad, who blessed and motivates me to complete this project work. This materials consists 5 easy units out of 10 units having overall weightage of 30 marks out of 70 marks. Each unit has Important Concepts and Formulas along with all expected questions and previous years Questions with Answers. At the end, all expected 30 important questions with answers from other left out units have been added to cover maximum portions.

I avail this opportunity to convey my sincere thanks to respected sir, Shri U. N. Khaware, Additional Commissioner(Acad), KVS Headquarter, New Delhi, respected sir, Shri S. Vijay Kumar, Joint Commissioner(Acad), KVS Headquarter, New Delhi, respected sir Shri P. V. Sairanga Rao, Deputy Commissioner(Acad), KVS Headquarter, New Delhi, respected sir Shri. D. Manivannan, Deputy Commissioner, KVS RO Hyderabad, respected sir Shri Isampal, Retd. Deputy Commissioner, KVS RO Bhopal, respected sir Shri P. Deva Kumar, Deputy Commissioner, KVS RO Bangalore, respected sir Shri Nagendra Goyal, Deputy Commissioner, KVS RO Ranchi, respected sir Shri Y. Arun Kumar, Deputy Commissioner, KVS RO Agra, respected sir Shri Sirimala Sambanna, Deputy Commissioner, KVS RO Jammu, respected sir Shri. K. L. Nagaraju, Retd. Assistant Commissioner, KVS RO Bangalore, respected sir Shri.Gangadharaiah, Retd. Assistant Commissioner, KVS RO Bangalore and respected Shri M.K. Kulshreshtha, Retd. Assistant Commissioner, KVS RO Chandigarh for their blessings, motivation and encouragement in bringing out this project in such an excellent form.

I also extend my special thanks to respected sir Shri. E. Krishnamurthy, Principal, KV Gachibowli, and respected sir Shri. P. S. Raju, Principal, KV No. 1 Uppal for their kind suggestions and motivation while preparing this Question Bank. I would like to place on record my thanks to respected sir Shri. P. K. Chandran, Principal, presently working in KV No. 1 Calicut. I have started my career in KVS under his guidance, suggestions and motivation.

Inspite of my best efforts to make this notes error free, some errors might have gone unnoticed. I shall be grateful to the students and teacher if the same are brought to my notice. You may send your valuable suggestions, feedback or queries through email to kumarsir34@gmail.com that would be verified by me and the corrections would be incorporated in the next year Question Bank.

M. S. KUMARSWAMY

DEDICATED

TO

MY FATHER

LATE SHRI. M. S. MALLAYYA

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ELECTROSTATICS

ELECTROSTATICS

MARKS WEIGHTAGE – 08 marks

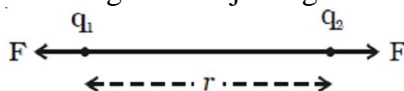
QUICK REVISION (Important Concepts & Formulas)

Charge

- **Quantization:** Charge is always in the form of an integral multiple of electronic charge and never its fraction.
 $q = \pm ne$ where n is an integer and $e = 1.6 \times 10^{-19}$ coulomb
 $= 1.6 \times 10^{-19}$ C.
- Charge on an electron/proton is the minimum charge.
Charge on an electron is -ve. $e = -1.6 \times 10^{-19}$ C.
Charge on a proton is +ve. $e = +1.6 \times 10^{-19}$ C.
Total charge = $\pm ne$.
- A particle/body is positively charged because it loses electrons or it has shortage of electrons.
- A particle is negatively charged because it gains electrons or it has excess of electron.
- **Conservation:** The total net charge of an isolated physical system always remains constant. Charge can neither be created nor destroyed. It can be transferred from one body to another.

Coulomb's inverse square law

Coulomb's law states that the force of attraction or repulsion between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them. The direction of forces is along the line joining the two point charges.



Let q_1 and q_2 be two point charges placed in air or vacuum at a distance r apart (see above Figure). Then, according to Coulomb's law,

$$F \propto \frac{q_1 q_2}{r^2} \text{ or } F = k \cdot \frac{q_1 q_2}{r^2}$$

where k is a constant of proportionality. In air or vacuum, $k = \frac{1}{4\pi\epsilon_0}$

- $F = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{r^2}$ where F denotes the force between two charges q_1 and q_2 separated by a distance r in free space. ϵ_0 is a constant known as permittivity of free space. Free space is vacuum and may be deemed to be air practically and $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \frac{Nm^2}{C^2}$

- **One Coulomb** is defined as the quantity of charge, which when placed at a distance of 1 metre in air or vacuum from an equal and similar charge, experiences a repulsive force of 9×10^9 N.
- If free space is replaced by a medium, then ϵ_0 is replaced by $(\epsilon_0 K)$ or $(\epsilon_0 \epsilon_r)$ where K is known as **dielectric constant** or relative permittivity or specific inductive capacity (S.I.C.) or dielectric coefficient of the medium/material/matter. Thus

$$F = \frac{1}{4\pi\epsilon} \cdot \frac{q_1 q_2}{r^2} = \frac{1}{4\pi\epsilon_0 K} \cdot \frac{q_1 q_2}{r^2} = \frac{1}{4\pi\epsilon_0 \epsilon_r} \cdot \frac{q_1 q_2}{r^2}$$

- $K = \frac{\epsilon}{\epsilon_0}$ or $\epsilon_r = \frac{\epsilon}{\epsilon_0}$
 $K = 1$ for vacuum (or air), $K = \infty$ for conductor/metal.
- $\epsilon_0 = 8.85 \times 10^{-12} C^2 N^{-1} m^{-2}$.

➤ Vector form of the law (q_1 and q_2 are like charges)

$$(i) \vec{F}_{12} = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{r_{21}^3} \vec{r}_{21} = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{|\vec{r}_1 - \vec{r}_2|^3} (\vec{r}_1 - \vec{r}_2)$$

$$(ii) \vec{F}_{21} = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{r_{12}^3} \vec{r}_{12} = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{|\vec{r}_2 - \vec{r}_1|^3} (\vec{r}_2 - \vec{r}_1)$$

➤ If \hat{r}_{21} is a unit vector pointing from q_2 to q_1 , then

$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{r_{21}^3} \hat{r}_{21} = \text{force on } q_1 \text{ by } q_2$$

When $q_1 q_2 > 0$ for like charges.

➤ If \hat{r}_{12} is a unit vector pointing from q_1 to q_2 , then

$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{r_{12}^3} \hat{r}_{12} = \text{force on } q_2 \text{ by } q_1$$

When $q_1 q_2 > 0$ for like charges.

Intensity/strength of electric field

➤ Intensity at a point is numerically equal to the force acting on a unit positive charge placed at the point.

➤ It is a vector quantity.

➤ The units of intensity E are NC^{-1} , volt/metre.

➤ The dimensions of E are $[\text{MLT}^{-3}\text{A}^{-1}]$.

Intensity due to a charge q at distance r

$$(i) E = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{r^2}$$

It acts in the direction in which a +ve charge moves.

$$(ii) E = \frac{1}{4\pi\epsilon_0 K} \cdot \frac{q}{r^2}, \text{ if point is in the medium.}$$

Potential (V) and intensity (E)

$$(i) E = -\frac{dV}{dr} \text{ when potential varies with respect to distance.}$$

$$(ii) E = \frac{\text{potential difference}}{\text{distance}} = \frac{V}{r}, \text{ when potential difference is constant.}$$

(iii) Potential at a point distance r from charge q .

$$V = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{r} \text{ in free space}$$

$$(iv) V = \frac{1}{4\pi\epsilon_0 K} \cdot \frac{q}{r} \text{ in medium}$$

(v) Potential is a scalar quantity

$$\vec{E} \cdot d\vec{r} = dV$$

➤ From positively charged surface, \vec{E} acts outwards at right angles *i.e.* along outward drawn normal.

➤ Intensity is equal to flux (number of electric lines of force) crossing unit normal area.

$$\vec{E} = \frac{\text{flux}(\Phi)}{\text{area}(s)}$$

Electric lines of force

- Electric lines of force start from positive charge and terminate on negative charge.
- From a positively charged conducting surface lines of force are normal to surface in outward direction.
- Electric lines of force about a negative point charge are radial, inwards and about a positive point charge are radial, outwards.
- Electric lines of force are always perpendicular to an equipotential surface.
- These lines of force contract along the length but expand at right angles to their length. There is longitudinal tension and lateral pressure in a line of force. Contraction shows attraction between opposite charges while expansion indicates that similar charges repel.
- The number of electric lines of force (flux) passing through unit normal area at any point indicates electric intensity at that point.
- For a charged sphere these lines are straight and directed along radius.
- These may be open or closed curves. They are not necessarily closed though the magnetic lines of force are closed.
- Two lines of force never intersect or cut each other.
- Lines of force are parallel and equally spaced in a uniform field.
- Tangent to the curve at a point shows direction of field.

Gauss law

- For a closed surface enclosing a net charge q , the net electric flux Φ emerging out is given by

$$\Phi = \oint_s \vec{E} \cdot d\vec{s} = \frac{q}{\epsilon_0}$$

- If a dipole is enclosed by a closed surface, flux Φ is equal to zero.
Here the algebraic sum of charges ($+q - q = 0$) is zero.
- The flux will come out if +ve charge is enclosed. The flux will enter if negative charge is enclosed.

Flux from a cube

- (i) If q is at the centre of cube, total flux (Φ) = $\frac{q}{\epsilon_0}$.

- (ii) From each face of cube, flux = $\frac{q}{6\epsilon_0}$.

Electric field due to a charged shell

- (i) At an external point, $E = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{r^2}$

This is the same as the field due to a point charge placed at the centre.

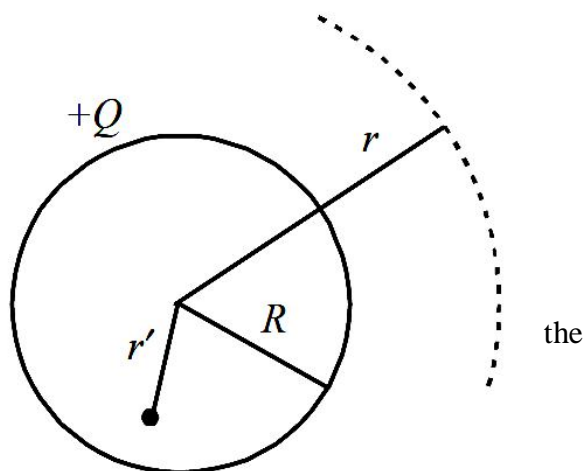
- (ii) At a point on surface of shell, this is E_{\max} .

$$E = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{R^2}$$

Again the shell behaves like a point charge placed at centre.

- (iii) At an inside point ($r' < R$), $E = 0$.

Thus a charge q placed inside a charged shell does not experience any force due to the shell.



Gaussian surface

- (i) For a sphere or spherical shell a concentric sphere.
- (ii) For a cylinder or an infinite rod a coaxial cylinder.
- (iii) For a plate a cube or a cuboid.

Potential and intensity due to a charged conducting sphere (or shell)

At a point outside the charged sphere

(i) Intensity, $E = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{r^2}$ ($r >$ radius of sphere R)

It is a vector quantity.

(ii) Potential, $V = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{r}$

It is a scalar quantity.

At a point on the surface of charged sphere

(i) Intensity, $E = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{R^2}$ ($r =$ radius of sphere R)

It is a vector quantity.

(ii) Potential, $V = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{R}$

It is a scalar quantity.

At a point inside the sphere ($r <$ radius of sphere)

(i) Intensity $E =$ zero.

(ii) Potential, $V = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{R}$

Potential is constant inside the sphere. This is same as potential at the surface of sphere.

At the centre of sphere

(i) Intensity $E =$ zero.

(ii) Potential, $V = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{R}$

At infinity

(i) Intensity $E =$ zero.

(ii) Potential $V =$ zero.

Electric field and potential due to charged nonconducting sphere

Outside the sphere when $r >$ radius of sphere R

(i) Electric intensity, $E = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{r^2}$ It is a vector quantity.

(ii) Electric potential, $V = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{r}$ It is a scalar quantity.

On the surface of the sphere where $r = R$

(i) Electric intensity, $E = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{R^2}$ It is a vector quantity.

(ii) Electric potential, $V = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{R}$ It is a scalar quantity.

Inside the sphere when $r < R$

(i) Electric intensity, $E = \frac{1}{4\pi\epsilon_0} \cdot \frac{qr}{R^3}$

Vectorially, $E = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{R^3} \vec{r}$

(ii) Electric potential, $V = \frac{1}{4\pi\epsilon_0} \cdot \frac{q(3R^2 - r^2)}{2R^3}$

At the centre of sphere when $r = 0$

(i) Electric intensity $E =$ zero.

(ii) Electric potential, $V = \frac{3}{2} \cdot \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{R}$

Potential at centre = $\frac{3}{2}$ \times potential at surface

At infinity

(i) Intensity = zero.

(ii) Potential = zero.

Electric dipole

Two equal and opposite charges (q) each, separated by a small distance (l) constitute an electric dipole. Many of the atoms/molecules are dipoles.

(i) Dipole moment, $\vec{p} = q \times (\vec{l})$

(ii) Dipole moment is a vector quantity.

(iii) The direction of \vec{p} is from negative charge to positive charge.

(iv) Unit of dipole moment = coulombmetre = Cm.

(v) Dimension of dipole moment = [ATL].

Intensity of electric field due to a dipole

(i) Along axis at distance r from centre of dipole

$E = \frac{2p}{r^3} \cdot \frac{1}{4\pi\epsilon_0}$ Direction of E is along the direction of dipole moment.

(ii) Along equator of dipole at distance r from centre

$E = \frac{p}{r^3} \cdot \frac{1}{4\pi\epsilon_0}$ Direction of E is anti-parallel to direction of p .

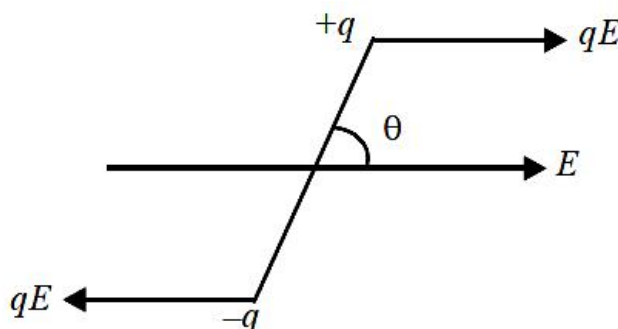
(iii) At any point along direction q

$E = \frac{p}{r^3} \sqrt{1 + 3 \cos^2 \theta} \cdot \frac{1}{4\pi\epsilon_0}$

The direction of E makes an angle β with the line joining the point with centre of dipole where $\tan \beta$

$= \frac{1}{2} \tan \theta$.

Torque on a dipole



Two forces [qE and $(-qE)$] equal, opposite and parallel, separated by a distance constitute a couple.

$$\text{torque } (\vec{\tau}) = \vec{p} \times \vec{E}$$

$$|\vec{\tau}| = pE \sin \theta$$

This direction of $\vec{\tau}$ is perpendicular to the plane containing \vec{p} and \vec{E} . The torque tends to align the dipole in the direction of field.

When dipole is parallel to electric field, it is in stable equilibrium. When it is antiparallel to electric field, it is in unstable equilibrium.

Torque is maximum when $\theta = 90^\circ$. Dipole is perpendicular to E . Therefore maximum torque = pE .

Potential energy of dipole in uniform electric field

Workdone in rotating the dipole from an angle θ_1 to angle θ_2 .

$$W = \int_{\theta_1}^{\theta_2} \tau d\theta = \int_{\theta_1}^{\theta_2} pE \sin \theta d\theta = pE [-\cos \theta]_{\theta_1}^{\theta_2} = -pE(\cos \theta_2 - \cos \theta_1)$$

(i) If $\theta_1 = 0$ and $\theta_2 = 180^\circ$, $W = 2pE$.

(ii) If $\theta_1 = 0$ and $\theta_2 = 90^\circ$, $W = pE$.

Potential energy of dipole, when it is turned through an angle θ from field direction is

$$U = -pE \cos \theta = -\vec{p} \cdot \vec{E}$$

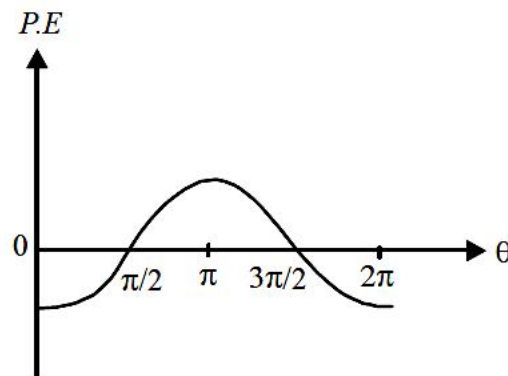
(i) If $\theta = 0$, $U = -pE$.

The dipole orients itself parallel to field.

(ii) If $\theta = 90^\circ$, $U = 0$.

(iii) If $\theta = 180^\circ$, $U = pE$.

Variation of potential energy of dipole with angle θ , between \vec{E} and \vec{p} , is shown in the figure.



(i) Potential energy is negative from 0 to $\pi/2$ and $3\pi/2$ to 2π . They are regions of stable equilibrium of dipole.

(ii) Potential energy is positive from $\pi/2$ to $3\pi/2$. This is the region of unstable equilibrium of the dipole.

Dipole in non-uniform electric field

In non-uniform electric field, the two ends of dipole are acted upon by forces qE_1 and $-qE_2$. They are not equal as $E_1 \neq E_2$ in non-uniform field. Hence a force and a torque both act on the dipole.

Force acting on the dipole can be represented by $\vec{F} = \vec{p} \times \frac{d\vec{E}}{dr}$

Broadly speaking,

Net force = $(qE_1 - qE_2)$ along direction of greater field intensity.

On account of net force upon dipole, it may undergo linear motion.

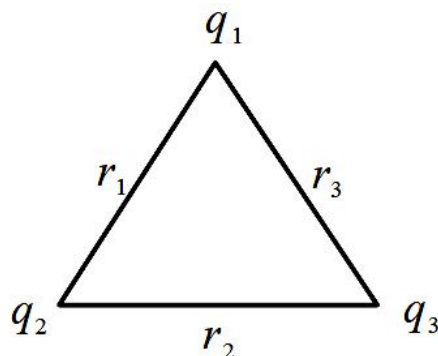
In a non-uniform electric field, a dipole may, therefore, undergo rotation as well as linear motion.

Potential energy of charge system

For two point charges q_1 and q_2 separated by a distance r , electrostatic potential energy U is given by

$$U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

For three point charges, $U = \frac{1}{4\pi\epsilon_0} \left[\frac{q_1 q_2}{r_1} + \frac{q_2 q_3}{r_2} + \frac{q_3 q_1}{r_3} \right]$



- For n charges, consider all pairs with due regard of signs of charges, positive or negative.
- S.I. unit of energy = joule (J)
- Another popular unit is electron volt (eV).
 $1 \text{ eV} = 1.6 \times 10^{-19} \text{ joule.}$

Charged soap bubble

For equilibrium of a charged soap bubble, pressure due to surface tension = $\frac{4T}{r}$ acting inwards.

Electric pressure due to charging = $\frac{\sigma^2}{2\epsilon_0}$ acting outwards.

At equilibrium, $\frac{4T}{r} = \frac{\sigma^2}{2\epsilon_0}$ where s = surface density of charge

$$\Rightarrow \frac{4T}{r} = \frac{1}{2\epsilon_0} \left(\frac{q}{4\pi r^2} \right)^2 \Rightarrow q = 8\pi r \sqrt{2\epsilon_0 r T}$$

Here air pressures, inside and outside the bubble, are supposed to be same.

Behaviour of a conductor in an electrostatic field

In the case of a charged conductor

- (i) Charge resides only on the outer surface of conductor.
- (ii) Electric field at any point inside the conductor is zero.
- (iii) Electric potential at any point inside the conductor is constant and equal to potential on the surface of the conductor, whatever be the shape and size of the conductor.
- (iv) Electric field at any point on the surface of charged conductor is directly proportional to the surface density of charge at that point, but electric potential does not depend upon the surface density of charge.

Capacitance

When a conductor is given a charge, its potential gets raised. The quantity of charge given to a conductor is found to be directly proportional to the potential raised by it. If q is the charge given to conductor and V is potential raised due to it, then $q \propto V$ or $q = CV$, where C is a constant, known as **capacitance** of the conductor.

$$\text{Capacitance} = \frac{\text{charge}}{\text{potential}}.$$

Unit of capacitance is **farad**.

1F = 1 coulomb/volt.

1 Farad = 9×10^{11} stat farad.

Dimensions of capacitance are $[M^{-1}L^{-2}T^4A^2]$.

Capacity of an isolated spherical conductor : Capacitance of an isolated spherical conductor of radius a placed in a medium of dielectric constant K ,

$$C = 4\pi\epsilon_0 K a \text{ farad}$$

For vacuum or air, $K = 1$, hence

$$C_0 = 4\pi\epsilon_0 a \text{ farad.}$$

i.e., capacitance of a spherical conductor μ radius.

Capacitor is a pair of two conductors of any shape which are close to each other and have equal and opposite charges.

A capacitor is an arrangement which can store sufficient quantity of charge.

The quantity of charge that can be given to a capacitor is limited by the fact that every dielectric medium becomes conducting at a certain value of electric field.

Capacitance of a capacitor is

(i) Directly proportional to the area of the plates (A).

(ii) Inversely proportional to distance between plates (d) -1 .

(iii) Directly proportional to dielectric constant of the medium filled between its plates (K).

Parallel plate capacitor : Capacitance of a parallel plate capacitor filled completely with some dielectric medium.

$$C = \frac{K\epsilon_0 A}{d}$$

For air and vacuum, $K = 1$.

$$C = \frac{\epsilon_0 A}{d}$$

Capacitance of a parallel plate capacitor filled with dielectric slab of thickness t is given by

$$C = \frac{\epsilon_0 A}{d - t \left[1 - \frac{1}{K} \right]}$$

Capacitance of a parallel plate capacitor filled with a conducting slab of thickness t is given by

$$C = \frac{\epsilon_0 A}{(d - t)}$$

The plates of a parallel plate capacitor attract each other with a force $F = \frac{Q^2}{2A\epsilon_0}$

Capacitance of a spherical condenser/capacitor, is $C = 4\pi\epsilon_0 K \left[\frac{ab}{b-a} \right]$

when a and b are the radii of inner and outer spheres respectively.

Dielectrics are of two types : Nonpolar and polar. The nonpolar dielectrics (like N_2 , O_2 , benzene, methane) etc. are made up of nonpolar atoms / molecules, in which the centre of mass of negative coincides with the centre of mass of negative charge of the atom / molecule.

The polar dielectrics (like H₂O, CO₂, NH₃, HCl) etc. are made up of polar atoms / molecules, in which the centre of mass of positive charge does not coincide with the centre of mass of negative charge of the atom / molecule.

A non-polar dielectric can be polarized by applying an external electric field on the dielectric.

The effective electric field \vec{E} in a polarised dielectric is given by $\vec{E} = \vec{E}_0 - \vec{E}_p$ where \vec{E}_0 is strength of external field applied and \vec{E}_p is intensity of induced electric field set up due to polarization. It is equal to surface density of induced charge.

The ratio $E_0 / E = K$, dielectric constant.

When a dielectric slab is placed between the plates of a parallel plate capacitor, the charge induced on its sides due to polarization of dielectric is

$$q_i = q \frac{(K - 1)}{K}$$

Capacitors in series: Equivalent capacitance of a series combination of capacitors is

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots$$

In series combination of capacitors, charge is same on each capacitor and is equal to charge supplied by source $CV = C_1V_1 = C_2V_2 = \dots$

Capacitors in parallel : Equivalent capacitance of a parallel combination of capacitors is $C_p = C_1 + C_2 + C_3 + \dots$

In parallel combination of capacitors, potential difference is same across each capacitor and is equal to applied potential difference $\frac{q}{C} = \frac{q_1}{C_1} = \frac{q_2}{C_2} = \frac{q_3}{C_3} = \dots$

Electric potential energy stored in a charged conductor or capacitor is

$$U = \frac{1}{2} CV^2 = \frac{1}{2} \frac{q^2}{C} = \frac{1}{2} qV$$

The electric potential energy of capacitor resides in the dielectric medium between the plates of the condenser.

When two charged conductors are connected together, the redistributed charges on them are in the ratio of their capacitance.

When two charged conductors having charges q_1 and q_2 and capacitances C_1 and C_2 are connected together, then after redistribution of charges, the common potential is $V = \frac{q_1 + q_2}{C_1 + C_2} = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}$ where V_1 and V_2 are the initial potentials of the charged conductors.

In case of charged capacitors, when plates of same polarity are connected together, common potential $V = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}$

But when plates of opposite polarity are connected together, then common potential is $V = \frac{C_1V_1 - C_2V_2}{C_1 + C_2}$

Total energy stored in any grouping of capacitors is equal to sum of the energies stored in individual capacitors.

If n charged drops, each of capacity C , charged to potential V with charge q , surface density σ and potential energy U coalesce to form a single drop, then for such a drop,

$$\text{total charge} = nq$$

$$\text{total capacity} = n^{1/3}C$$

$$\text{potential} = n^{2/3}V$$

$$\text{Surface density of charge} = n^{1/3}\sigma,$$

$$\text{and total potential energy} = n^{2/3}U.$$

Sharing of charges

(i) **Common potential** : When two capacitors at different potentials V_1 and V_2 are connected, charged q_1 ($= C_1V_1$) and q_2 ($= C_2V_2$) are redistributed till a common potential V is reached. Then

$$V = \frac{\text{total charge}}{\text{total capacity}} = \frac{q_1 + q_2}{C_1 + C_2} = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}$$

(ii) **Loss of energy** : During sharing of charges, energy is lost; mostly as heat, partly as cracking noise and partly as sparking light.

$$\text{Loss of energy} = \frac{1}{2} \frac{C_1C_2(V_1 - V_2)^2}{C_1 + C_2}$$



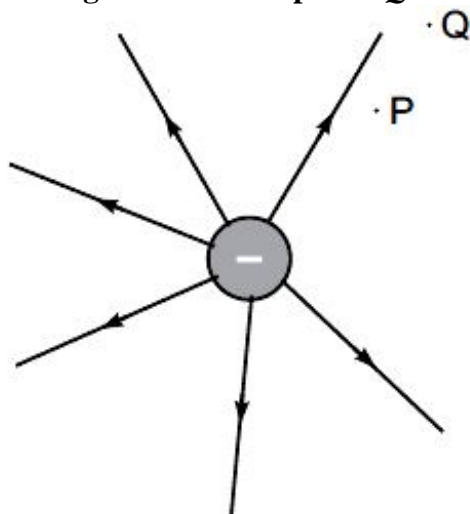
Important Questions & Answers

VERY SHORT ANSWER TYPE QUESTIONS (1 MARK)

1. Why must electrostatic field at the surface of a charged conductor be normal to the surface at every point? Give reason.

Ans. The work done in moving a charge from one point to another on an equipotential surface is zero. If electric field is not normal, it will have a non-zero component along the surface which would cause work to be done in moving a charge on an equipotential surface.

2. Figure shows the field lines due to a positive point charge. Give the sign of potential energy difference of a small negative charge between the points Q and P.



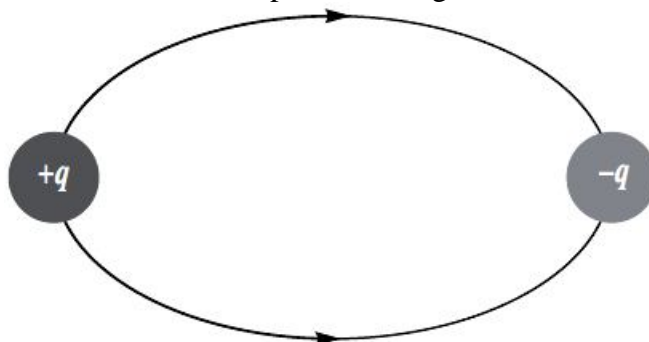
Ans. $U = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1q_2}{r'}$

Here, $U_Q < U_P$

Therefore, $U_Q - U_P$ is negative

3. Why do the electrostatic field lines not form closed loops?

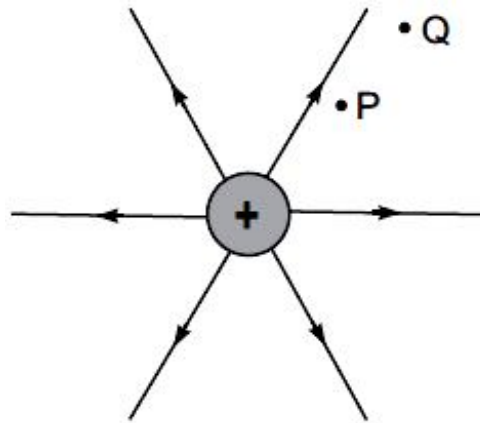
Ans. The electrostatic field lines start from positive charge and end on negative charge.



4. Why do the electric field lines never cross each other?

Ans. If the field lines cross each other, then at the point of intersection, there will be two directions for the same electric field which is not possible.

5. Figure shows the field lines on a positive charge. Is the work done by the field in moving a small positive charge from Q to P positive or negative? Give reason.



Ans. The work done by the field is negative. This is because the charge is moved against the force exerted by the field.

6. At what position is the electric dipole in uniform electric field in its most stable equilibrium position? [AI 2008]

Ans. When $\theta = 0^\circ$ between \vec{P} and \vec{E}

7. If the radius of the Gaussian surface enclosing a charge is halved, how does the electric flux through the Gaussian surface change? [AI 2008]

Ans. The electric flux remains the same, as the charge enclosed remains the same.

8. Define the term electric dipole moment of a dipole. State its S.I. unit. [AI 2008]

Ans. Strength of an electric dipole is measured by its electric dipole moment, whose magnitude is equal to product of magnitude of either charge and separation between the two charges *i.e.*, $\vec{p} = q \cdot 2\vec{a}$ and is directed from negative to positive charge, along the line joining the two charges. Its SI unit is Cm.

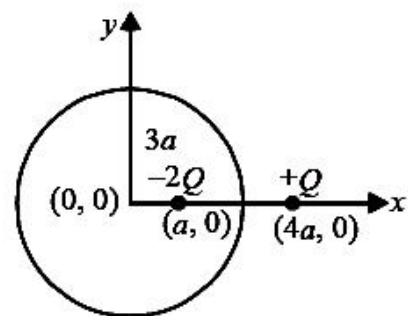
9. A charge 'q' is placed at the centre of a cube of side l. What is the electric flux passing through each face of the cube? [AI 2012]

Ans. Flux through whole of the cube, $\phi = \frac{q}{\epsilon_0}$

Flux through each face of the cube, $\phi' = \frac{\phi}{6} = \frac{q}{6\epsilon_0}$

10. Two charges of magnitudes $-2Q$ and $+Q$ are located at points $(a, 0)$ and $(4a, 0)$ respectively. What is the electric flux due to these charges through a sphere of radius ' $3a$ ' with its centre at the origin? [AI 2013]

Ans. Electric flux $\phi = \frac{q_{\text{inside}}}{\epsilon_0} = \frac{-2Q}{\epsilon_0}$



11. What is the electrostatic potential due to an electric dipole at an equatorial point? [AI 2009]

Ans. Zero

12. Name the physical quantity whose S.I. unit is J C^{-1} . Is it a scalar or a vector quantity? [AI 2010]

Ans. J C^{-1} is the S.I. unit of electrostatic potential. It is a scalar quantity.

13. What is the value of the angle and between the vectors \vec{p} and \vec{E} for which the potential energy of an electric dipole of dipole moment \vec{p} , kept in an external electric field \vec{E} , has the maximum value.

Ans. Potential energy = $-\vec{p} \cdot \vec{E} = -pE \cos \theta$

Therefore, Potential energy is the maximum when $\cos \theta = -1$ i.e. $\theta = \pi$ or 180°

14. A point charge Q is placed at point O as shown in the figure. Is the potential difference $V_A - V_B$ positive, negative or zero, if Q is (i) positive (ii) negative? [AI 2011]



- Ans. (i) If Q is positive, $V_A - V_B$ is positive.
(ii) If Q is negative, $V_A - V_B$ is negative.

SHORT ANSWER TYPE QUESTIONS (2 MARKS/3 MARKS)

15. Define electric flux. Write its S.I. unit.

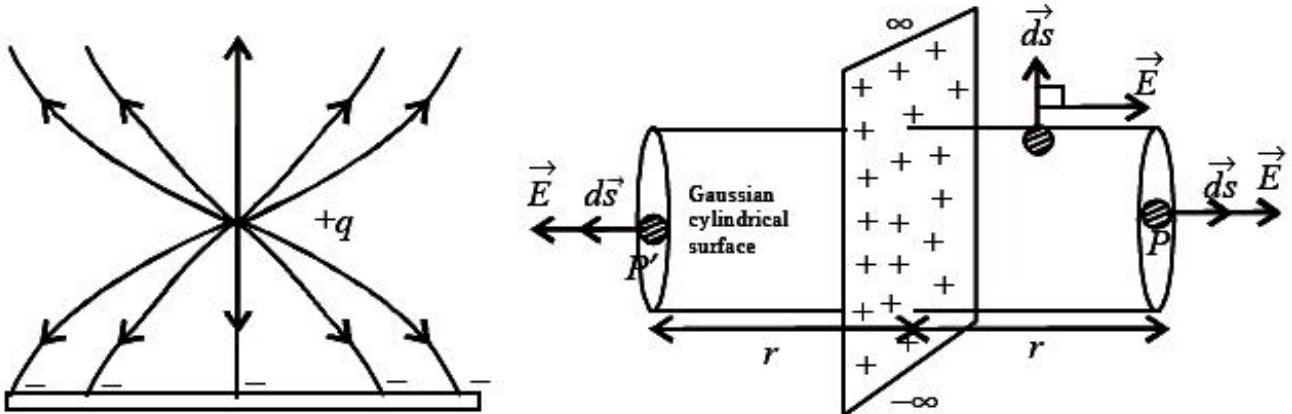
A charge q is enclosed by a spherical surface of radius R . If the radius is reduced to half, how would the electric flux through the surface change? [AI 2009]

Ans. Electric flux linked with a surface is the number of electric lines of force cutting through the surface normally. It's SI unit is Nm^2C^{-1} or Vm on decreasing the radius of spherical surface to half there will be no effect on the electric flux.

16. A positive point charge ($+q$) is kept in the vicinity of an uncharged conducting plate. Sketch electric field lines originating from the point on to the surface of the plate. Derive the expression for the electric field at the surface of a charged conductor. [AI 2009]

Ans. Let us consider an infinite plane sheet of charge of uniform charge density where q is charge in area A on sheet of charge.

$$\sigma = \frac{q}{A}$$



Let P be any point on the one side of sheet and P' on the other side of sheet, at same distance r from it. We draw a Gaussian cylindrical surface S of cross section area A cutting through the plane sheet of charge, such that points P and P' lie on its plane faces. Then electric flux linked with cylindrical surface S is

$$\begin{aligned} \phi &= \oint \vec{E} \cdot d\vec{s} \\ \text{or } \phi &= \int_{\text{lpf}} \vec{E} \cdot d\vec{s} + \int_{\text{cs}} \vec{E} \cdot d\vec{s} + \int_{\text{rpf}} \vec{E} \cdot d\vec{s} \\ \text{or } \phi &= \int_{\text{lpt}} E ds \cos 0 + \int_{\text{cs}} E ds \cos 90 + \int_{\text{rpf}} E ds \cos 0 \\ \text{or } \phi &= E \int_{\text{lpf}} ds + 0 + E \int_{\text{rpf}} ds = EA + EA \end{aligned}$$

$$\text{or } \phi = 2EA \quad \dots(\text{ii})$$

But by Gauss's theorem

$$\phi = \frac{q}{\epsilon_0} \quad \dots(\text{iii})$$

where q is the charge in area A of sheet, enclosed by cylindrical surface S .

By equations (ii) and (iii), we get

$$2EA = \frac{q}{\epsilon_0} \quad \text{or } E = \frac{q}{2A \epsilon_0}$$

$$\text{or } E = \frac{\sigma}{2 \epsilon_0}$$

This gives the electric field intensity at any point near or on the surface of the infinite thin plane sheet of charge.

17. A parallel plate capacitor is charged by a battery. After some time the battery is disconnected and a dielectric slab of dielectric constant K is inserted between the plates. How would (i) the capacitance, (ii) the electric field between the plates and (iii) the energy stored in the capacitor, be affected? Justify your answer. [AI 2009]

Ans. (i) On filling the dielectric constant of K in the space between the plates, capacitance of parallel plate capacitor becomes K times *i.e.* $C = KC_0$

(ii) As the battery was disconnected, so the charge on the capacitor remains the same *i.e.* $Q = Q_0$. So, the electric field in the space between the plates becomes $E = \frac{E_0}{KA\epsilon_0} = \frac{Q_0}{KA\epsilon_0}$ or $E = \frac{E_0}{K}$ *i.e.* electric

field becomes $\frac{1}{K}$ times.

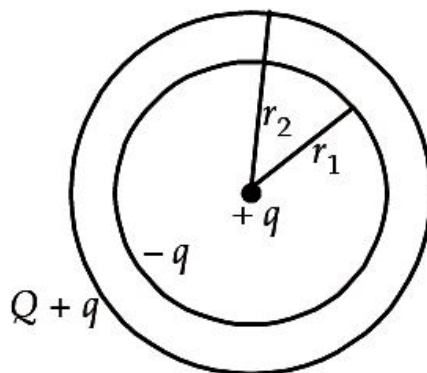
(iii) Energy stored in capacitor becomes $U = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2} \frac{Q_0^2}{KC}$ or $U = \frac{1}{2} U_0$ *i.e.* becomes $\frac{1}{K}$ times.

18. A spherical conducting shell of inner radius r_1 and outer radius r_2 has a charge Q . A charge q is placed at the centre of the shell.

(a) What is the surface charge density on the (i) inner surface, (ii) outer surface of the shell?

(b) Write the expression for the electric field at a point $x > r_2$ from the centre of the shell. [AI 2010]

Ans. (a) (i) Surface charge density on the inner surface of shell is $\sigma_{in} = \frac{-q}{4\pi r_1^2}$



(ii) Surface charge density on the outer surface of shell is $\sigma_{out} = \frac{Q + q}{4\pi r_2^2}$

(b) Using, Gauss's law, $E(x) = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q+q}{x^2}$

19. Explain the meaning of the statement 'electric charge of a body is quantized'.

Ans. The electric charge of a body is quantized means that the charge on a body can occur in some particular values only. Charge on any body is the integral multiple of charge on an electron because the charge of an electron is the elementary charge in nature. The charge on any body can be expressed by the formula

$q = \pm ne$, where, n = number of electrons transferred and e = charge on one electron.

The cause of quantization is that only integral number of electrons can be transferred from one body to other.

20. Why can one ignore quantization of electric charge when dealing with macroscopic, i.e., large scale charges?

Ans. We can ignore the quantization of electric charge when dealing with macroscopic charges because the charge on one electron is 1.6×10^{-19} C in magnitude, which is very small as compared to the large scale change.

21. An electrostatic field line is a continuous curve. That is, a field line cannot have sudden breaks. Why not?

Ans. An electrostatic field line represents the actual path travelled by a unit positive charge in an electric field. If the line have sudden breaks it means the unit positive test charge jumps from one place to another which is not possible. It also means that electric field becomes zero suddenly at the breaks which is not possible. So, the field line cannot have any sudden breaks.

22. Explain why two field lines never cross each other at any point?

Ans. If two field lines cross each other, then we can draw two tangents at the point of intersection which indicates that (as tangent drawn at any point on electric line of force gives the direction of electric field at that point) there are two directions of electric field at a particular point, which is not possible at the same instant. Thus, two field lines never cross each other at any point.

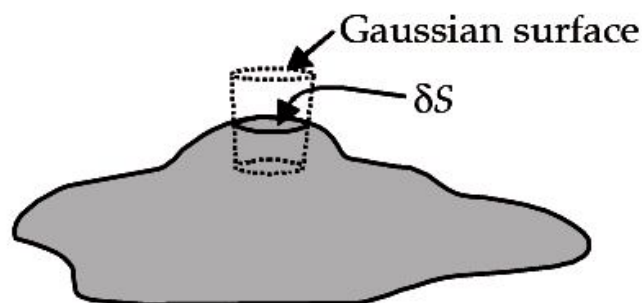
23. Show that the electric field at the surface of a charged conductor is given by $\vec{E} = \frac{\sigma}{\epsilon_0} \hat{n}$ where

σ is the surface charge density and is a unit vector normal to the surface in the outward direction. [AI 2010]

Ans. Consider an elementary area δS on the surface of the charged conductor. Enclose this area element with a cylindrical gaussian surface as shown in figure.

Now electric field inside a charged conductor is zero. Therefore, direction of field, just out side δS will be normally outward i.e. in direction of \hat{n} .

According to Gauss's theorem, total electric flux coming out is



$$\vec{E} \cdot \delta \vec{S} = \frac{\sigma \delta S}{\epsilon_0} \quad [\vec{E} \text{ is electric field at the surface}]$$

$$\Rightarrow E \delta S \cos 0^\circ = \frac{\sigma \delta S}{\epsilon_0}$$

$$\Rightarrow E = \frac{\sigma}{\epsilon_0}$$

24. Using Gauss's law obtain the expression for the electric field due to a uniformly charged thin spherical shell of radius R at a point outside the shell. Draw a graph showing the variation of electric field with r , for $r > R$ and $r < R$. [AI 2011]

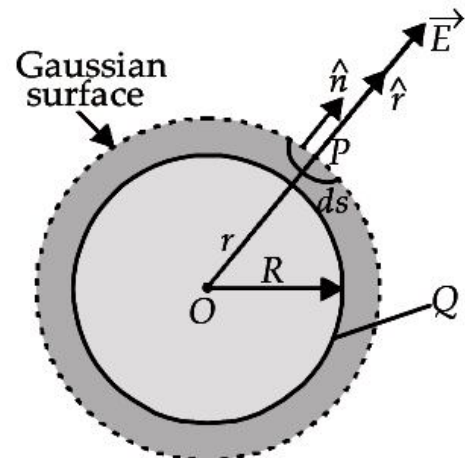
Ans. Consider a thin spherical shell of radius R carrying charge Q . To find the electric field outside the shell, we consider a spherical Gaussian surface of radius $r (> R)$, concentric with given shell.

The electric field \vec{E} is same at every point of Gaussian surface and directed radially outwards (as is unit vector \hat{n} so that $\theta = 0^\circ$)

According to Gauss's theorem, $\oint_s \vec{E} \cdot d\vec{s} = \oint_s \vec{E} \cdot \hat{n} d\vec{s} = \frac{Q}{\epsilon_0}$

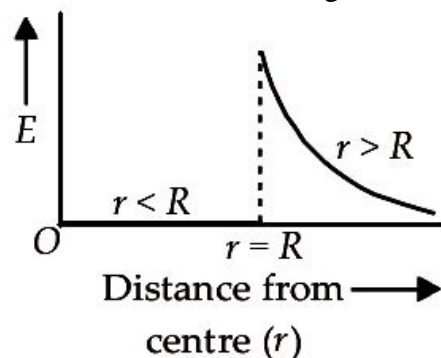
$$\text{or } E \oint_s ds = \frac{Q}{\epsilon_0}$$

$$\therefore E(4\pi r^2) = \frac{Q}{\epsilon_0} \Rightarrow E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$



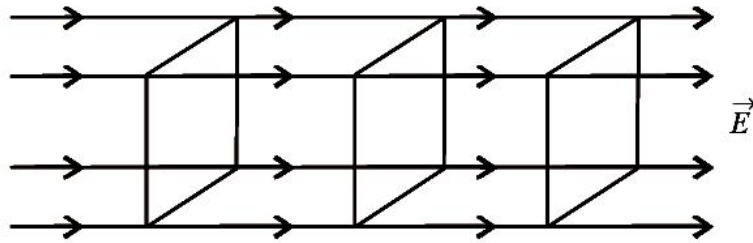
Hence, electric field outside a charged thin spherical shell is the same as if the whole charge Q is concentrated at the centre.

The variation of electric field \vec{E} with distance from centre of a uniformly charged spherical shell is shown in figure.

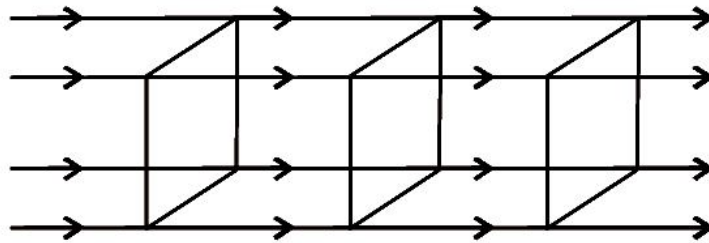


25. Draw 3 equipotential surfaces corresponding to a field that uniformly increases in magnitude but remains constant along Z direction. How are these surfaces different from that of a constant electric field along Z direction? [AI 2009]

Ans. For constant electric field, equipotential surfaces are equidistant for same potential difference between these surfaces. For increasing electric field, separation between equipotential surfaces decreases, in the direction of increasing field, for the same potential difference between them.

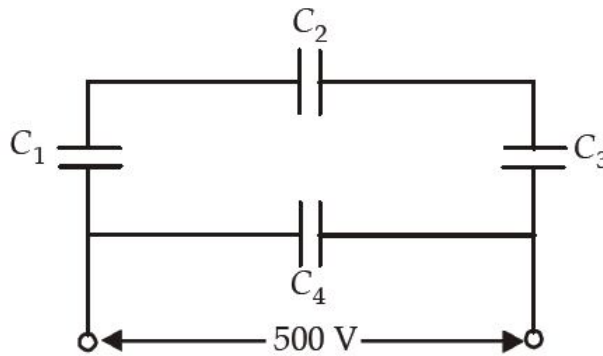


For increasing electric field



For constant electric field

26. A network of four capacitors each of $12 \mu F$ capacitance is connected to a $500 V$ supply as shown in the figure. Determine (a) equivalent capacitance of the network and (b) charge on each capacitor.



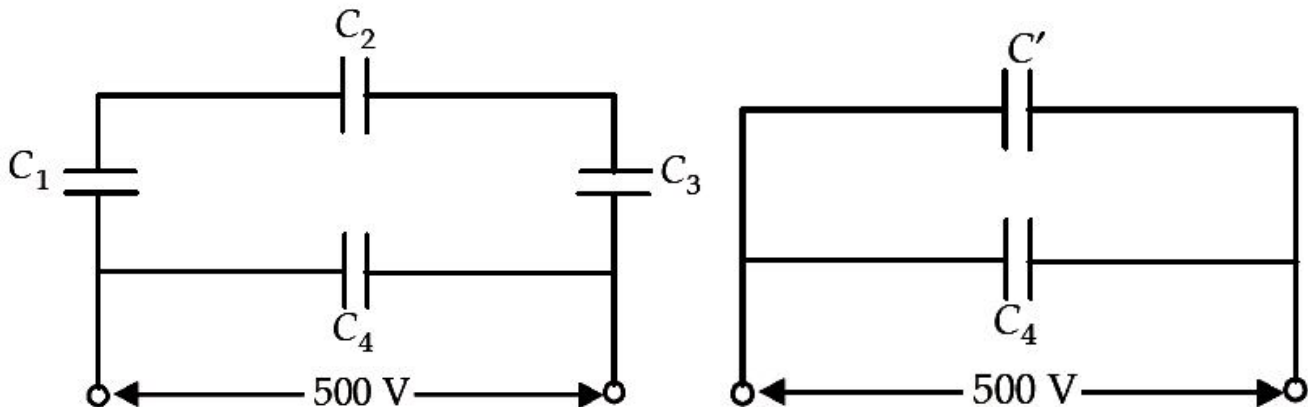
Ans. Here C_1 , C_2 and C_3 are in series, hence their equivalent capacitance is C' given by

$$\frac{1}{C'} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$C' = \frac{12}{3} \mu F \Rightarrow C' = 4 \mu F$$

The circuit can be redrawn as shown, above. Since C' and C_4 are in parallel

$$\therefore C_{net} = C' + C_4 = 4 \mu F + 12 \mu F = 16 \mu F$$



(b) Since C' and C_4 are in parallel, potential difference across both of them is 500 V.

$$\therefore \text{Charge across } C_4 \text{ is } Q_4 = C_4 \times 500 \text{ C}$$

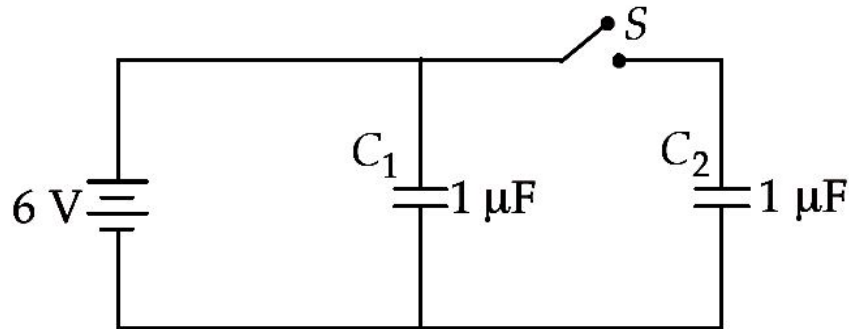
$$= 12 \times 10^{-6} \times 500 \text{ C} = 6 \text{ mC}$$

and Charge across C' , $Q' = C' \times 500 \text{ C}$

$$= 4 \times 10^{-6} \times 500 \text{ C} = 2 \text{ mC}$$

$\therefore C_1, C_2, C_3$ are in series, charge across them is same, which is $Q' = 2 \text{ mC}$

27. Figure shows two identical capacitors C_1 and C_2 , each of $1 \mu\text{F}$ capacitance connected to a battery of 6 V. Initially switch S is closed. After sometime S is left open and dielectric slabs of dielectric constant $K = 3$ are inserted to fill completely the space between the plates of the two capacitors. How will the (i) charge and (ii) potential difference between the plates of the capacitors be affected after the slabs are inserted?



Ans. When the switch S is closed, the two capacitors in parallel will be charged by the same potential difference V .

So, charge on capacitor C_1

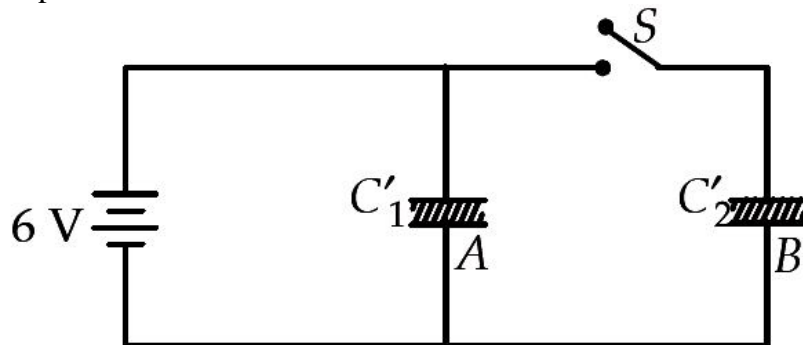
$$q_1 = C_1 V = 1 \times 6 = 6 \text{ mC}$$

and charge on capacitor C_2

$$q_2 = C_2 V = 1 \times 6 = 6 \text{ mC}$$

$$q = q_1 + q_2 = 6 + 6 = 12 \text{ mC.}$$

When switch S is opened and dielectric is introduced. Then



Capacity of both the capacitors becomes K times

$$\text{i.e., } C'_1 = C'_2 = KC = 3 \times 1 = 3 \text{ mF}$$

Capacitor A remains connected to battery

$$\therefore V_1 = V = 6 \text{ V}$$

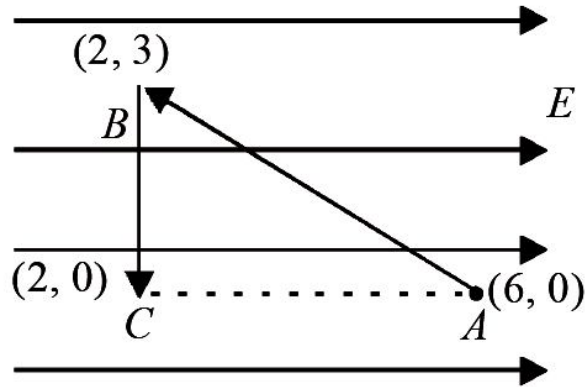
$$q'_1 = Kq = 3 \times 6 \text{ mC} = 18 \text{ mC}$$

Capacitor B becomes isolated

$$\therefore q'_2 = q_2 \text{ or } C'_2 V_2 = C_2 V_2 \text{ or } (KC)V_2 = CV$$

$$V'_2 = \frac{V}{K} = \frac{6}{3} = 2 \text{ V}$$

28. A test charge ' q ' is moved without acceleration from A to C along the path from A to B and then from B to C in electric field E as shown in the figure. (i) Calculate the potential difference between A and C' . (ii) At which point (of the two) is the electric potential more and why? [AI 2012]



Ans. In the relation

$$E = \frac{-dV}{dr} \Rightarrow E = - \left[\frac{V_C - V_A}{(2-6)} \right]$$

(i) $V_C - V_A = 4E$ (ii) Hence $V_C > V_A$

Also electric field is directed from points of high potential to low potential.

29. Deduce the expression for the electrostatic energy stored in a capacitor of capacitance 'C' and having charge 'Q'. How will the (i) energy stored and (ii) the electric field inside the capacitor be affected when it is completely filled with a dielectric material of dielectric constant 'K'? [AI 2012]

Ans. Potential difference between the plates of capacitor $V = \frac{q}{C}$

Work done to add additional charge dq on the capacitor

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

\therefore Total energy stored in the capacitor

$$U = \int dW = \int_0^Q \frac{q}{C} dq = \frac{1}{2} \frac{Q^2}{C}$$

When battery is disconnected

(i) Energy stored will be decreased or energy stored = $\frac{1}{K}$ times the initial energy.

(ii) Electric field would decrease

$$\text{or } E' = \frac{E}{K}$$

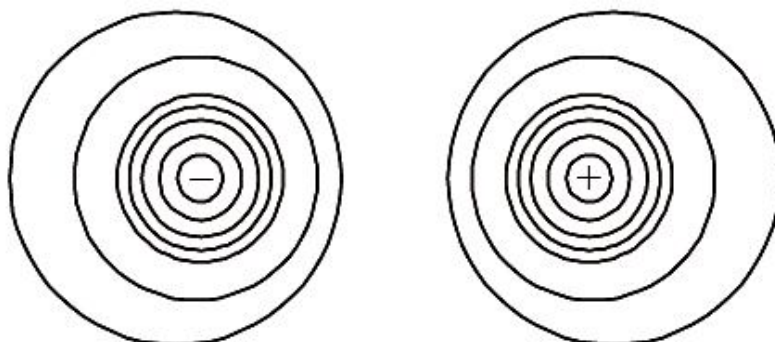
Alternatively, if a student attempts to answer by keeping the battery connected, then

(i) energy stored will increase or become K times the initial energy.

(ii) electric field will not change.

30. Draw the equipotential surfaces due to an electric dipole. Locate the points where the potential due to the dipole is zero.

Ans.



● *A*



● *B*

Alternatively Any point on the equatorial plane (*AB*) of the dipole.

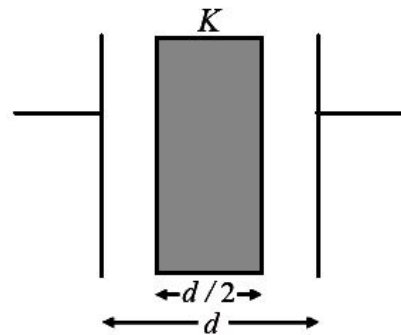
31. A slab of material of dielectric constant K has the same area as that of the plates of a parallel plate capacitor but has the thickness $d/2$, where d is the separation between the plates. Find out the expression for its capacitance when the slab is inserted between the plates of the capacitor. [AI 2013]

Ans.

Capacitance of a capacitor partially filled with a dielectric

$$C = \frac{\epsilon_0 A}{d - t + \frac{t}{K}}$$

$$\Rightarrow C = \frac{\epsilon_0 A}{d - \frac{d}{2} + \frac{d}{2K}} = \frac{2\epsilon_0 AK}{d(K+1)}$$



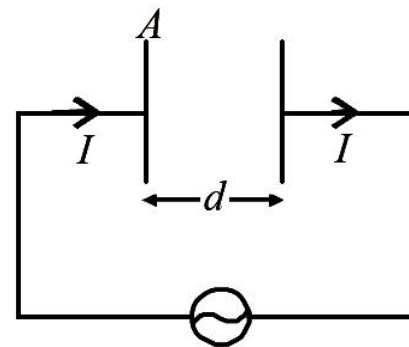
32. A capacitor, made of two parallel plates each of plate area A and separation d , is being charged by an external ac source. Show that the displacement current inside the capacitor is the same as the current charging the capacitor. [AI 2013]

Ans. The displacement current within capacitor plates

$$I_d = \epsilon_0 \frac{d\phi_E}{dt}$$

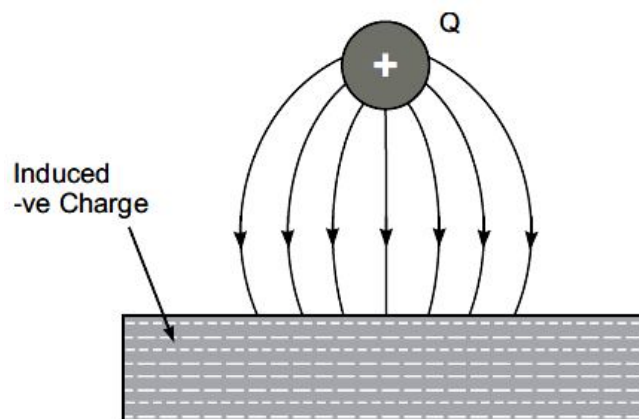
$$\text{where } \phi_E = EA = \frac{q}{A\epsilon_0} A = \frac{q}{\epsilon_0}$$

$$I_d = \frac{\epsilon_0}{\epsilon_0} \frac{dq}{dt} \Rightarrow I_d = I$$



33. A point charge ($+Q$) is kept in the vicinity of uncharged conducting plate. Sketch electric field lines between the charge and the plate.

Ans.



The lines of force start from $+Q$ and terminate at metal plate inducing negative charge on it. The lines of force will be perpendicular to the metal surface.

34. Derive the expression for the electric field of a dipole at a point on the equatorial plane of the dipole.

Ans. It is the product of magnitude of either charge and the distance between the two equal and opposite charges. Alternatively,

$$\vec{p} = q2a\hat{a}$$

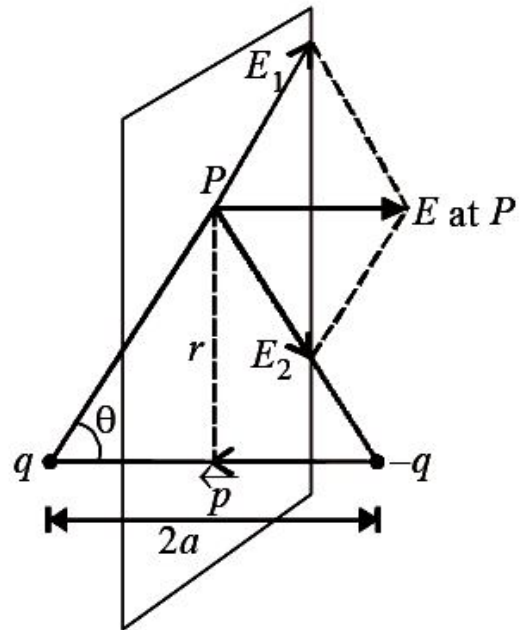
It is a vector quantity.

$$E = E_1 \cos \theta + E_1 \cos \theta = 2E_1 \cos \theta$$

$$E = \frac{2}{4\pi\epsilon_0} \frac{q}{(r^2 + a^2)} \cdot \frac{a}{(r^2 + a^2)^{1/2}}$$

$$E = \frac{2}{4\pi\epsilon_0} \frac{qa}{(r^2 + a^2)^{3/2}} = \frac{1}{4\pi\epsilon_0} \frac{2qa}{(r^2 + a^2)^{3/2}}$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{p}{(r^2 + a^2)^{3/2}} \text{ where } p = 2qa$$



35. Using Gauss' law deduce the expression for the electric field due to a uniformly charged spherical conducting shell of radius R at a point (i) outside and (ii) inside the shell. Plot a graph showing variation of electric field as a function of $r > R$ and $r < R$. (r being the distance from the centre of the shell)

Ans.

By Gauss Law, $r > R$ (outside)

$$\oint \vec{E} \cdot d\vec{S} = \frac{q}{\epsilon_0}$$

$$\Rightarrow E \oint d\vec{S} = \frac{q}{\epsilon_0}$$

$$\Rightarrow E4\pi r^2 = \frac{q}{\epsilon_0} \Rightarrow E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$$

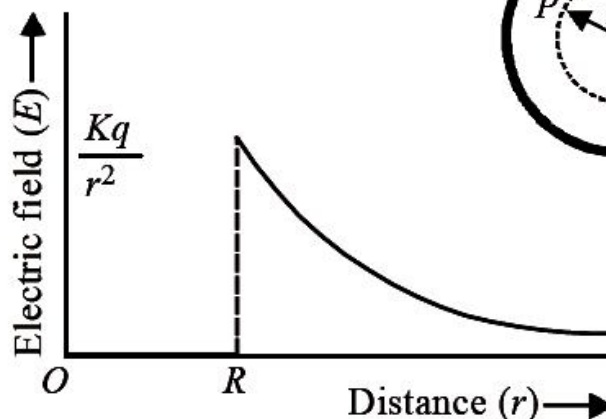
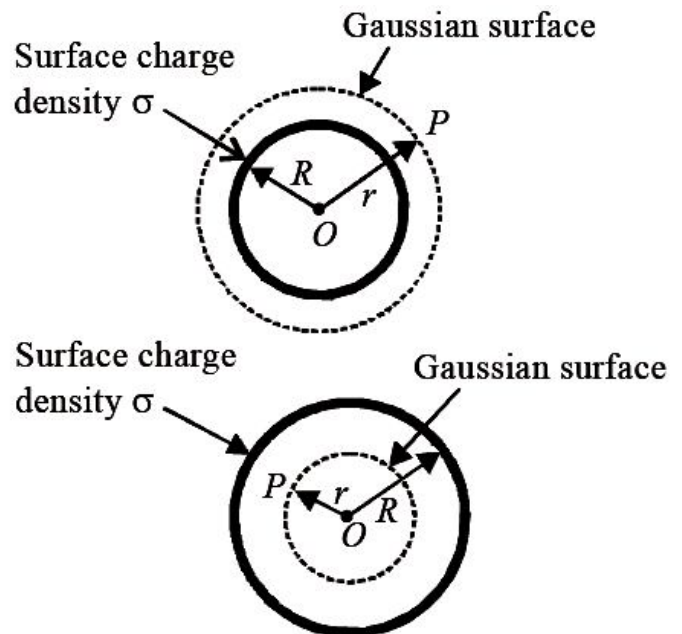
Similarly, $r < R$ (inside)

$$E \oint d\vec{S} = \frac{q}{\epsilon_0}$$

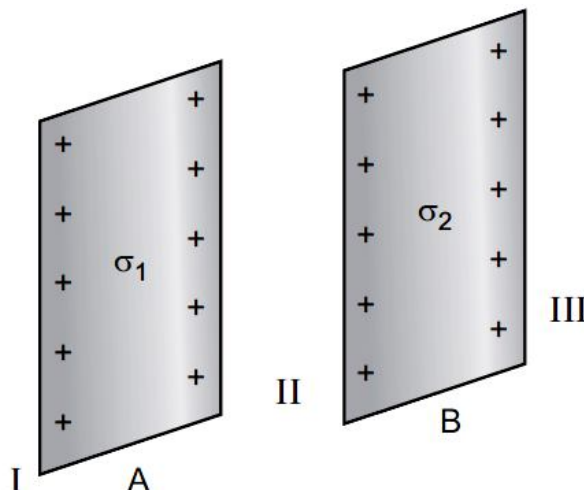
As inside the shell $q = 0$

$$\therefore E4\pi R^2 = 0$$

As $R \neq 0$, $E = 0$



36. Two infinitely large plane thin parallel sheets having surface charge densities σ_1 and σ_2 ($\sigma_1 > \sigma_2$) are shown in the figure. Write the magnitudes and directions of the net fields in the regions marked II and III.



Ans. (i) Net electric field in region II = $\frac{1}{2\epsilon_0}(\sigma_1 - \sigma_2)$

Direction of electric field is from sheet A to sheet B.

(ii) Net electric field in region III = $\frac{1}{2\epsilon_0}(\sigma_1 + \sigma_2)$

Direction is away from the two sheets i.e. towards right side.

37. In a parallel plate capacitor with air between the plates, each plate has an area of $6 \times 10^{-3} \text{ m}^2$ and the separation between the plates is 3 mm.

(i) Calculate the capacitance of the capacitor.

(ii) If this capacitor is connected to 100 V supply, what would be the charge on each plate?

(iii) How would charge on the plates be affected, if a 3 mm thick mica sheet of $K = 6$ is inserted between the plates while the voltage supply remains connected?

Ans. Here, $A = 6 \times 10^{-3} \text{ m}^2$, $d = 3 \text{ mm} = 3 \times 10^{-3} \text{ m}$

(i) Capacitance, $C = \frac{\epsilon_0 A}{d} = \frac{8.85 \times 10^{-12} \times 6 \times 10^{-3}}{3 \times 10^{-3}} = 17.7 \times 10^{-12} \text{ F}$

(ii) Charge, $Q = CV = 17.7 \times 10^{-12} \times 100 \text{ C} = 17.7 \times 10^{-10} \text{ C}$

(iii) New charge, $Q' = KQ = 6 \times 17.7 \times 10^{-10} \text{ C} = 106.2 \times 10^{-10} \text{ C}$

38. In a parallel plate capacitor with air between the plates, each plate has an area of $5 \times 10^{-3} \text{ m}^2$ and the separation between the plates is 2.5 mm.

(i) Calculate the capacitance of the capacitor.

(ii) If this capacitor is connected to 100 V supply, what would be the charge on each plate?

(iii) How would charge on the plates be affected, if a 2.5 mm thick mica sheet of $K = 8$ is inserted between the plates while the voltage supply remains connected?

Ans. Here, $A = 5 \times 10^{-3} \text{ m}^2$, $d = 2.5 \text{ mm} = 2.5 \times 10^{-3} \text{ m}$

(i) Capacitance, $C = \frac{\epsilon_0 A}{d} = \frac{8.85 \times 10^{-12} \times 5 \times 10^{-3}}{2.5 \times 10^{-3}} = 17.7 \times 10^{-12} \text{ F}$

(ii) Charge, $Q = CV = 17.7 \times 10^{-12} \times 100 \text{ C} = 17.7 \times 10^{-10} \text{ C}$

(iii) New charge, $Q' = KQ = 8 \times 17.7 \times 10^{-10} \text{ C} = 141.6 \times 10^{-10} \text{ C}$

39. Two equal balls having equal positive charge 'q' coulombs are suspended by two insulating strings of equal length. What would be the effect on the force when a plastic sheet is inserted between the two?

Ans. Force will decrease.

Reason: Force between two charges each 'q' in vacuum is

$$F_0 = \frac{1}{4\pi\epsilon_0} \cdot \frac{q^2}{r^2}$$

On inserting a plastic sheet (a dielectric $K > 1$)

Then $F = \frac{1}{4\pi\epsilon_0 K} \cdot \frac{q^2}{r^2}$ i.e. Force $F = \frac{F_0}{K}$

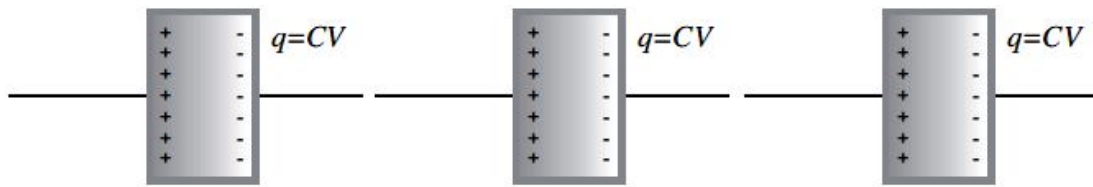
The force between charged balls will decrease.

40. A parallel plate capacitor of capacitance C is charged to a potential V. It is then connected to another uncharged capacitor having the same capacitance. Find out the ratio of the energy stored in the combined system to that stored initially in the single capacitor.

Ans. The charge on the capacitor $q = CV$ and initial energy stored in the capacitor

$$U_1 = \frac{1}{2} \frac{q^2}{C} = \frac{1}{2} CV^2 \quad \text{----- (i)}$$

(a) If another uncharged capacitor is connected in series then the same amount of the charge will transfer as shown in figure.



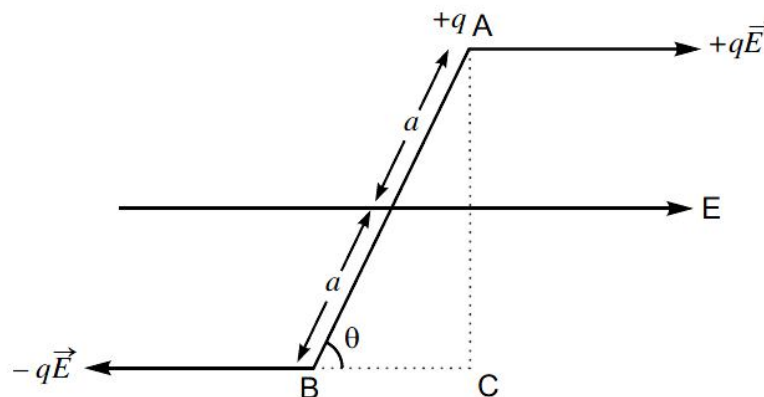
Keeping charge constant, and final voltage $v \square \square 2v$

$$U_f = \frac{1}{2} \frac{q^2}{C} + \frac{1}{2} \frac{q^2}{C} = \frac{q^2}{C}$$

$$U_f : U_i = \frac{q^2}{C} : \frac{q^2}{2C} = 2 : 1$$

41. Deduce the expression for the torque acting on a dipole of dipole moment \vec{p} in the presence of a uniform electric field \vec{E} .

Ans. Expression for torque



An electric dipole having charges $\pm q$, and of size $2a$ is placed in uniform electric field \vec{E} as shown in figure. The forces, acting on the charges are $+q\vec{E}$ and $-q\vec{E}$.

The net force on the dipole is $\vec{F} = +q\vec{E} + (-q\vec{E}) = 0$

Both forces provides an equivalent torque with magnitude

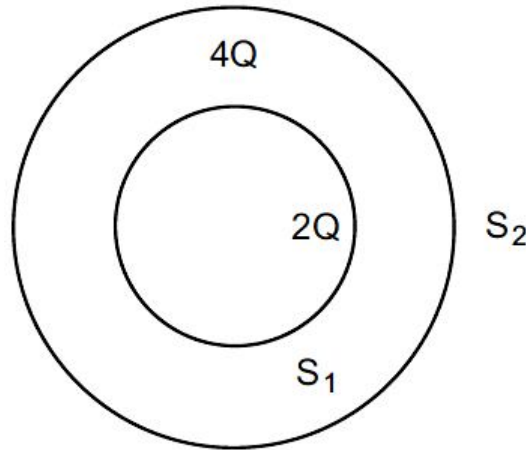
$$t = |qE| \times \text{Perpendicular distance (AC)}$$

$$= q |E| \cdot 2a \sin \theta$$

$$= |P| |E| \sin \theta$$

The direction of the torque can be given by $\vec{\tau} = \vec{p} \times \vec{E}$

42. Consider two hollow concentric spheres, S_1 and S_2 , enclosing charges $2Q$ and $4Q$ respectively as shown in the figure. (i) Find out the ratio of the electric flux through them. (ii) How will the electric flux through the sphere S_1 change if a medium of dielectric constant ' ϵ_r ' is introduced in the space inside S_1 in place of air? Deduce the necessary expression.



Ans. Using Gauss's Theorem $\oint \vec{E} \cdot d\vec{s} = \frac{q(T)}{\epsilon_0}$

$$\text{Electric flux through sphere } S_1 = \phi_1 = \frac{2(q)}{\epsilon_0}$$

$$\text{Electric flux through sphere } S_2 = \phi = \frac{(2Q + 4Q)}{\epsilon_0} = \frac{6Q}{\epsilon_0}$$

$$\text{Ratio} = \frac{\phi_1}{\phi} = \frac{\frac{2Q}{\epsilon_0}}{\frac{6Q}{\epsilon_0}} = \frac{1}{3}$$

If a medium of dielectric constant $K(=\epsilon_r)$ is filled in the sphere S_1 , electric flux through

$$\text{sphere, } \phi'_1 = \frac{2Q}{\epsilon_r \epsilon_0} = \frac{2Q}{K \epsilon_0}$$

43. "For any charge configuration, equipotential surface through a point is normal to the electric field." Justify.

Ans. The work done in moving a charge from one point to another on an equipotential surface is zero. If electric field is not normal to the equipotential surface, it would have non-zero component along the surface. In that case work would be done in moving a charge on an equipotential surface.

44. An electric dipole of length 4 cm, when placed with its axis making an angle of 60° with a uniform electric field, experiences a torque of $4\sqrt{3}$ Nm. Calculate the potential energy of the dipole, if it has charge ± 8 nC.

Ans. Torque, $t = pE \sin \theta$

$$4\sqrt{3} = pE \sin 60^\circ$$

$$4\sqrt{3} = pE \times \frac{\sqrt{3}}{2} \Rightarrow pE = 8$$

Now, potential energy, $U = -pE \cos \theta = -8 \cos 60^\circ = -8 \cdot \frac{1}{2} = -4 \text{ J}$

45. Given a uniform electric field $\vec{E} = 5 \times 10^3 \hat{i} \text{ N/C}$, find the flux of this field through a square of 10 cm on a side whose plane is parallel to the y - z plane. What would be the flux through the same square if the plane makes a 30° angle with the x -axis?

Ans. Here, $\vec{E} = 5 \times 10^3 \hat{i} \text{ N/C}$, i.e. field is along positive direction of x -axis.
Surface area, $A = 10 \text{ cm} \times 10 \text{ cm} = 0.10 \text{ m} \times 0.10 \text{ m} = 10^{-2} \text{ m}^2$

(i) When plane parallel to $y - z$ plane, the normal to plane is along x axis. Hence

$$\theta = 0^\circ$$

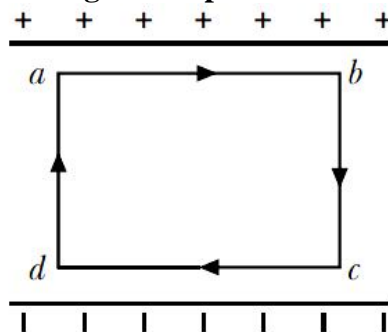
$$\phi = EA \cos \theta = 5 \times 10^3 \times 10^{-2} \cos 0^\circ = 50 \text{ NC}^{-1} \text{ m}^2$$

(ii) When the plane makes a 30° angle with the x -axis, the normal to its plane makes 60° angle with x -axis. Hence

$$\theta = 60^\circ$$

$$\phi = EA \cos \theta = 5 \times 10^3 \times 10^{-2} \cos 60^\circ = 25 \text{ NC}^{-1} \text{ m}^2$$

46. The electric field inside a parallel plate capacitor is E . Find the amount of work done in moving a charge q over a closed rectangular loop $abcd$.



Ans. Work done in moving a charge q from a to $b = 0$

Work done in moving a charge q from c to $d = 0$

This is because the electric field is perpendicular to the displacement.

Now, work done from b to $c = -$ work done from d to a

Therefore, total work done in moving a charge q over a closed loop = 0.

47. Obtain the expression for the energy stored per unit volume in a charged parallel plate capacitor.

Ans. When a capacitor is charged by a battery, work is done by the charging battery at the expense of its chemical energy. This work is stored in the capacitor in the form of electrostatic potential energy.

Consider a capacitor of capacitance C . Initial charge on capacitor is zero. Initial potential difference between capacitor plates = zero. Let a charge Q be given to it in small steps. When charge is given to capacitor, the potential difference between its plates increases. Let at any instant when charge on

capacitor be q , the potential difference between its plates $V = \frac{q}{C}$

Now work done in giving an additional infinitesimal charge dq to capacitor

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

The total work done in giving charge from 0 to Q will be equal to the sum of all such infinitesimal works, which may be obtained by integration. Therefore total work

$$W = \int_0^Q V dq = \int_0^Q \frac{q}{C} dq = \frac{1}{C} \left[\frac{q^2}{2} \right]_0^Q = \frac{1}{C} \left(\frac{Q^2}{2} - 0 \right) = \frac{Q^2}{2C}$$

If V is the final potential difference between capacitor plates, then $Q = CV$

$$W = \frac{(CV)^2}{2C} = \frac{1}{2} CV^2 = \frac{1}{2} QV$$

This work is stored as electrostatic potential energy of capacitor *i.e.*,

$$\text{Electrostatic potential energy, } U = \frac{Q^2}{2C} = \frac{1}{2} CV^2 = \frac{1}{2} QV$$

Energy density: Consider a parallel plate capacitor consisting of plates, each of area A , separated by a distance d . If space between the plates is filled with a medium of dielectric constant K , then

$$\text{Capacitance of capacitor, } C = \frac{K\epsilon_0 A}{d}$$

If σ is the surface charge density of plates, then electric field strength between the plates

$$E = \frac{\sigma}{K\epsilon_0} \Rightarrow \sigma = K\epsilon_0 E$$

Charge on each plate of capacitor $Q = \sigma A = K\epsilon_0 EA$

$$\therefore \text{Energy stored by capacitor, } U = \frac{Q^2}{2C} = \frac{(K\epsilon_0 EA)^2}{2 \left(\frac{K\epsilon_0 A}{d} \right)} = \frac{1}{2} K\epsilon_0 E^2 Ad$$

But $Ad =$ volume of space between capacitor plates

$$\therefore \text{Energy stored, } U = \frac{1}{2} K\epsilon_0 E^2 Ad$$

$$\text{Electrostatic Energy stored per unit volume, } u_e = \frac{U}{Ad} = \frac{1}{2} K\epsilon_0 E^2$$

This is expression for electrostatic energy density in medium of dielectric constant K .

$$\text{In air or free space } (K = 1), \text{ therefore energy density, } u_e = \frac{1}{2} \epsilon_0 E^2$$

48. Two charged spherical conductors of radii R_1 and R_2 when connected by a conducting wire acquire charges q_1 and q_2 respectively. Find the ratio of their surface charge densities in terms of their radii.

Ans. When two charged spherical conductors are connected by a conducting wire, they acquire the same potential.

$$\frac{kq_1}{R_1} = \frac{kq_2}{R_2}$$

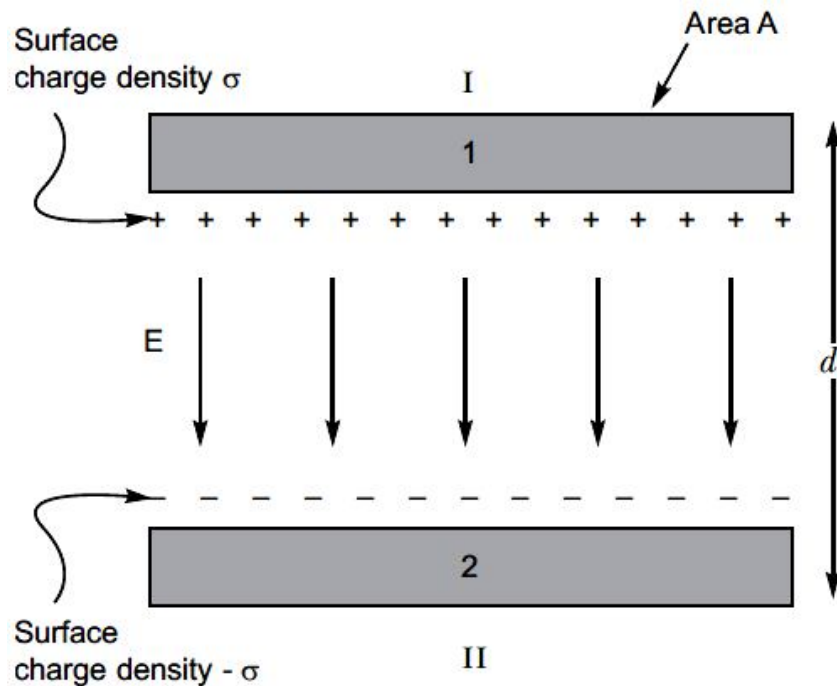
$$\Rightarrow \frac{q_1}{R_1} = \frac{q_2}{R_2} \Rightarrow \frac{q_1}{q_2} = \frac{R_1}{R_2}$$

Hence, the ratio of surface charge densities

$$\frac{\sigma_1}{\sigma_2} = \frac{\frac{q_1}{4\pi R_1^2}}{\frac{q_2}{4\pi R_2^2}} = \frac{q_1 R_2^2}{q_2 R_1^2}$$

49. Derive the expression for the capacitance of a parallel plate capacitor having plate area A and plate separation d .

Ans.



In the region between the plates the net electric field is equal to the sum of the electric fields due to the two charged plates. Thus, the net electric field is given by

$$E = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0} = \frac{\sigma}{\epsilon_0}$$

The electric field is constant in the region between the plates. Therefore, the potential difference between the plates will be

$$V = Ed = \frac{\sigma d}{\epsilon_0}$$

Now, capacitance $C = \frac{Q}{V} = \frac{Q\epsilon_0}{\sigma d}$

Surface charge density $\sigma = \frac{Q}{A}$, where A is the area of cross-section of the plates.

$$C = \frac{Q\epsilon_0 A}{Qd} = \frac{\epsilon_0 A}{d}$$

$$\Rightarrow \frac{\sigma_1}{\sigma_2} = \frac{R_1}{R_2} \times \frac{R_2^2}{R_1^2} = \frac{R_2}{R_1}$$

50. Derive an expression for the energy stored in a parallel plate capacitor. On charging a parallel plate capacitor to a potential V, the spacing between the plates is halved, and a dielectric medium of $E_r = 10$ is introduced between the plates, without disconnecting the d.c. source. Explain, using suitable expressions, how the

- (i) capacitance,
- (ii) electric field and
- (iii) energy density of the capacitor change.

Ans.

$$(i) C = \frac{k\epsilon_0 A}{\frac{d}{2}} = \frac{2k\epsilon_0 A}{d} = 2kC_0 = 2 \times 10C_0$$

$$\Rightarrow C = 20C_0$$

(ii) As battery remains connected so, potential difference V remains same across the capacitor.

$$\therefore E = \frac{V}{\frac{d}{2}} = \frac{2V}{d} \Rightarrow E = 2E_0$$

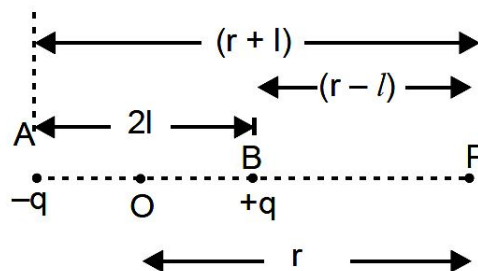
(iii) Initial energy density = $\frac{1}{2} \epsilon_0 E_0^2$

Final energy density = $\frac{1}{2} \epsilon_0 E^2$
 $= \frac{1}{2} \epsilon_0 (2E_0)^2 = 4 \times \frac{1}{2} \epsilon_0 E_0^2$

or Final energy density = 4 Initial energy density.

51. Derive the expression for the electric potential at any point along the axial line of an electric dipole ?

Ans. Electric Potential due to an electric dipole at axial point. Consider an electric dipole AB , having charges $-q$ and $+q$ at points A and B respectively. The separation between the charges is $2l$.



Electric dipole moment, $\vec{p} = q \cdot 2l$, directed from $-q$ to $+q$.

Consider a point P on the axis of dipole at a distance r from mid-point O of dipole.

The distance of point P from charge $+q$ is $BP = r - l$

The distance of point P from charge $-q$ is $AP = r + l$

Let V_1 and V_2 be the potentials at P due to charges $+q$ and $-q$ respectively. Then

$$V_1 = \frac{1}{4\pi\epsilon_0} \frac{q}{(r-l)} \text{ and } V_2 = \frac{1}{4\pi\epsilon_0} \frac{-q}{(r+l)}$$

\therefore Resultant potential at P due to dipole

$$V = V_1 + V_2 = \frac{1}{4\pi\epsilon_0} \frac{q}{(r-l)} + \frac{1}{4\pi\epsilon_0} \frac{-q}{(r+l)}$$

$$\Rightarrow V = \frac{q}{4\pi\epsilon_0} \left[\frac{1}{(r-l)} - \frac{1}{(r+l)} \right] = \frac{q}{4\pi\epsilon_0} \left[\frac{(r+l) - (r-l)}{(r-l)(r+l)} \right]$$

$$\Rightarrow V = \frac{1}{4\pi\epsilon_0} \frac{q \cdot 2l}{(r^2 - l^2)}$$

As $q \cdot 2l = p$ (dipole moment)

$$\therefore V = \frac{1}{4\pi\epsilon_0} \frac{p}{(r^2 - l^2)}$$

If point P is far away from the dipole, then $r \gg l$

$$\therefore V = \frac{1}{4\pi\epsilon_0} \frac{p}{r^2}$$

CURRENT ELECTRICITY

CURRENT ELECTRICITY

MARKS WEIGHTAGE – 7 marks

QUICK REVISION (Important Concepts & Formulas)

Electric current

The current is defined as the rate of flow of charges across any cross sectional area of a conductor. If a net charge q passes through any cross section of a conductor in time t , then the current is given by

$$I = \frac{q}{t}, \text{ where } q \text{ is in coulomb and } t \text{ is in second.}$$

The S.I unit of current is called **ampere** (A) (coulomb/second).

If the rate of flow of charge is not uniform, the current varies with time and the instantaneous value of current I is given by $I = \frac{dq}{dt}$

Current is a scalar quantity. The direction of conventional current is taken as the direction of flow of positive charges or opposite to the direction of flow of electrons.

Electromotive force The emf (e) of the source is defined as the work done per unit charge in taking a positive charge through the seat of the emf from the low potential end to the high potential end. Thus,

$$e = \frac{W}{Q}.$$

When no current flows, the emf of the source is exactly equal to the potential difference between its ends. The unit of emf is the same as that of potential, i.e. volt.

The average flow of electrons in the conductor not connected to battery is zero *i.e.* the number of free electrons crossing any section of the conductor from left to right is equal to the number of electrons crossing the section from right to left. Thus no current flows through the conductor until it is connected to the battery.

Drift velocity of free electrons in a metallic conductor In the absence of an electric field, the free electrons in a metal move randomly in all directions and therefore their average velocity is zero. When an electric field is applied, they are accelerated opposite to the direction of the field and therefore they have a net drift in that direction. However, due to frequent collisions with the atoms, their average velocity is very small. This average velocity with which the electrons move in a conductor under a potential difference is called the **drift velocity**.

If E is the applied field, e is the charge of an electron, m is the mass of an electron and t is the time interval between successive collisions (relaxation time), then the acceleration of the electron is $a = \frac{eE}{m}$.

Since the average velocity just after a collision is zero and just before the next collision, it is $a\tau$, the drift velocity must be

$$v_d = \frac{eE}{m}\tau$$

If I is the current through the conductor and n is the number of free electrons per unit volume, then it can be shown that $I = nAev_d$.

The **mobility** μ of a charge carrier is defined as the drift velocity per unit electric field.

$$\mu = \frac{v_d}{E}$$

Current density (J)

(i) $J = \frac{I}{\text{area}} = nev_d$

(ii) S.I. unit of $J = \text{Am}^{-2}$.

(iii) Current density is a vector quantity. Its direction is that of the flow of positive charge at the given point inside the conductor.

(iv) Dimensions of current density = $[\text{M}^0\text{L}^{-2}\text{T}^0\text{A}^1]$.

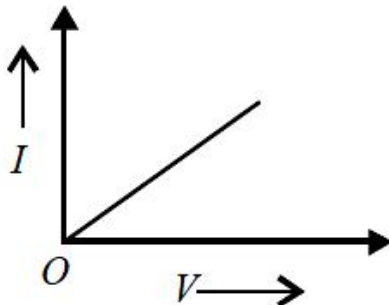
Current carriers: The current is carried by electrons in conductors, ions in electrolytes and electrons and holes in semiconductors.

Ohm's law Physical conditions (such as temperature) remaining unchanged, the current flowing through a conductor is proportional to the potential difference across its ends.

i.e. $V \propto I$ or $V = RI$.

The constant of proportionality R is called the resistance of the conductor. This law holds for metallic conductors.

According to Ohm's law, the graph between V and I is a straight line. Ohm's law is not valid for semiconductors, electrolytes and electronic devices etc. These are called non-ohmic or non-linear conductors.



The **resistance** of a conductor is a measure of the opposition offered by the conductor to the flow of current. This opposition is due to frequent collision of the electrons with the atoms of the conductor.

The resistance of a conductor is directly proportional to its length l and inversely proportional to the area of cross section A

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

where the constant ρ depends on the nature of the material. It is called the **resistivity** (or specific resistance) of the material. The S.I. unit of resistance is ohm (Ω) and resistivity is ohm-metre (Ωm).

The resistivity of material of a conductor is given by $\rho = \frac{m}{ne^2\tau}$

where n is number of free electrons per unit volume and τ is the relaxation time of the free electron. Its value depends on the nature of the material of the conductor and its temperature.

The inverse of resistance is called **conductance** G

$$G = \frac{1}{R}$$

Its S.I. unit Ω^{-1} is called **siemens** (S).

The inverse of resistivity is called **conductivity**, σ .

$$\sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m}$$

Its S.I. unit is $\Omega^{-1}m^{-1}$ or Sm^{-1} or $mho.m^{-1}$.

The value of specific resistance or resistivity is low for metals, more for semiconductors and still greater for alloys like nichrome and manganin.

Magnetic field applied to metals increases the resistivity/specific resistance of material.

The exceptions are ferromagnetic materials like iron, cobalt and nickel wherein the resistivity decreases when magnetic field is applied.

Variation of resistivity of metals with temperature : If ρ_0 and ρ_t are the values of resistivities at $0^\circ C$ and $t^\circ C$ respectively then over a temperature range that is not too large, we have approximately,

$$\rho_t = \rho_0(1 + \alpha t)$$

where α is called the **temperature coefficient of resistivity** of the material.

Temperature coefficient of resistance (a)

(i) If R_2 and R_1 represent resistances at temperatures $t_2^\circ C$ and $t_1^\circ C$, $\alpha = \frac{R_2 - R_1}{R_1(t_2 - t_1)}$

(ii) For metals, α is positive.

(iii) For semiconductors, α is negative.

(iv) For insulators, α is negative.

(v) For some alloys like nichrome, manganin and constantan, α is very low.

Non-Ohmic resistances

(i) Ohm's law does not hold good for some substances and conductors. These are called non-ohmic resistances.

(ii) Some examples are vacuum tubes (diode, triode), semiconductor diode, liquid electrolyte, transistor.

Superconductors A number of materials have the property that below a certain critical temperature, which is very close to absolute zero (0.1 K to 20 K), their resistivity suddenly drops to zero. Such a material is called a superconductor. A current once established in a superconductor continues for a long time without any driving field.

(i) Super conductors are those materials which offer almost zero resistance to the flow of current through them.

(ii) Some known examples are mercury at 4.2 K, lead at 7.25 K and niobium at 9.2 K.

(iii) Specific resistance of super conductor \approx zero.

(iv) Specific conductance of super conductor \approx infinite.

(v) Temperature coefficient of resistance \approx zero.

Applications of superconductors

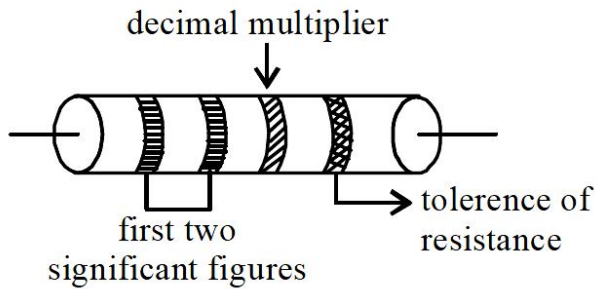
(i) Superconductors form the basis of energy saving power systems, namely the superconducting generators, which are smaller in size and weight, in comparison with conventional generators.

(ii) Superconducting magnets have been used to levitate trains above its rails. They can be driven at high speed with minimal expenditure of energy.

(iii) Superconducting magnetic propulsion systems may be used to launch satellites into orbits directly from the earth without the use of rockets.

- (iv) High efficiency ore-separating machines may be built using superconducting magnets which can be used to separate tumor cells from healthy cells by high gradient magnetic separation method.
- (v) Since the current in a superconducting wire can flow without any change in magnitude, it can be used for transmission lines.
- (vi) Superconductors can be used as memory or storage elements in computers.

The value of resistances used in electric and electronic circuit vary over a very wide range. Such high resistances used are usually carbon resistances and the values of such resistance are marked on them according to a **colour code**.



Colour	Figure
black	0
brown	1
red	2
orange	3
yellow	4
green	5
blue	6
violet	7
grey	8
white	9

Colour	tolerance
gold	5%
silver	10%
no colour	20%

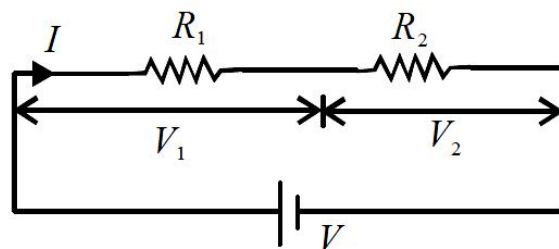
For resistances in series, $R_{eq} = R_1 + R_2$

In general, for n resistors in series, $R_{eq} = \sum_{i=1}^n R_i$

If $R_1 = R_2 = \dots R_n = R$, then $R_{eq} = nR$.

In case of resistances in series, $\frac{V_1}{V_2} = \frac{R_1}{R_2}$

$V_1 = \frac{VR_1}{R_1 + R_2}$; $V_2 = \frac{VR_2}{R_1 + R_2}$ as the current is the same.



In series combination of resistors,

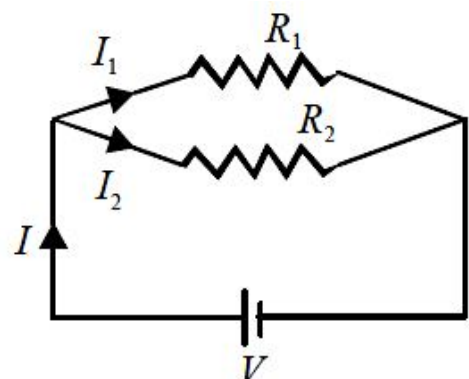
- (i) current through all the resistors is same
- (ii) potential difference across a resistor is proportional to its resistance.
- (iii) The equivalent resistance is greater than the greatest of the resistances connected in series.

For resistances in parallel,

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} \text{ or } R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

In general, for n resistors in parallel

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}$$



If $R_1 = R_2 = \dots = R_n = R$, then $R_{eq} = \frac{R}{n}$.

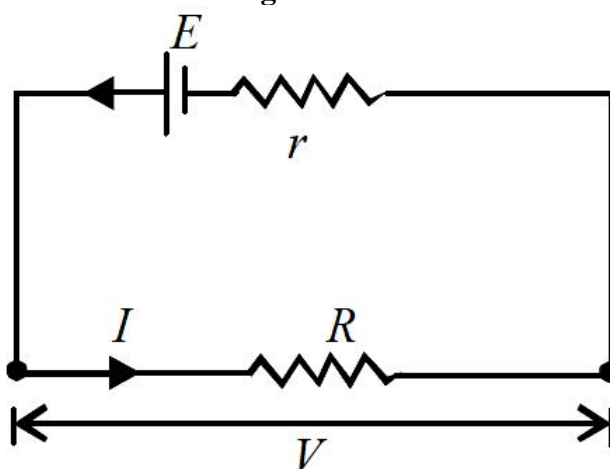
In parallel combination of resistors,

- (i) potential difference across all of them is same
- (ii) current through any resistance is inversely proportional to its resistance.
- (iii) The equivalent resistance is less than the smallest of the resistances connected in parallel.

In case of resistances in parallel, $\frac{I_1}{I_2} = \frac{R_2}{R_1}$

- Acid and alkali accumulators or storage cells are the secondary cells which have a low internal resistance. Hence a large current can be drawn from such cells. These can be charged and used again and again.
- Acid accumulators have large e.m.f. but are delicate.
- Alkali accumulators have low e.m.f. but are robust.

Internal resistance of a cell and terminal voltage



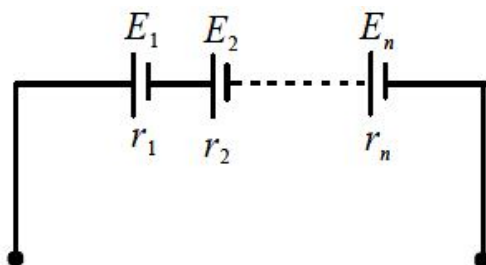
The resistance offered by the electrolyte to the flow of current through the cell is called the *internal resistance* of the cell.

$$V = E - Ir.$$

V is called the **terminal voltage**. If $I = 0$ then $V = E$.

When a cell is charged by an external source V , then $V = E + Ir$.

Cells in series :



If n cells having emfs E_1, E_2, \dots, E_n and internal resistances r_1, r_2, \dots, r_n are connected in series as shown, then

$$E_{eq} = E_1 + E_2 + \dots + E_n.$$

$$\text{and } r_{eq} = r_1 + r_2 + \dots + r_n$$

In particular, if $E_1 = E_2 = \dots = E_n = E$ and $r_1 = r_2 = \dots = r_n = r$, then $E_{eq} = nE$ and $r_{eq} = nr$.

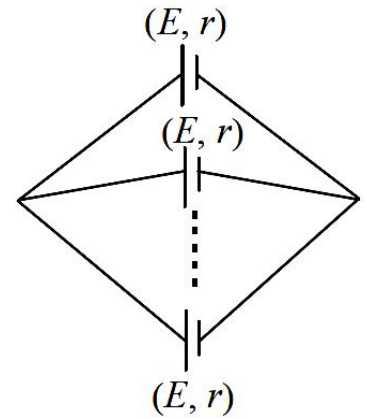
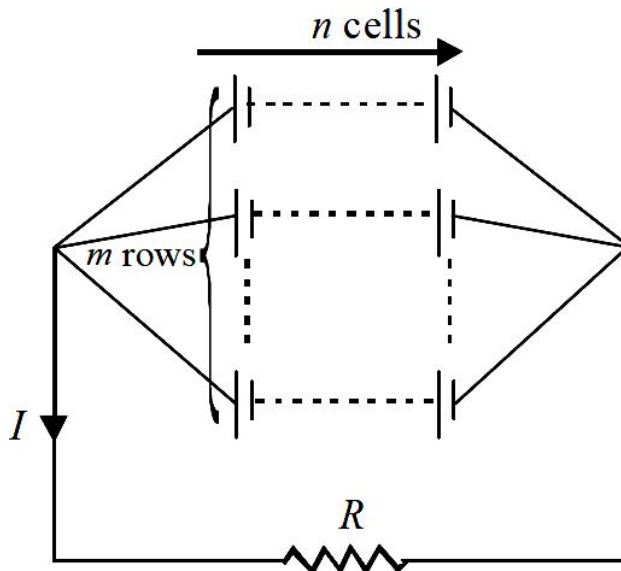
Cells in parallel :

If n cells, each of emf E and internal resistance r are connected in parallel as shown, then

$$E_{eq} = E \text{ and } r_{eq} = \frac{r}{n}$$

If the emfs of the cells are not all equal then we have to use Kirchoff's rules.

Mixed combination of cells : Consider a combination of cells having m rows, each row having n cells. Let the emf of each cell be E and its internal resistance be r .



We have $E_{eq} = nE$, and $r_{eq} = \frac{nr}{m}$, $I = \frac{nE}{R + \frac{nr}{m}} = \frac{mnE}{mR + nr}$

It can be shown that for I to be maximum, $mR = nr$.

Cells are grouped in series if $R \gg r$.

Cells are grouped in parallel if $r \gg R$.

In a mixed grouping of cell, maximum current is available if the total internal resistance of battery is

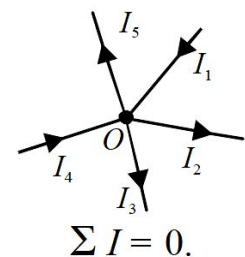
equal to external resistance. $R = \frac{nr}{m}$ (m rows of n cells each)

Inside the cell, the current flows from negative plate to positive plate while outside the cell from positive plate to negative plate. But during charging of cell, this direction is reversed.

When the cell is charged, then potential difference across the two plates (V) is greater than e.m.f. of cell. $V > E$

In open circuit when no current is drawn from a cell, $V = E$.

When current is drawn from a cell, $V < E$.



Kirchoff's rules : All electrical networks cannot be reduced to simple series parallel combinations. Kirchoff gave two simple and general rules which can be applied to find the currents flowing through or voltage drops across resistances in such networks.

First rule (junction rule) : The algebraic sum of the currents at a junction is zero.

According to Kirchhoff's first law, $I_1 - I_2 - I_3 + I_4 - I_5 = 0$.

This rule follows the conservation of charge, since no charges can accumulate at a junction.

While applying this rule, we (arbitrarily) take the currents entering into a junction as positive and those leaving it as negative.

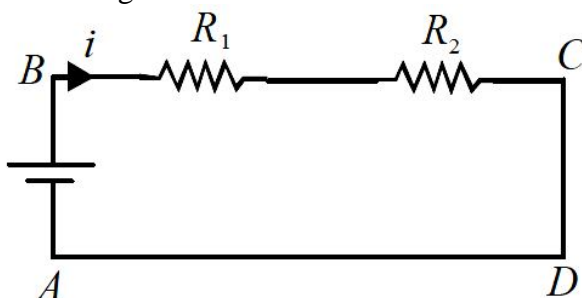
Second rule (loop rule) : According to this rule in any closed part of an electrical circuit, the algebraic sum of the emfs is equal to the algebraic sum of the products of the resistances and currents flowing through them.

$$\sum E = \sum IR$$

This rule follows from the law of conservation of energy.

The following procedure should be adopted while applying the rules to some network:

(i) In the resistors, $i \times R$ is +ve if it is against the current and -ve in the direction of the current.



(ii) Apply the junction rule for all junctions.

(iii) Choose any loop in the network and designate a direction, clockwise or anticlockwise, to traverse the loop.

(iv) In the cell, positive to negative terminals will be negative (down the potential) and positive to negative terminals will be positive if one takes from the negative terminal to the positive terminal (up the potential gradient).

(v) If necessary, choose another loop and repeat steps (iii) and

(iv) until there are as many equations as unknowns.

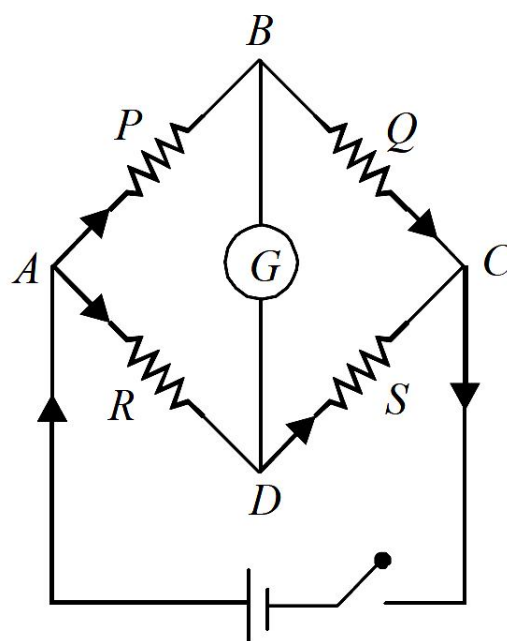
The Wheatstone's bridge is an arrangement of four resistances P , Q , R and S connected as shown in the figure.

Their values are so adjusted that the galvanometer G shows no deflection. The bridge is then said to be balanced. When this happens, the points B and D are at the same potential and it can be shown that

$$\frac{P}{Q} = \frac{R}{S}$$

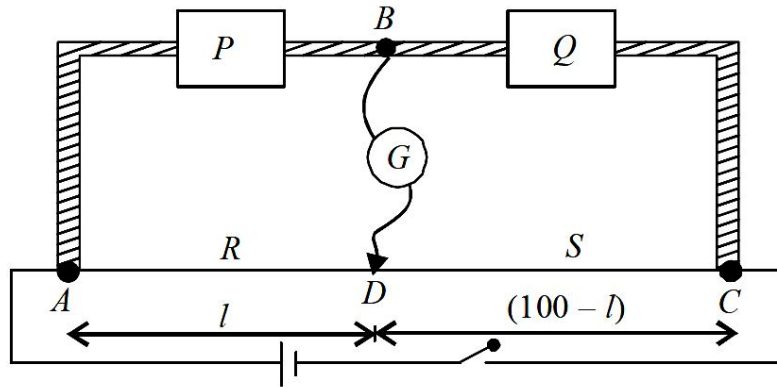
This is called the **balancing condition**. If any three resistances are known, the fourth can be found.

Wheatstone's bridge is most sensitive when resistances in the four ratio arms are of the same order.



The measurement of resistance by Wheatstone's bridge is not affected by the internal resistance of the cell.

The Metre Bridge : The metre bridge is the practical application of the Wheatstone network principle in which the ratio of two of the resistances, say R and S , is deduced from the ratio of their balancing lengths. AC is a 1 m long uniform wire. If $AD = l$ cm, then $DC = (100 - l)$ cm.



Clearly, $\frac{P}{Q} = \frac{l}{100-l}$. If P is known then Q can be determined.

Applications of metre bridge:

(i) To measure unknown resistance, $X = \frac{R(100-l)}{l}$.

Knowing the value of R and l , the value of X can be found.

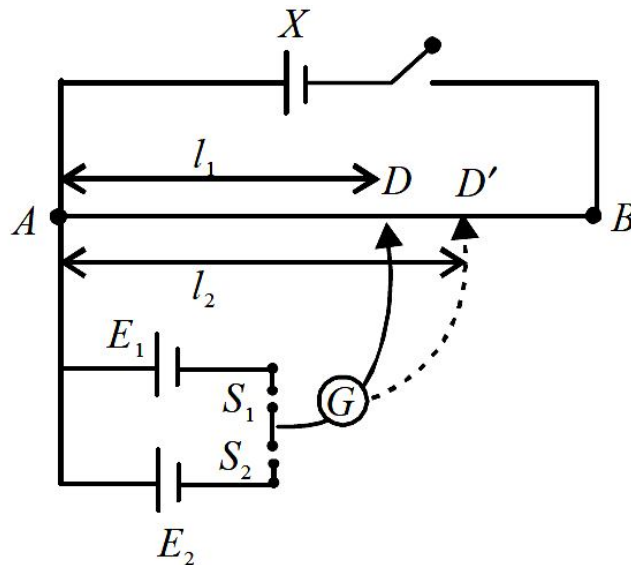
(ii) To compare two unknown resistances $\frac{R_1}{R_2} = \frac{l_2(100-l_1)}{l_1(100-l_2)}$

Knowing the value of l_1 and l_2 , the ratio $\frac{R_1}{R_2}$ can be found.

(iii) To measure the unknown temperature $\theta = \frac{R - R_0}{R_{100} - R_0} \times 100$

The unknown resistance X (in form of metallic wire) is immersed in ice and its resistance R_0 at 0°C is measured. The unknown resistance is then maintained at a temperature of 100°C (by placing the wire in steam) and its resistance R_{100} at 100°C is measured. At last resistance is immersed in hot bath at unknown temperature θ and experiment is repeated to measure its resistance R_θ at 0°C . After substituting the value of R_0 , R_{100} and R_θ in the equation, the unknown temperature of the hot bath can be found.

Potentiometer : It is a device commonly used for comparison of emfs of cells and for finding the internal resistance of a primary cell. A battery X is connected across a long uniform wire AB . The cells E_1 and E_2 whose emfs are to be compared are connected as shown along with a galvanometer G which detects the flow of current.

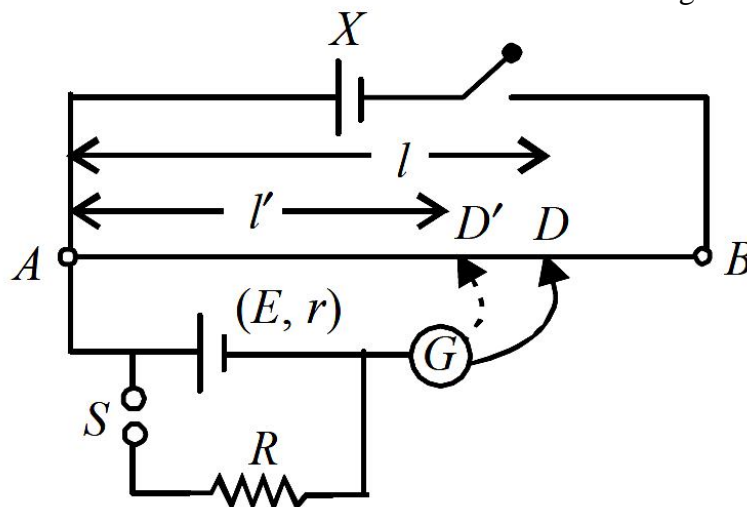


First the key S_1 is pressed which brings E_1 in the circuit. The sliding contact D is moved till the galvanometer shows no deflection. Let the length $AD = l_1$. Next S_1 is opened and S_2 is closed. This brings E_2 in the circuit. Let D' be the new null point and let $AD' = l_2$. Then, clearly,

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

Potentiometer compares the true emfs of cells because no current flows through the cells at the balance points and therefore no errors are introduced due to internal resistances.

To find the internal resistance of a primary cell, first the emf E of the cell is balanced against a length $AD = l$. A known resistance R is then connected to the cell as shown in the figure.



The terminal voltage V is now balanced against a smaller length $AD' = l'$.

$$\text{Then, } \frac{E}{V} = \frac{l}{l'}$$

$$\text{But we know that } \frac{E}{V} = \frac{R+r}{R}$$

$$\text{Therefore, } \frac{R+r}{R} = \frac{l}{l'} \Rightarrow r = \left(\frac{l}{l'} - 1 \right) R$$

Potentiometer is an ideal voltmeter.

Sensitivity of potentiometer is increased by increasing length of potentiometer wire.

Resistance of wire

(i) If a resistance wire is stretched to a greater length, keeping volume (V) constant,

$$R = \rho \frac{l}{S} = \left(\frac{\rho}{V}\right) l^2$$

Suppose length is drawn to n times, $l' = nl$ then

$$R' = \left(\frac{\rho}{V}\right) n^2 l^2 = n^2 R$$

(ii) If a resistance wire is drawn to n times its radius, $r' = nr$

$$R = \frac{\rho l}{S} = \frac{\rho l}{\pi r^2} = \frac{\rho}{\pi r^2} \left(\frac{\text{Volume}}{\pi r^2}\right) = \frac{\rho V}{\pi^2 r^4}$$

$$R' = \left(\frac{\rho V}{\pi^2}\right) \left(\frac{1}{nr}\right)^4 = \frac{\rho V}{\pi^2 r^4} \cdot \frac{1}{n^4} = \frac{R}{n^4}$$

(iii) If a resistance wire is drawn to n times its area of cross section S , keeping volume V constant, then $S' = nS$.

$$R = \frac{\rho l}{S} = \frac{\rho}{S} \left(\frac{\text{Volume}}{S}\right) = \frac{\rho V}{S^2}$$

$$R' = \frac{\rho V}{(nS)^2} = \frac{\rho V}{S^2} \cdot \frac{1}{n^2} = \frac{R}{n^2}$$

Electric Power

The rate at which work is done by the source of emf in maintaining the electric current in a circuit is called **electric power** of the circuit.

$$P = VI$$

where V is the potential difference across the conductor, I is current flowing through the conductor.

SI unit of electric power is watt.

$$1 \text{ W} = 1 \text{ V} \times 1 \text{ A}$$

Bigger unit of electric power

$$\begin{aligned} 1 \text{ kilowatt (kW)} &= 10^3 \text{ W} \\ 1 \text{ megawatt (MW)} &= 10^6 \text{ W} \end{aligned}$$

$$\text{Other expressions for power } P = I^2 R \Rightarrow P = \frac{V^2}{R}$$

The total work done (or energy supplied) by the source of emf in maintaining the electric current in the circuit for a given time is called **electric energy** consumed in the circuit.

Electric energy = electric power \times time

SI unit of electric energy is joule but another unit is **watt hour**.

The bigger unit of electric energy is kilowatt hour (kWh). It is known as **Board of Trade Unit (BOT)**.

$$1 \text{ kilowatt hour} = 1000 \text{ watt} \times 1 \text{ hour} = (1000 \text{ J/s}) \times (3600 \text{ s}) = 3.6 \times 10^6 \text{ J}$$

$$1 \text{ horse power} = 746 \text{ watt.}$$

The electric energy consumed in kWh is given by

$$\text{W (in kWh)} = \frac{\text{V (in volt)} \times \text{I (in ampere)} \times \text{t (in hour)}}{1000}$$

CURRENT ELECTRICITY

MARKS WEIGHTAGE – 7 marks

Important Questions & Answers

VERY SHORT ANSWER TYPE QUESTIONS (1 MARK)

1. Two conducting wires X and Y of same diameter but different materials are joined in series across a battery. If the number density of electrons in X is twice that in Y , find the ratio of drift velocity of electrons in the two wires. [AI 2010]

Ans. Since the wires are connected in series, current I through both is same. Therefore ratio of drift velocities

$$\frac{v_X}{v_Y} = \frac{\frac{I}{n_X e A_X}}{\frac{I}{n_Y e A_Y}} \Rightarrow \frac{v_X}{v_Y} = \frac{n_Y}{n_X} = \frac{1}{2} \quad (\text{Given } A_X = A_Y, n_X = 2n_Y)$$

where, n_X, n_Y = respective electron densities, A_X, A_Y = cross sectional Areas

$$\therefore v_X : v_Y = 1 : 2$$

2. Define the term 'Mobility' of charge carries in a conductor. Write its SI unit.

Ans. Mobility is defined as the magnitude of the drift velocity per unit electric field.

$$\mu = \frac{v_d}{E} = \frac{l\tau}{m}$$

where τ is the average collision time for electrons.

The SI unit of mobility is m^2/Vs or $\text{m}^2\text{V}^{-1}\text{s}^{-1}$.

3. Define the term 'electrical conductivity' of a metallic wire. Write its S.I. unit.

Ans. The reciprocal of the resistivity of a material is called its conductivity and is denoted by σ .

$$\text{Conductivity} = \frac{1}{\text{Resistivity}}$$

The SI unit of conductivity is $\text{ohm}^{-1}\text{m}^{-1}$ or Sm^{-1} .

4. Define the term 'drift velocity' of charge carriers in a conductor and write its relationship with the current flowing through it.

Ans. Drift velocity is defined as the average velocity acquired by the free electrons in a conductor under the influence of an electric field applied across the conductor. It is denoted by v_d .

Current, $I = neA \cdot v_d$

5. Why are the connections between the resistors in a meter bridge made of thick copper strips?

Ans. A thick copper strip offers a negligible resistance, so does not alter the value of resistances used in the meter bridge.

6. Why is it generally preferred to obtain the balance point in the middle of the meter bridge wire?

Ans. If the balance point is taken in the middle, it is done to minimise the percentage error in calculating the value of unknown resistance.

7. Which material is used for the meter bridge wire and why?

Ans. Generally alloys magnin/constantan/nichrome are used in meter bridge, because these materials have low temperature coefficient of resistivity.

8. A resistance R is connected across a cell of emf ε and internal resistance r . A potentiometer now measures the potential difference between the terminals of the cell as V . Write the expression for r in terms of ε , V and R . [AI 2011]

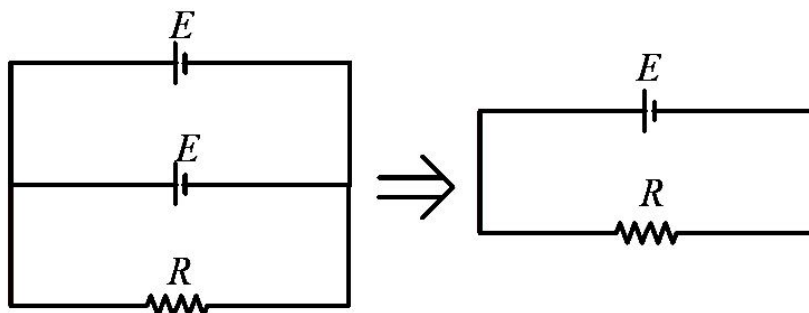
Ans. $\varepsilon = I(R+r)$ and $V = IR$

$$\therefore \frac{\varepsilon}{V} = \frac{R+r}{R}$$

We get, $r = \left(\frac{\varepsilon}{V} - 1\right)R$

9. Two identical cells, each of emf E , having negligible internal resistance, are connected in parallel with each other across an external resistance R . What is the current through this resistance?

Ans.



So, current $I = \frac{E}{R}$

10. Two wires of equal length, one of copper and the other of manganin have the same resistance. Which wire is thicker? [AI 2012]

Ans. $R_{Cu} = R_m$

$$\rho_{Cu} \frac{\rho_{Cu}}{A_{Cu}} = \rho_m \frac{\rho_m}{A_m}$$

Here, $\rho_{Cu} = \rho_m$ as $\rho_m > \rho_{Cu}$

$$\frac{\rho_{Cu}}{A_{Cu}} = \frac{\rho_m}{A_m}, \quad \frac{\rho_m}{\rho_{Cu}} = \frac{A_m}{A_{Cu}} \quad \text{as, } \rho_m > \rho_{Cu}$$

So, $A_m > A_{Cu}$

Manganin wire is thicker than copper wire.

SHORT ANSWER TYPE QUESTIONS (2 MARKS/3 MARKS)

11. Two metallic wires of the same material have the same length but cross sectional area is in the ratio 1 : 2. They are connected (i) in series and (ii) in parallel. Compare the drift velocities of electrons in the two wires in both the cases (i) and (ii). [AI 2008]

Ans. (i) In series, current I through both the metallic wires is same, so $\frac{v_1}{v_2} = \frac{\frac{I}{neA_1}}{\frac{I}{neA_2}} \Rightarrow \frac{v_1}{v_2} = \frac{A_2}{A_1} = \frac{2}{1}$

(ii) In Parallel, potential difference V applied across both of them is same, so $\frac{v_1}{v_2} = \frac{\frac{eV}{ml}}{\frac{eV}{ml}} = \frac{1}{1}$

12. Using the mathematical expression for the conductivity of a material, explain how it varies with temperature for (i) semiconductors, (ii) good conductors. [AI 2008]

Ans. (i) Variation of resistivity in semiconductors

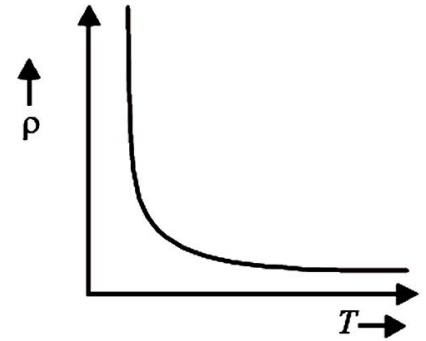
Resistivity of semiconductors decrease rapidly with increase in temperature. This is because more and more electrons becomes free in semiconductors and insulators on heating, there by increasing number density n of free electrons. So, in insulators and semiconductors, it is not the relaxation time t but the number density ' n ' of free electrons that matters. An exponential relation exist between number of free electrons and temperature.

$$n(\tau) = n_0 e^{\frac{-E_g}{kT}}$$

Here E_g is the energy gap between valance and conduction band, n_0 is number of charge carriers at absolute zero temperature. So, the resistivity of insulators decreases exponentially with increasing temperature.

$$\rho_\tau = \rho_0 e^{\frac{-E_g}{kT}}$$

Hence, temperature coefficient a of resistivity is negative in semiconductors and insulators.

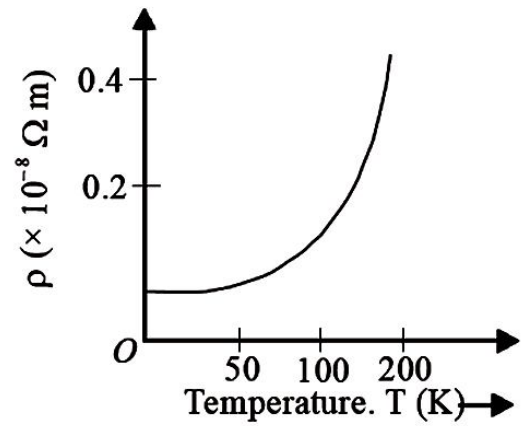


(ii) Variation of resistivity in conductors

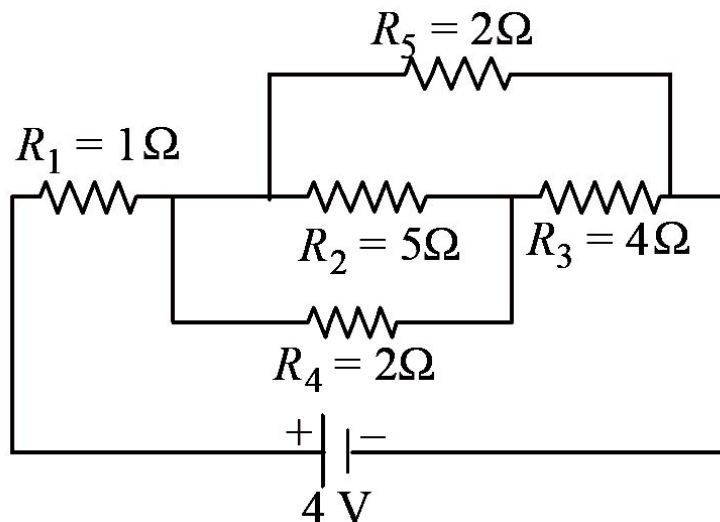
On increasing the temperature of a conductor its resistivity and resistance increases. In metals, the number of free electron is fixed. As the temperature is increased, the atom/ions vibrates with increasing amplitude also the kinetic energy of free electrons increases. Thus now the electrons collide more frequently with atoms and hence the relaxation time t decreases.

As resistivity of a conductor, $\rho = \frac{m}{ne^2\tau}$ or $\rho \propto \frac{1}{\tau}$

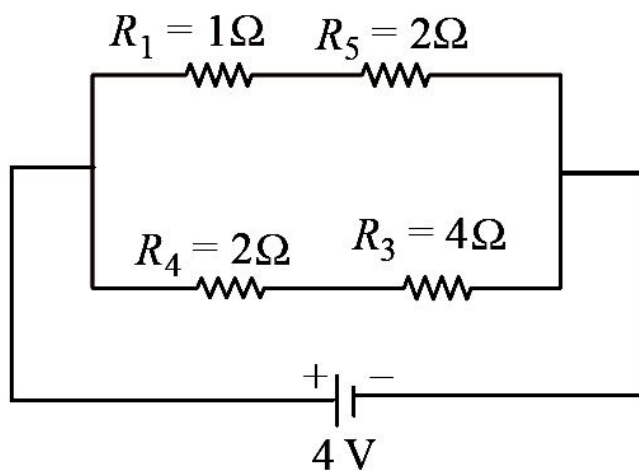
So the resistivity of a conductor increase, there by increasing the resistance of conductor. Resistivity increases non linearly in conductors. For example, variation of resistivity of copper is as shown in the graph.



13. Calculate the current drawn from the battery in the given network.



Ans. It is a balanced Wheatstone bridge, so it can be reduced to as shown below.



As R_1 and R_5 are in series, so their equivalent resistance is $R' = R_1 + R_5 = 1 + 2 = 3\ \Omega$

As R_4 and R_3 are in series, so their equivalent resistance is $R'' = R_4 + R_3 = 2 + 4 = 6\ \Omega$

So, net resistance of the network is

$$\frac{1}{R} = \frac{1}{R'} + \frac{1}{R''} = \frac{1}{3} + \frac{1}{6} = \frac{2+1}{6} = \frac{3}{6} = \frac{1}{2}$$

or $R = 2\ \Omega$

So, current drawn from the battery is

$$I = \frac{V}{R} \text{ or } I = 2\ \text{A.}$$

14. Derive an expression for the current density of a conductor in terms of the drift speed of electrons. [AI 2008]

Ans. Current density \vec{J} is the current flowing through a conductor per unit area of cross section, it is a vector quantity and has the direction same as current.

$$I = \vec{J} \cdot \vec{A}$$

Magnitude of current density

$$J = \frac{I}{A} = nev_d$$

15. A wire of $15\ \Omega$ resistance is gradually stretched to double its original length. It is then cut into two equal parts. These parts are then connected in parallel across a 3.0 volt battery. Find the current drawn from the battery. [AI 2009]

Ans. When the wire of $15\ \Omega$ resistance is stretched to double its original length, then its resistance becomes

$$R' = n^2 \times 15 = 2^2 \times 15 = 60\ \Omega$$

When it cut into two equal parts, then resistance of each part becomes

$$R'' = \frac{R'}{2} = \frac{60}{2} = 30\ \Omega$$

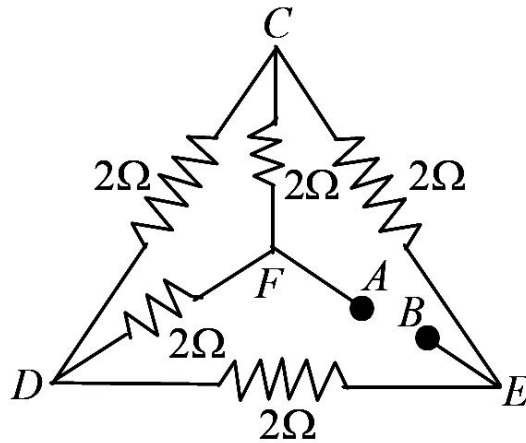
These parts are connected in parallel, then net resistance of their combination is

$$R = \frac{R''}{2} = \frac{30}{2} = 15\ \Omega$$

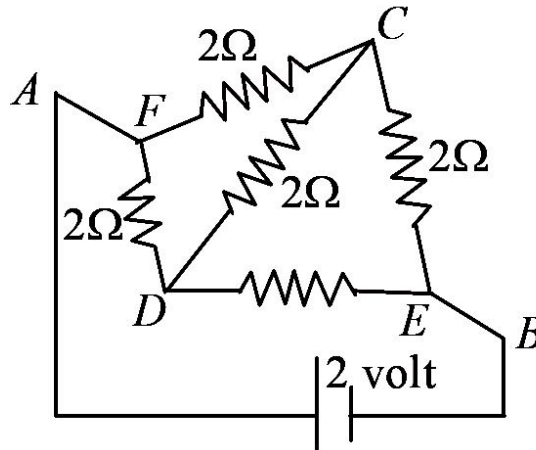
So, the current drawn from the battery

$$I = \frac{V}{R} = \frac{3}{15} = \frac{1}{5} \text{ or } I = 0.2\ \text{A.}$$

16. A potential difference of 2 Volts is applied between the points A and B as shown in the network drawn in figure. Calculate (i) equivalent resistance of the network, across the point A and B, the (ii) the magnitudes of currents flowing in the arms AFCEB and AFDEB. (iii) current through CD and ACB, if a 10V d.c. source is connected between A and B. [AI 2008]

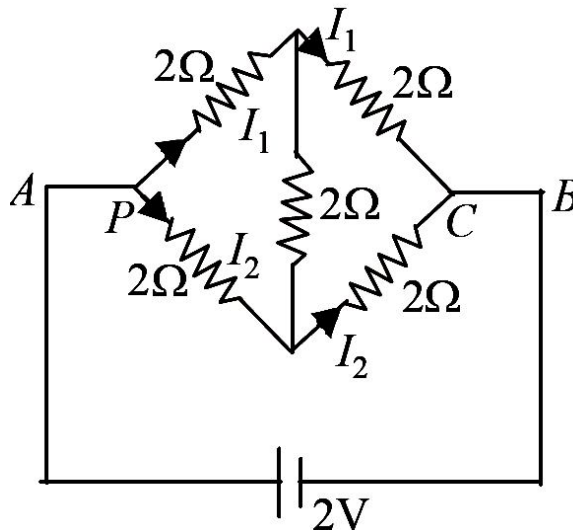


Ans. The given circuit, can also be opened up by stretching A and B as shown below.



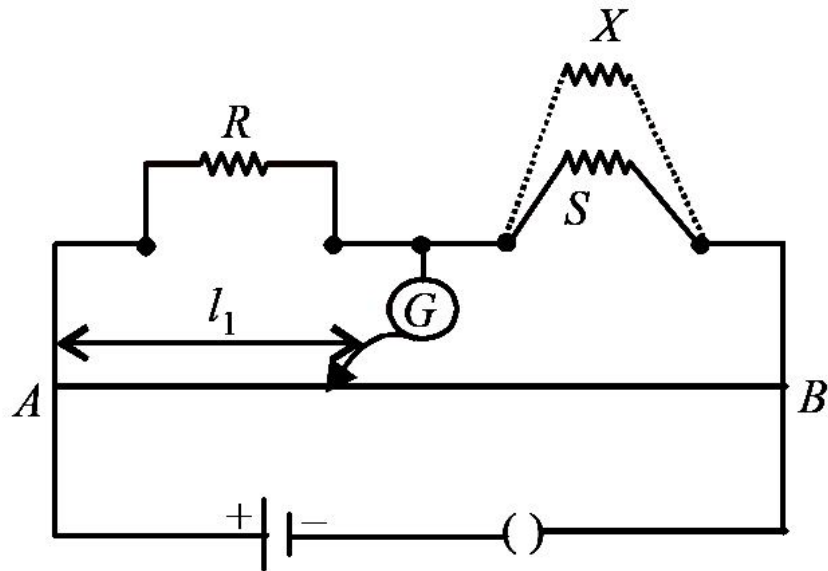
Now it is a balanced wheatstone bridge. The potential at point C and D is the same. No current flows between C and D.

- (i) The equivalent resistance is $R_{eq} = 2\ \Omega$
- (ii) $2 = 4I_1 = 4I_2$



$I_1 = I_2 = 0.5\ \text{A}$
Current through both the arms is 0.5 A.

17. (i) State the principle of working of a meter bridge. (ii) In a meter bridge balance point is found at a distance l_1 with resistances R and S as shown in the figure. When an unknown resistance X is connected in parallel with the resistance S , the balance point shifts to a distance l_2 . Find the expression for X in terms of l_1 , l_2 and S . [AI 2009]



Ans.

(i) Meter bridge works on the principle of Wheatstone bridge.

(ii) In first case, $\frac{R}{S} = \frac{l_1}{100-l_1} \Rightarrow R = \frac{S.l_1}{100-l_1}$ ----- (i)

In second case, $\frac{R}{\left(\frac{XS}{X+S}\right)} = \frac{l_2}{100-l_2} \Rightarrow R = \frac{l_2 \times XS}{(100-l_2)(X+S)}$ ----- (ii)

By equations (i) and (ii), we get

$$\begin{aligned} \frac{S.l_1}{100-l_1} &= \frac{l_2 \times XS}{(100-l_2)(X+S)} \\ \Rightarrow l_1(100-l_2)(X+S) &= Xl_2(100-l_1) \\ \Rightarrow (100l_1 - l_1l_2)(X+S) &= 100Xl_2 - Xl_1l_2 \\ \Rightarrow 100Xl_1 - Xl_1l_2 + 100Sl_1 - Sl_1l_2 &= 100Xl_2 - Xl_1l_2 \\ \Rightarrow 100Xl_1 - 100Xl_2 &= Sl_1l_2 - 100Sl_1 \\ \Rightarrow 100X(l_1 - l_2) &= Sl_1(l_2 - 100) \\ \Rightarrow X &= \frac{Sl_1(l_2 - 100)}{100(l_1 - l_2)} \end{aligned}$$

18. Write any two factors on which internal resistance of a cell depends. The reading on a high resistance voltmeter, when a cell is connected across it, is 2.2 V. When the terminals of the cell are also connected to a resistance of 5Ω as shown in the circuit, the voltmeter reading drops to 1.8 V. Find the internal resistance of the cell.

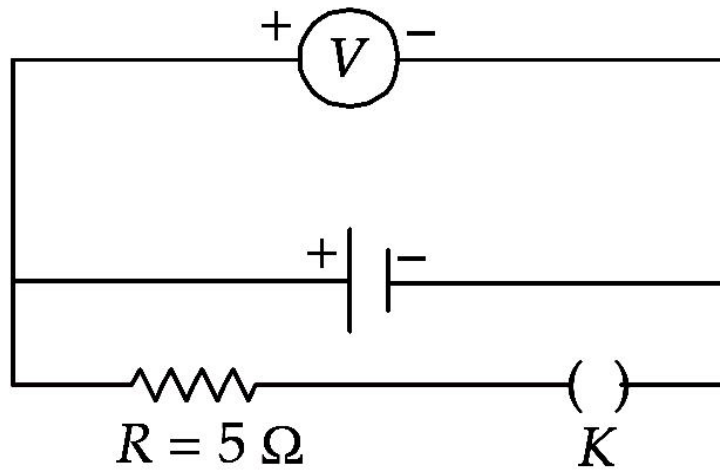
Ans. Internal resistance of a cell depends upon

- (i) surface area of each electrode.
- (ii) distance between the two electrodes.
- (iii) nature, temperature and concentration of electrolyte.

Let internal resistance of cell be r .

Initially when K is open, voltmeter reads 2.2 V.

i.e. emf of the cell, $\varepsilon = 2.2$ V



Later when K is closed, voltmeter reads 1.8 V which is actually the terminal potential difference, V .
i.e. if I is the current flowing, then $\varepsilon = I(R + r)$

$$\Rightarrow 2.2 = I(5 + r) \text{ ----- (i)}$$

and $V = \varepsilon - Ir$

$$1.8 = 2.2 - Ir \text{ ----- (ii)}$$

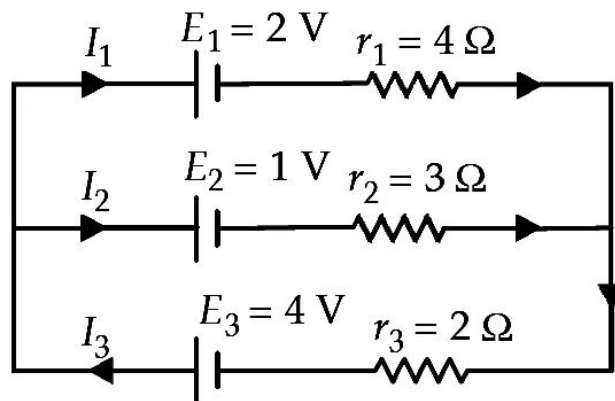
Solving (i) and (ii),

$$I = 0.36\text{ A}$$

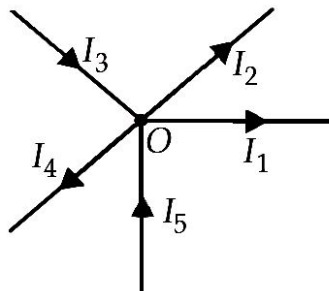
Substituting in (ii)

$$r = \frac{0.4}{0.36} = \frac{10}{9}\Omega$$

19. State Kirchhoff's rules. Use these rules to write the expressions for the currents I_1 , I_2 and I_3 in the circuit diagram shown.



Ans. Kirchhoff's first law of electrical network or junction rule states that at any junction of electrical network, sum of incoming currents is equal to the sum of outgoing currents *i.e.*,
 $I_1 + I_2 + I_4 = I_3 + I_5$



Kirchhoff's second law of electrical network or loop rule states that in any closed loop, the algebraic sum of the applied emf's is equal to the algebraic sum of potential drops across the resistors of the loop *i.e.*, $\sum \varepsilon = \sum IR$

To find I_1, I_2, I_3 in the given diagram.

For loop $ABCFA$

$$E_1 + I_1 r_1 - I_2 r_2 - E_2 = 0$$

$$\Rightarrow 2 + 4I_1 - 3I_2 - 1 = 0$$

$$\Rightarrow 4I_1 - 3I_2 + 1 = 0 \text{ ----- (i)}$$

Using loop $FCDEF$

$$E_2 + I_2 r_2 + I_3 r_3 - E_3 = 0$$

$$\Rightarrow 1 + 3I_2 + 2I_3 - 4 = 0$$

$$\Rightarrow 3I_2 + 2I_3 - 3 = 0 \text{ ----- (ii)}$$

Also using junction rule $I_3 = I_1 + I_2$ ----- (iii)

Using (ii) and (iii)

$$3I_2 + 2I_1 + 2I_2 - 3 = 0$$

$$\Rightarrow 2I_1 + 5I_2 - 3 = 0 \text{ ... (iv)}$$

Solving (i) and (iv)

$$4I_1 - 3I_2 + 1 = 0$$

$$\underline{-2 \times (2I_1 + 5I_2 - 3) = 0I_1}$$

$$\underline{0 - 13I_2 + 7 = 0}$$

$$\Rightarrow I_2 = \frac{7}{13} A$$

$$4I_1 - 3 \times \frac{7}{13} + 1 = 0$$

$$\Rightarrow 4I_1 = \frac{8}{13} \Rightarrow I_1 = \frac{2}{13} A$$

$$\Rightarrow I_3 = I_1 + I_2 = \frac{2}{13} + \frac{7}{13} = \frac{9}{13} A$$

20. Define the terms (i) drift velocity, (ii) relaxation time. A conductor of length L is connected to a dc source of emf e . If this conductor is replaced by another conductor of same material and same area of cross section but of length $3L$, how will the drift velocity change? [AI 2011]

Ans. (i) Drift velocity : It is defined as the average velocity of electrons with which they move along the length of the conductor when an electric field is applied across the conductor and is given by

$$v_d = \frac{e}{m} \left(\frac{V}{L} \right) \tau$$

where, V is potential difference across the conductor, L is length of conductor and τ is relaxation time m is the mass of the electron.

(ii) Relaxation time :

$$\text{Relaxation time} = \frac{\text{mean free path of electron}}{\text{drift speed of electron}}$$

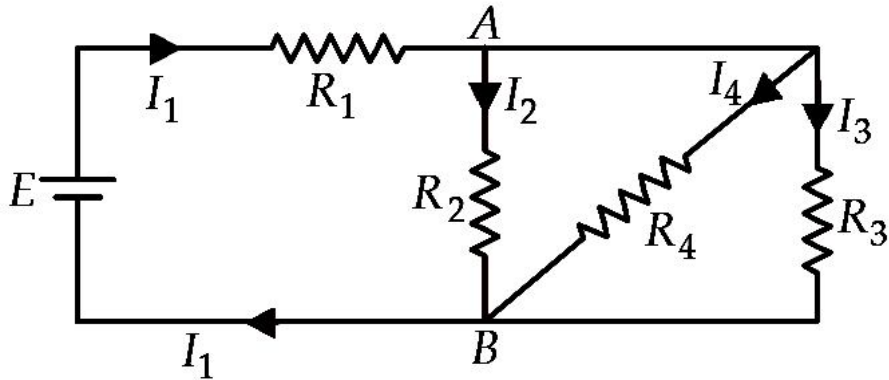
$$\text{Drift velocity, } v_d = \frac{I}{neA} = \frac{V}{neAR} \left(\because V = IR \right)$$

$$\Rightarrow v_d = \frac{V}{neA \left(\frac{\rho L}{A} \right)} \left(\because R = \frac{\rho L}{A} \right)$$

$$\Rightarrow v_d = \frac{V}{nAeL} \text{ or } v_d \propto \frac{1}{L}$$

$$\therefore \frac{v'_d}{v_d} = \frac{L}{3L} \Rightarrow v'_d = \frac{v_d}{3}$$

21. In the circuit shown, $R_1 = 4\Omega$, $R_2 = R_3 = 15\Omega$, $R_4 = 30\Omega$ and $E = 10\text{ V}$. Calculate the equivalent resistance of the circuit and the current in each resistor.



Ans. From figure, R_2 , R_3 and R_4 are connected in parallel.

\therefore Effective resistance R_p

$$\frac{1}{R_p} = \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{15} + \frac{1}{15} + \frac{1}{30} = \frac{5}{30}$$

$$\Rightarrow R_p = 6\Omega$$

Now, equivalent resistance of circuit,

$$R = R_1 + R_p = 4 + 6 = 10\ \Omega$$

$$\text{Current, } I_1 = \frac{10}{10} = 1\ \text{A}$$

$$\text{Potential drop across } R_1, = I_1 R_1 = 1 \times 4 = 4\ \text{V}$$

$$\text{Potential drop across all other resistances} = 10 - 4 = 6\ \text{V}$$

Current through R_2 or R_3 ;

$$I_2 = \frac{6}{15}\ \text{A}, I_3 = \frac{6}{15}\ \text{A}$$

$$\text{Current through } R_4, I_4 = \frac{6}{30}\ \text{A}$$

22. Define relaxation time of the free electrons drifting in a conductor. How is it related to the drift velocity of free electrons? Use this relation to deduce the expression for the electrical resistivity of the material. [AI 2012]

Ans. Relaxation time (τ): The average time interval between two successive collisions. For the free electrons drifting within a conductor (due to the action of the applied electric field), is called relaxation time.

$$v_d = \left(\frac{-eV\tau}{ml} \right)$$

Relation for drift velocity,

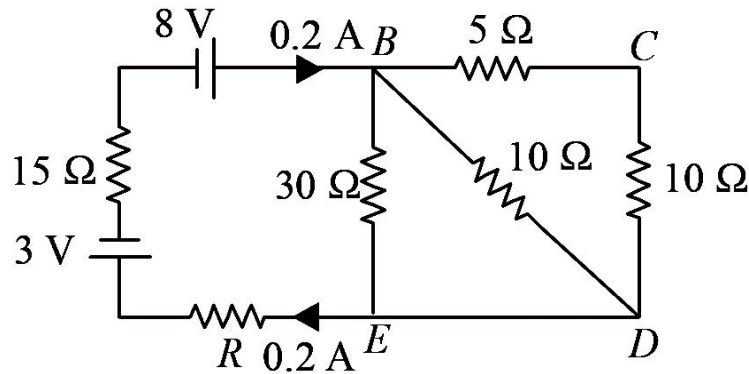
$$\text{Since } I = -neAv_d$$

$$\Rightarrow I = -neA \left(\frac{-eV\tau}{ml} \right) = \frac{ne^2 A \tau V}{ml}$$

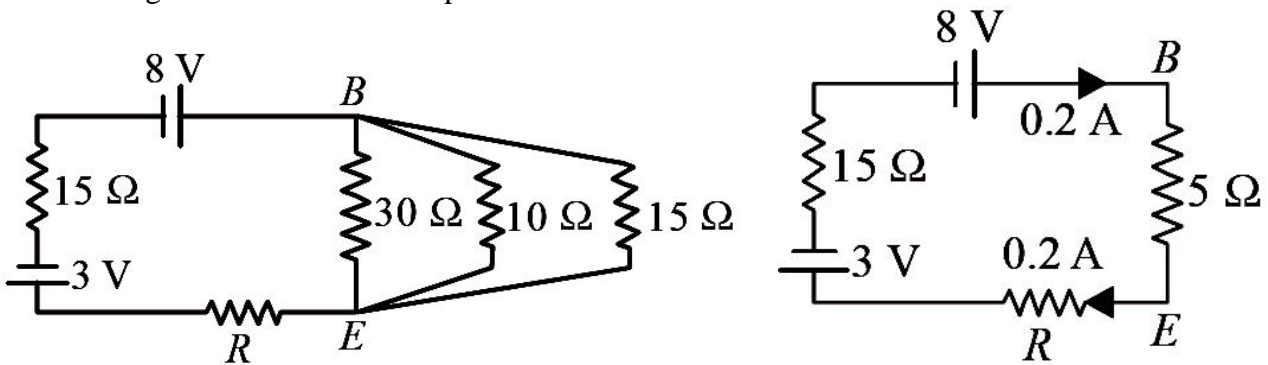
$$\therefore \frac{V}{I} = \frac{ml}{ne^2 A \tau} = \frac{\rho l}{A} \left(\because \frac{V}{I} = R = \frac{\rho L}{A} \right)$$

$$\therefore \rho = \frac{m}{ne^2 \tau}$$

23. Calculate the value of the resistance R in the circuit shown in the figure so that the current in the circuit is $0.2\ \text{A}$. What would be the potential difference between points B and E ? [AI 2012]



Ans. The given circuit can be simplified



In the given circuit

$$I = 0.2 = \frac{8-3}{5+15+R}$$

$$\Rightarrow 0.2 = \frac{5}{20+R} \Rightarrow 20+R = 25$$

$$\Rightarrow R = 5\Omega$$

$$V_{BE} = I(5) = 0.2 \times 5 = 1.0V$$

24. Explain the term 'drift velocity' of electrons in a conductor. Hence obtain the expression for the current through a conductor in terms of 'drift velocity'.

Ans. Drift velocity : It is the average velocity acquired by the free electrons superimposed over the random motion in the direction opposite to electric field and along the length of the metallic conductor.

Let n = number of free electrons per unit volume, v_d = Drift velocity of electrons

Total number of free electrons passing through a cross section in unit time

$$\frac{N}{t} = Anv_d$$

So, total charge passing through a cross section in unit time

$$i.e., \text{ current, } I = \frac{Q}{t} = \frac{Ne}{t} = Anev_d$$

25. A potentiometer wire of length 1 m has a resistance of 10 Ω . It is connected to a 6 V battery in series with a resistance of 5 Ω . Determine the emf of the primary cell which gives a balance point at 40 cm.

Ans. Here, $l = 1$ m, $R_1 = 10\Omega$, $V = 6$ V, $R_2 = 5$ Ω

Current flowing in potentiometer wire,

$$I = \frac{V}{R_1 + R_2} = \frac{6}{10+5} = \frac{6}{15} = 0.4A$$

Potential drop across the potentiometer wire

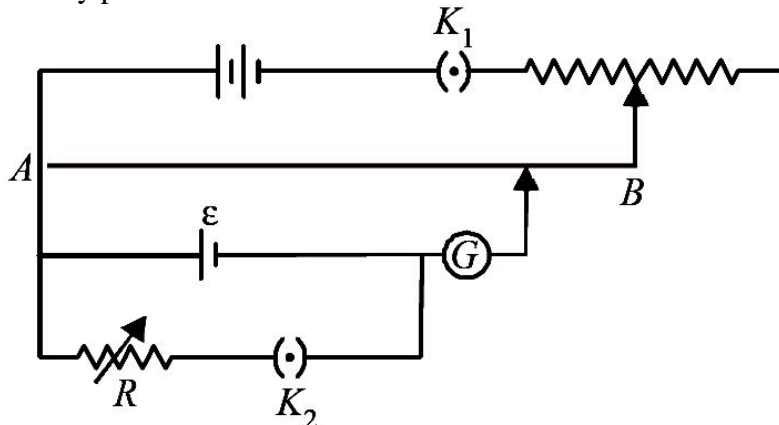
$$V' = IR = 0.4 \times 10 = 4V$$

$$\text{Potential gradient, } K = \frac{V'}{l} = \frac{4}{1} = 4 \text{ V/m}$$

Emf of the primary cell = $KI = 4 \times 0.4 = 1.6 \text{ V}$

26. Describe briefly, with the help of a circuit diagram, how a potentiometer is used to determine the internal resistance of a cell. [AI 2013]

Ans. Internal resistance by potentiometer



Initially key K_2 is off

Then at balancing length l_1

$$e = Kl_1 \text{ ----- (i)}$$

Now key K_2 is made on

At balancing length l_2

$$V = Kl_2 \text{ ----- (ii)}$$

$$\text{So, } \frac{\varepsilon}{V} = \frac{l_1}{l_2} \text{ ----- (iii)}$$

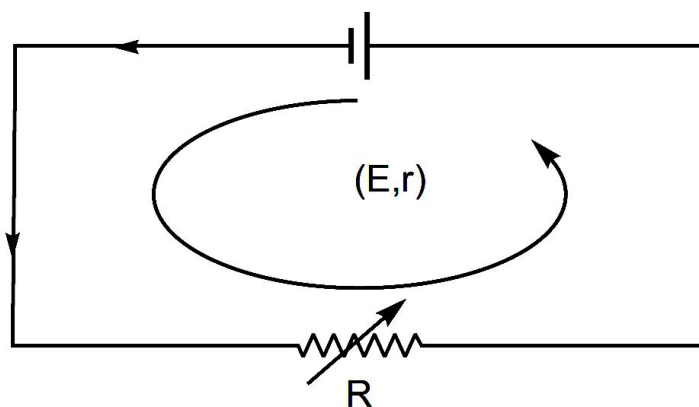
where internal resistance r is

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

$$\Rightarrow r = \left(\frac{l_1}{l_2} - 1 \right) R$$

27. A cell of emf ' E ' and internal resistance ' r ' is connected across a variable resistor ' R '. Plot a graph showing variation of terminal voltage ' V ' of the cell versus the current ' I '. Using the plot, show how the emf of the cell and its internal resistance can be determined.

Ans.



Suppose a current I flows through the circuit and using loop rule

$$E - IR - Ir = 0$$

$$\Rightarrow E - Ir = V \quad [V = IR]$$

$$\Rightarrow V = E - Ir \dots\dots\dots (i)$$

If terminal voltage V is the function of current I , Reason – Equation of straight line, $y = -mx + c = c - mx$

Then,

Using the graph

For point A, $I = 0$ and on using equation (i)

$$V = E - 0 \times r = E$$

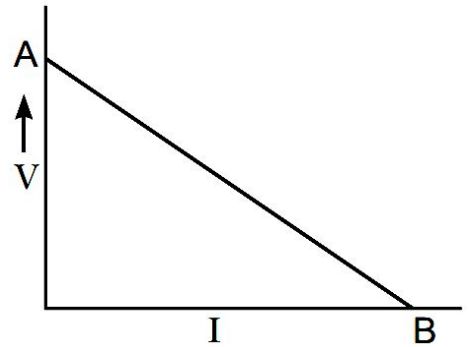
Hence voltage intercept (intercept on the vertical axis) measures emf of the cell.

For point B, $V = 0$, from equation (i)

$$0 = E - Ir$$

$$\Rightarrow r = \frac{E}{I}$$

i.e., negative of the slope if $V - I$ graph measures the internal resistance r .



- 28. Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area $1.0 \times 10^{-7} \text{ m}^2$ carrying a current of 1.5 A. Assume the density of conduction electrons to be $9 \times 10^{28} \text{ m}^{-3}$.**

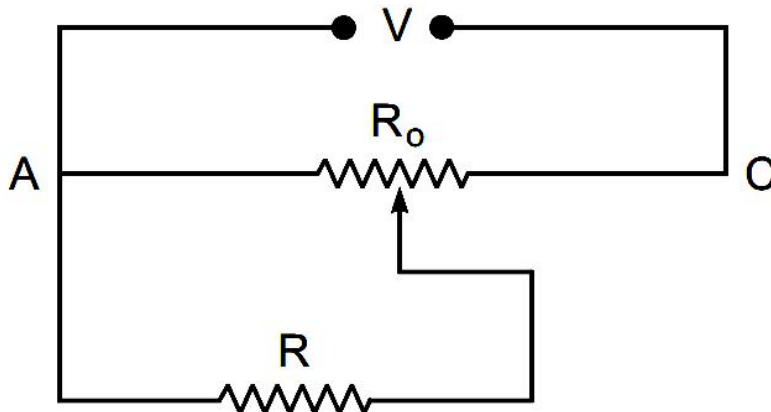
Ans. Flow of current in the conductor due to drift velocity of the free electrons is given by

$$I = neAv_d$$

$$v_d = \frac{I}{neA} = \frac{15}{9 \times 10^{28} \times 1.6 \times 10^{-19} \times 1.0 \times 10^{-7}}$$

$$\Rightarrow v_d = 1.048 \times 10^{-3} \text{ m/s} \approx 1 \text{ mm/s}$$

- 29. A resistance of $R \Omega$ draws current from a potentiometer as shown in the figure. The potentiometer has a total resistance $R_0 \Omega$. A voltage V is supplied to the potentiometer. Derive an expression for the voltage across R when the sliding contact is in the middle of the potentiometer.**

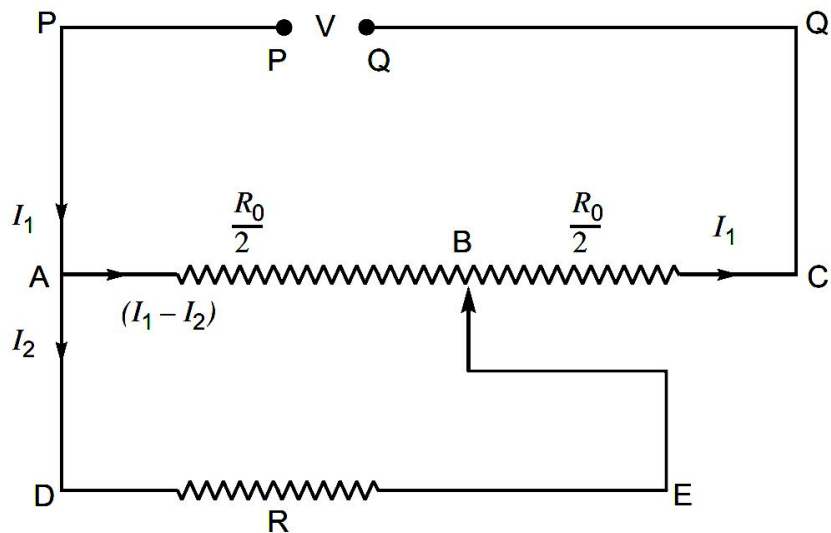


Ans. In loop ABEDA

$$(I_1 - I_2) \frac{R_0}{2} - I_2 R = 0$$

$$\Rightarrow I_1 \frac{R_0}{2} = I_2 \left(R + \frac{R_0}{2} \right) = \frac{I_2}{2} (R_0 + 2R)$$

$$\Rightarrow I_1 R_0 = I_2 (R_0 + 2R) \quad \text{----- (i)}$$



In Loop $PABCQP$

$$V = (I_1 - I_2) \times \frac{R_0}{2} + I_1 \frac{R_0}{2} = I_1 \frac{R_0}{2} - I_2 \frac{R_0}{2} + I_1 \frac{R_0}{2}$$

$$\Rightarrow V = I_1 R_0 - I_2 \frac{R_0}{2} \quad \text{-----(ii)}$$

From equation (i) and (ii)

$$V = R_0 \times \frac{I_2 (R_0 + 2R)}{R} - I_2 \frac{R_0}{2}$$

$$\Rightarrow V = I_2 \left(\frac{R_0 (R_0 + 2R)}{R} - \frac{R_0}{2} \right)$$

$$\Rightarrow V = \frac{I_2 R_0}{2R} (2(R_0 + 2R) - R) = I_2 \times \frac{R_0}{2R} (R_0 + 2R)$$

$$\Rightarrow I_2 = \frac{2VR}{R_0 (R_0 + 2R)}$$

30. State the principle of a potentiometer. Define potential gradient. Obtain an expression for potential gradient in terms of resistivity of the potentiometer wire.

Ans. It is based on the fact that the fall of potential across any segment of the wire is directly proportional to the length of the segment of the wire, provided wire is of uniform area of cross-section and a constant current is flowing through it.

$$V \propto l$$

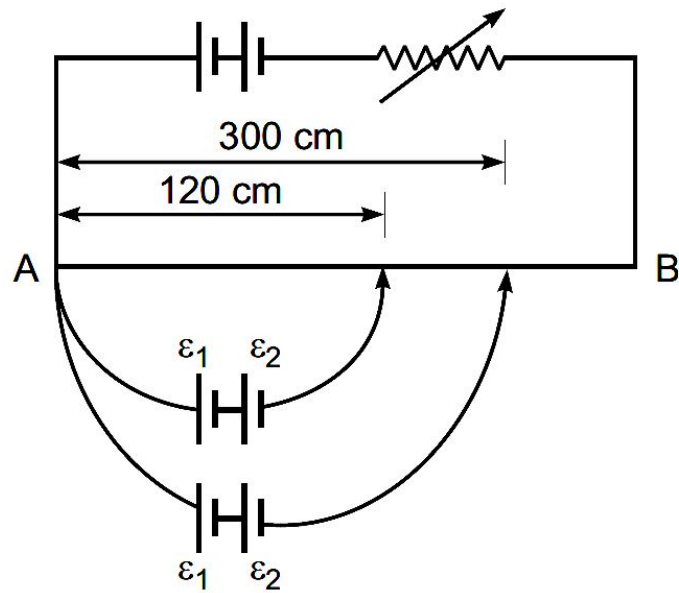
Potential gradient is the fall of potential per unit length of potentiometer wire.

$$\text{Potential gradient } K = \frac{V}{l} = \frac{IR}{l} \quad (\because V = IR)$$

$$\Rightarrow K = \frac{I \rho l}{l A} \quad \left(\because R = \frac{\rho l}{A} \right)$$

$$\Rightarrow K = \frac{I \rho}{A}$$

31. Figure shows a long potentiometer wire AB having a constant potential gradient. The null points for the two primary cells of emfs ϵ_1 and ϵ_2 connected in the manner shown are obtained at a distance of $l_1 = 120$ cm and $l_2 = 300$ cm from the end A . Determine (i) ϵ_1/ϵ_2 and (ii) position of null point for the cell ϵ_1 only.



Ans. Let k = potential gradient in V/cm

$$\varepsilon_1 + \varepsilon_2 = 300k \dots(i)$$

$$\varepsilon_1 - \varepsilon_2 = 120k \dots(ii)$$

Adding (i) and (ii), we get $2\varepsilon_1 = 420k$

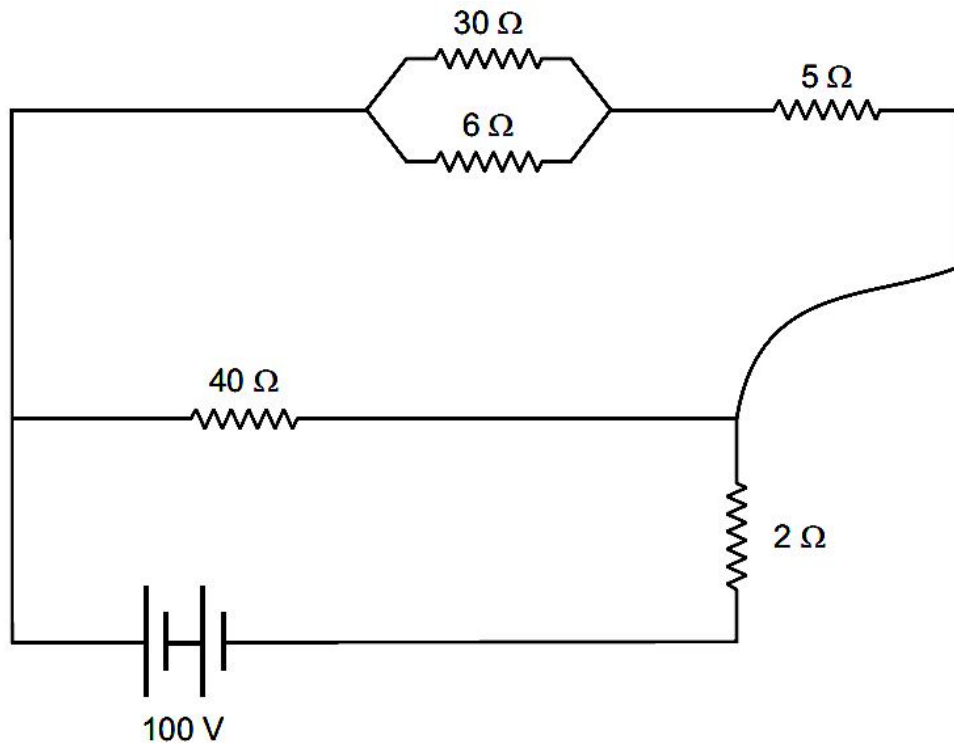
$$\Rightarrow \varepsilon_1 = 210k$$

Substituting the value of ε_1 in equation (i), we get $\varepsilon_2 = 90k$

$$\text{Therefore, } \frac{\varepsilon_1}{\varepsilon_2} = \frac{210}{90} = \frac{7}{3}$$

Balancing length for cell ε_1 is 210 cm.

32. A 100 V battery is connected to the electric network as shown. If the power consumed in the 2Ω resistor is 200 W, determine the power dissipated in the 5Ω resistor.



Ans. We know that Power, $P = I^2 R$

$$\Rightarrow 200 = I^2 \times 2$$

$$I^2 = \frac{200}{2} = 100$$

$$\Rightarrow I = \sqrt{100} = 10A$$

∴ Current flowing through 2Ω resistor = 10 A

Potential drop across 2Ω resistor, $V = IR$

$$= 10 \times 2 = 20 \text{ V}$$

Equivalent resistance of 30Ω and 6Ω

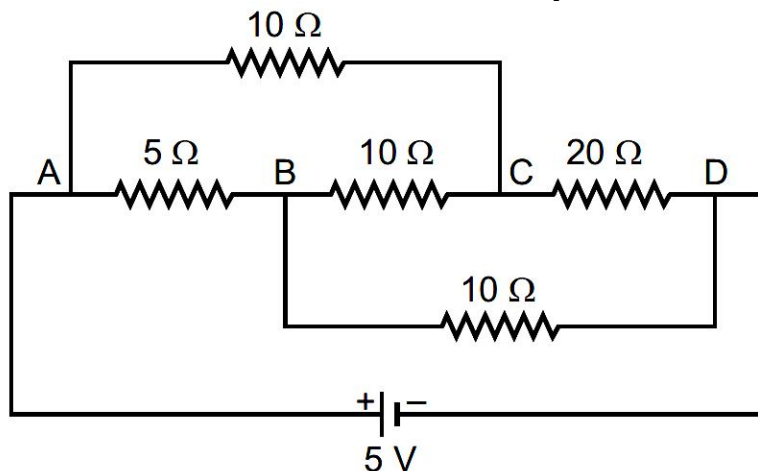
$$\frac{30 \times 6}{30 + 6} = \frac{180}{36} = 5\Omega$$

∴ Therefore, potential across parallel combination of 40Ω and $10\Omega = 10 \times 8 = 80 \text{ V}$

∴ Current through 5Ω resistor, $I = \frac{80}{10} = 8A$

∴ Power dissipated in 5Ω resistor = $I^2 R = 8^2 \times 5 = 320 \text{ W}$

33. Calculate the value of the current drawn from a 5 V battery in the circuit as shown.



Ans.

In case of balanced Wheatstone bridge, no current flows through the resistor 10Ω between points B and C.

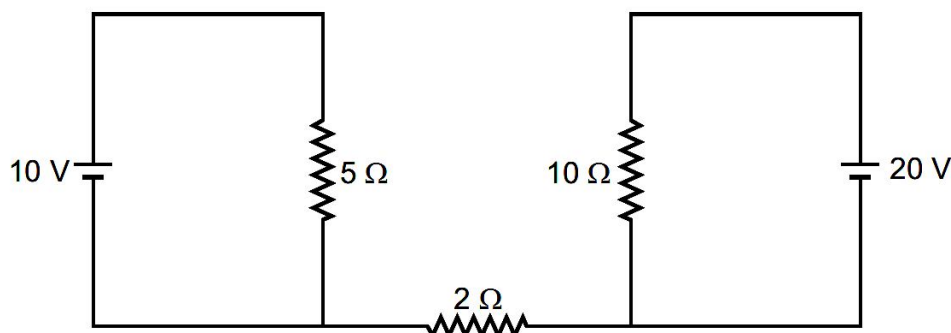
The resistance of arm ACD, $R_1 = 10 + 20 = 30\Omega$

The resistance of arm ABD, $R_2 = 5 + 10 = 15\Omega$

Equivalent resistance $R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{30 \times 15}{30 + 15} = \frac{450}{45} = 10\Omega$

Current drawn from the source, $I = \frac{V}{R_{eq}} = \frac{5}{10} = 0.5A$

34. What will be the value of current through the 2Ω resistance for the circuit shown in the figure? Give reason to support your answer.



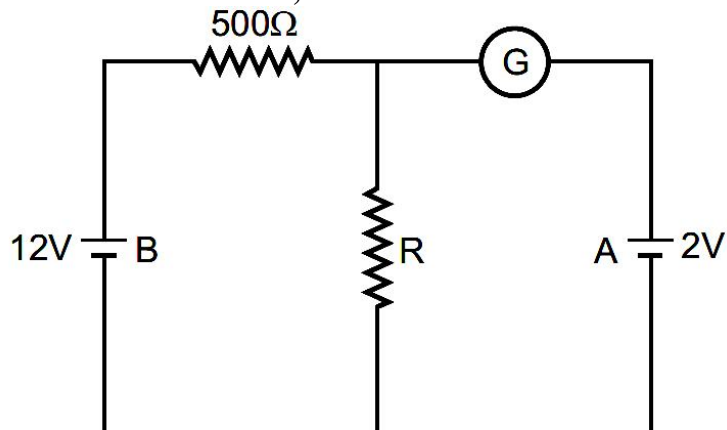
Ans. No current will flow through 2Ω resistor, because in a closed loop, total p.d. must be zero. So

$$10 \text{ V} - 5I_1 = 0 \dots (1)$$

$$20 \text{ V} - 10I_2 = 0 \dots (2)$$

Equation (1) and (2) have no solutions and resistor 2Ω is not part of any loop ABCD and EFGH.

35. In the circuit shown in the figure, the galvanometer 'G' gives zero deflection. If the batteries A and B have negligible internal resistance, find the value of the resistor R.



Ans. If galvanometer G gives zero deflection, then current of source of 12V flows through R, and voltage across R becomes 2V.

$$\text{Current in the circuit, } I = \frac{\varepsilon}{R_1 + R_2} = \frac{12.0V}{500 + R}$$

$$\text{and } V = IR = 2.0V$$

$$\left(\frac{12.0V}{500 + R} \right) R = 2.0$$

$$\Rightarrow 12R = 1000 + 2R$$

$$\Rightarrow 10R = 1000$$

$$\Rightarrow R = 100 \Omega$$

.....

ELECTRONIC DEVICES

QUICK REVISION (Important Concepts & Formulas)

Electronics

It is the branch of science, which deals with the study of flow and control of electrons through a vacuum, gas or semiconductor.

Classification of substances on the basis of conduction of electricity.

Solid

We know that, each substance is composed of atoms. Substances are mainly classified into three categories namely solids, liquids and gases.

In each solid atoms are at a definite positions and the average distance between them is constant.

Depending upon the internal arrangement of atoms, solids are further divided into two groups.

1. Crystalline Solids

The solid in which the atoms are arranged in a regular order are called the crystalline solids. In other words, we can say that in a crystalline solid, there is periodicity and regularity of its component atoms in all the directions. For example sodium chloride (common salt), diamond,

- Sugar, silver etc are the crystalline solids.
- Their atoms are arranged in a definite geometrical shape.
- They have a definite melting point.
- They are anisotropic, i.e., their physical properties such as thermal Conductivity refractive index etc, are different in different directions.
- They are the real solids.

2. Amorphous Solids

The Solids in which the atoms do not have a definite arrangement are called the amorphous solids. They are also called the glassy solids. For example glass, rubber, plastic, power, etc are the amorphous solids.

- They do not have a definite arrangement of its atoms, i e., they do not have a characteristic geometrical shape.
- They do not have a definite melting point.
- They are isotropic. i.e., their physical properties such as conductivity of heat refractive index etc, are same in all the directions.
- They are not the real solids.

Monocrystal and Polycrystalline

- Monocrystal is a crystal in which the ordered arrangements of the atoms or molecules extends throughout the piece of solid, irrespective of its size.
- Polycrystal is a crystalline solid in which each piece of the solid has a number of monocrystals with developed faces joined together.
- The polycrystal ceramic made from PbO, ZnO and TiO are used in gas lighters and telephone receivers.

Liquid Crystals

- Some organic crystalline solid when heated acquire fluidity but retain their anisotropic properties. They are called liquid crystals.
- Some liquid crystals like cyanobiphenyl can change the plane of polarization of light and such Liquid Crystal Displays (LCD) are used in watches and micro calculators.

Crystal Lattice

- A crystal is made up of a three- dimensional array of points such that each point is surrounded by the eight nearest points in an identical way. Such an array of points is known as Bravais lattice or space lattice.

- Unit cell is the smallest unit of the crystal lattice, repetition of which in three dimensions gives rise to crystal lattice.
- The length of three sides of a unit cell are called Primitives or lattice constant represented by a , b , c . The angle between three crystallographic axis are called interfacial angles represented by α , β and γ . The primitives and interfacial angles constitute the lattice parameters of a unit cell.
- [The cubic crystal may be of the form, simple cubic (sc) lattice, the body centred cubic (bcc) lattice, the face centred Cubic (fcc) lattice.]
- The coordination number is defined as the number of nearest neighbours around any lattice point (or atom) in the crystal lattice.
 - (a) For sc, coordination number is 6.
 - (b) For bcc, coordination number is 8.
 - (c) For fcc, coordination number is 12.
 - (d) For sc, atomic radius is $a / 2$.
 - (e) For bcc, atomic radius is $a \sqrt{3} / 4$.
 - (f) For fcc, atomic radius is $a / 2\sqrt{2}$.

Classification of solids on the basis of conductivity

- (i) **Conductor** Conductors are those substances through which electricity can pass easily, e.g., all metals are conductors.
- (ii) **Insulator** Insulators are those substances through which electricity cannot pass, e.g., wood, rubber, mica etc.
- (iii) **Semiconductor** Semiconductors are those substances whose conductivity lies between conductors and insulators. e.g., germanium, silicon, carbon etc.

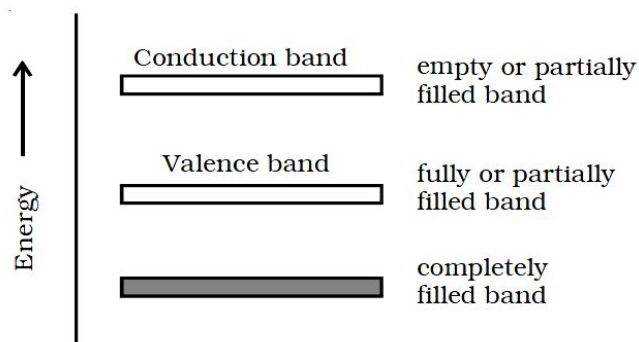
ENERGY BANDS OF SOLIDS

Energy Band

In a crystal due to interatomic interaction valence electrons of one atom are shared by more than one atom in the crystal. Now splitting of energy levels takes place. The collection of these closely spaced energy levels is called an energy band.

1. Valence Band

This energy band contains valence electrons. This band may be partially or completely filled with electrons but never be empty. The electrons in this band are not capable of gaining energy from external electric field to take part in conduction of current.



2. Conduction Band

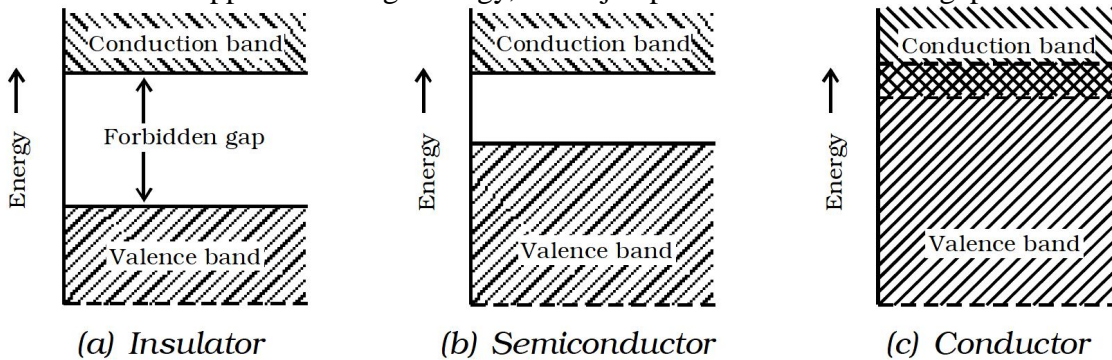
This band contains conduction electrons. This band is either empty or partially filled with electrons. Electrons present in this band take part in the conduction of current.

3. Forbidden Band

This band is completely empty. The minimum energy required to shift an electron from valence band to conduction band is called forbidden energy gap. If an electron is to be transferred from valence band to conduction band, external energy is required, which is equal to the forbidden energy gap.

Insulators

In an insulator, the forbidden energy gap is very large (see below fig a). In general, the forbidden energy gap is more than 3eV and almost no electrons are available for conduction. Therefore, a very large amount of energy must be supplied to a valence electron to enable it to move to the conduction band. If the electron is supplied with high energy, it can jump across the forbidden gap.



Energy band of solids

Semiconductors

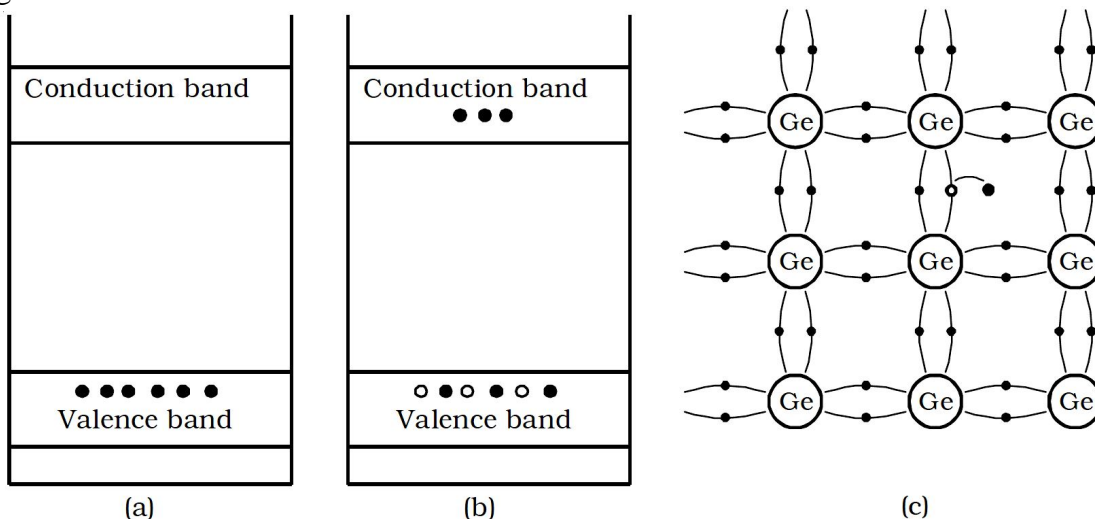
In semiconductors (see above fig b), the forbidden gap is very small. Germanium and silicon are the best examples of semiconductors. The forbidden gap energy is of the order of 0.7eV for Ge and 1.1eV for Si. There are no electrons in the conduction band. The valence band is completely filled at 0 K . With a small amount of energy that is supplied, the electrons can easily jump from the valence band to the conduction band.

Conductors

In conductors, there is no forbidden gap available, the valence and conduction band overlap each other (see above Fig c). The electrons from valence band freely enter into the conduction band. Due to the overlapping of the valence and conduction bands, a very low potential difference can cause the continuous flow of current.

Electrons and holes in semiconductors

The charge carriers at absolute zero temperature and at room temperature respectively is shown in below fig a and b.



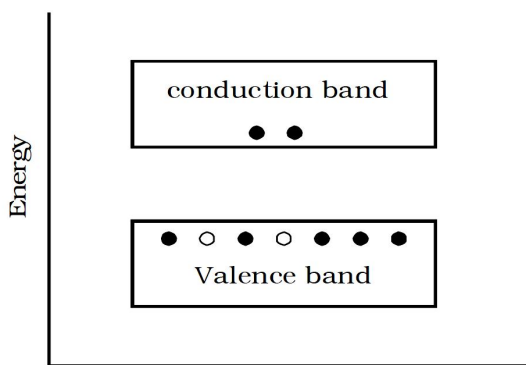
The electrons in an intrinsic semiconductor, which move in to the conduction band at high temperatures are called as intrinsic carriers. In the valence band, a vacancy is created at the place where the electron was present, before it had moved in to the conduction band. This vacancy is called hole. Fig c helps in understanding the creation of a hole. Consider the case of pure germanium crystal. It has four electrons in its outer or valence orbit. These electrons are known as valence electrons. When two atoms of germanium are brought close to each other, a covalent bond is formed between the atoms. If some additional energy is received, one of the electrons contributing to a covalent bond breaks and it is free to move in the crystal lattice.

While coming out of the bond, a hole is said to be created at its place, which is usually represented by a open circle. An electron from the neighbouring atom can break the covalent bond and can occupy this hole, creating a hole at another place. Since an electron has a unit negative charge, the hole is associated with a unit positive charge. The importance of hole is that, it may serve as a carrier of electricity in the same manner as the free electron, but in the opposite direction.

Intrinsic semiconductor

A semiconductor which is pure and contains no impurity is known as an intrinsic semiconductor. In an intrinsic semiconductor, the number of free electrons and holes are equal. Common examples of intrinsic semiconductors are pure germanium and silicon.

The forbidden energy gap is so small that even at ordinary room temperature, there are many electrons which possess sufficient energy to cross the forbidden energy gap and enter into the conduction band. Schematic band diagram of an intrinsic semiconductor at room temperature is represented in below Figure.



Doping a semiconductor

Electrons and holes can be generated in a semiconductor crystal with heat energy or light energy. But in these cases, the conductivity remains very low. The efficient and convenient method of generating free electrons and holes is to add very small amount of selected impurity inside the crystal. The impurity to be added is of the order of 100 ppm (parts per million). The process of addition of a very small amount of impurity into an intrinsic semiconductor is called doping. The impurity atoms are called dopants. The semiconductor containing impurity atoms is known as impure or doped or extrinsic semiconductor.

There are three different methods of doping a semiconductor.

- (i) The impurity atoms are added to the semiconductor in its molten state.
- (ii) The pure semiconductor is bombarded by ions of impurity atoms.
- (iii) When the semiconductor crystal containing the impurity atoms is heated, the impurity atoms diffuse into the hot crystal. Usually, the doping material is either pentavalent atoms (bismuth, antimony, phosphorous, arsenic which have five valence electrons) or trivalent atoms (aluminium, gallium, indium, boron which have three valence electrons).

The pentavalent doping atom is known as donor atom, since it donates one electron to the conduction band of pure semiconductor. The trivalent atom is called an acceptor atom, because it accepts one electron from the pure semiconductor atom.

Extrinsic semiconductor

An extrinsic semiconductor is one in which an impurity with a valency higher or lower than the valency of the pure semiconductor is added, so as to increase the electrical conductivity of the semiconductor. Depending upon the type of impurity atoms added, an extrinsic semiconductor can be classified as N-type or P-type.

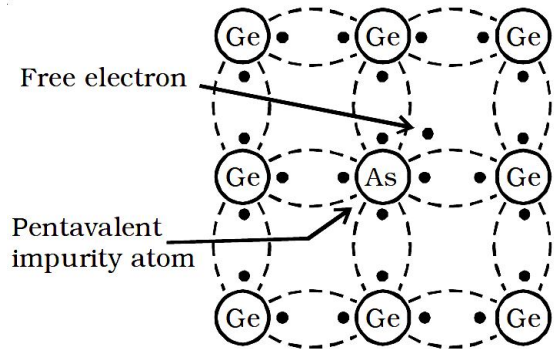
(a) N-type semiconductor

When a small amount of pentavalent impurity such as arsenic is added to a pure germanium semiconductor crystal, the resulting crystal is called N-type semiconductor.

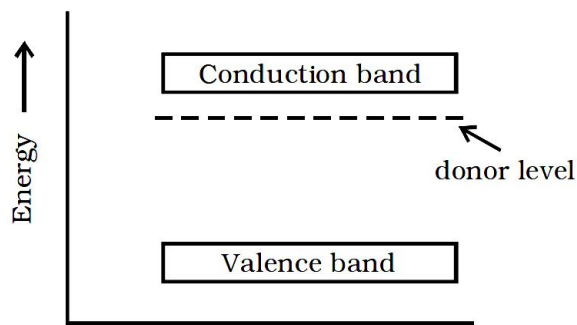
The below Figure shows the crystal structure obtained when pentavalent arsenic impurity is added with pure germanium crystal. The four valence electrons of arsenic atom form covalent bonds with electrons of neighbouring four germanium atoms. The fifth electron of arsenic atom is loosely bound. This

electron can move about almost as freely as an electron in a conductor and hence it will be the carrier of current. In the energy band picture, the energy state corresponding to the fifth valence electron is in the forbidden gap and lies slightly below the conduction band (see below Fig b). This level is known as the donor level.

When the fifth valence electron is transferred to the conduction band, the arsenic atom becomes positively charged immobile ion. Each impurity atom donates one free electron to the semiconductor. These impurity atoms are called donors. In N-type semiconductor material, the number of electrons increases, compared to the available number of charge carriers in the intrinsic semiconductor. This is because, the available larger number of electrons increases the rate of recombination of electrons with holes. Hence, in N-type semiconductor, free electrons are the majority charge carriers and holes are the minority charge carriers.



a N-type semiconductor

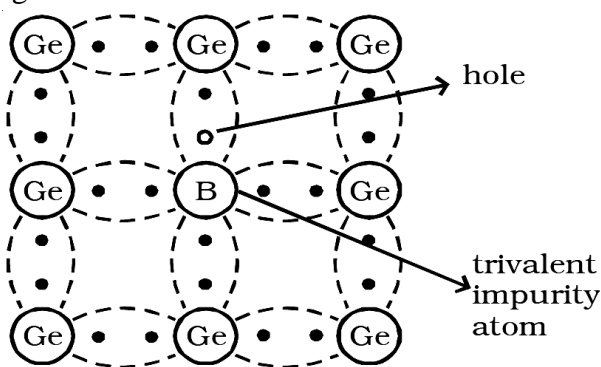


b Energy band diagram of N-type semiconductor

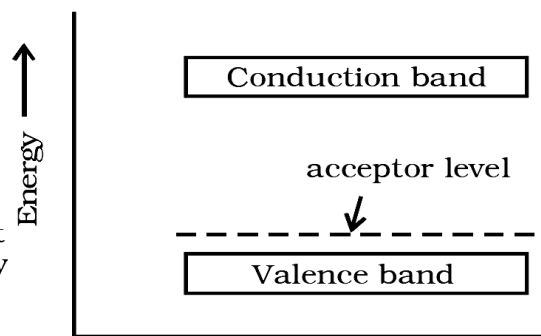
(b) P-type semiconductor

When a small amount of trivalent impurity (such as indium, boron or gallium) is added to a pure semiconductor crystal, the resulting semiconductor crystal is called P-type semiconductor.

The below figure shows the crystal structure obtained, when trivalent boron impurity is added with pure germanium crystal. The three valence electrons of the boron atom form covalent bonds with valence electrons of three neighbourhood germanium atoms. In the fourth covalent bond, only one valence electron is available from germanium atom and there is deficiency of one electron which is called as a hole. Hence for each boron atom added, one hole is created. Since the holes can accept electrons from neighbourhood, the impurity is called acceptor. The hole, may be filled by the electron from a neighbouring atom, creating a hole in that position from where the electron moves. This process continues and the hole moves about in a random manner due to thermal effects. Since the hole is associated with a positive charge moving from one position to another, this is called as P-type semiconductor. In the P-type semiconductor, the acceptor impurity produces an energy level just above the valence band. (see below Fig b). Since, the energy difference between acceptor energy level and the valence band is much smaller, electrons from the valence band can easily jump into the acceptor level by thermal agitation.



a P-type semiconductor

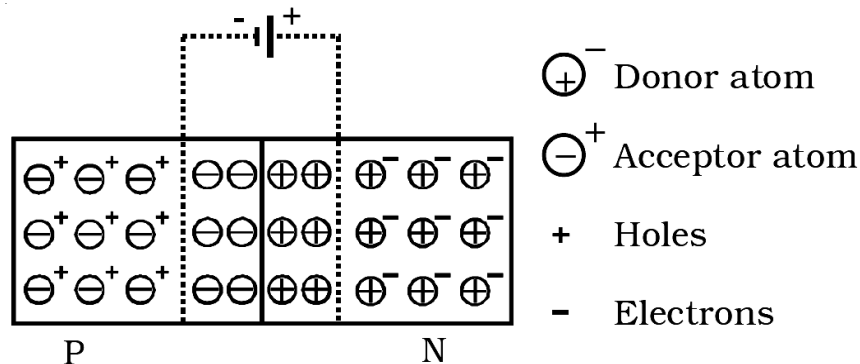


b Energy band diagram of a P-type semiconductor

In P-type semiconductors, holes are the majority charge carriers and free electrons are the minority charge carriers.

PN JUNCTION DIODE

If one side of a single crystal of pure semiconductor (Ge or Si) is doped with acceptor impurity atoms and the other side is doped with donor impurity atoms, a PN junction is formed as shown in below figure.



P region has a high concentration of holes and N region contains a large number of electrons. As soon as the junction is formed, free electrons and holes cross through the junction by the process of diffusion. During this process, the electrons crossing the junction from N-region into the P region, recombine with holes in the P-region very close to the junction. Similarly holes crossing the junction from the P-region into the N-region, recombine with electrons in the N-region very close to the junction. Thus a region is formed, which does not have any mobile charges very close to the junction. This region is called depletion region. In this region, on the left side of the junction, the acceptor atoms become negative ions and on the right side of the junction, the donor atoms become positive ions.

SYMBOL FOR A SEMICONDUCTOR DIODE

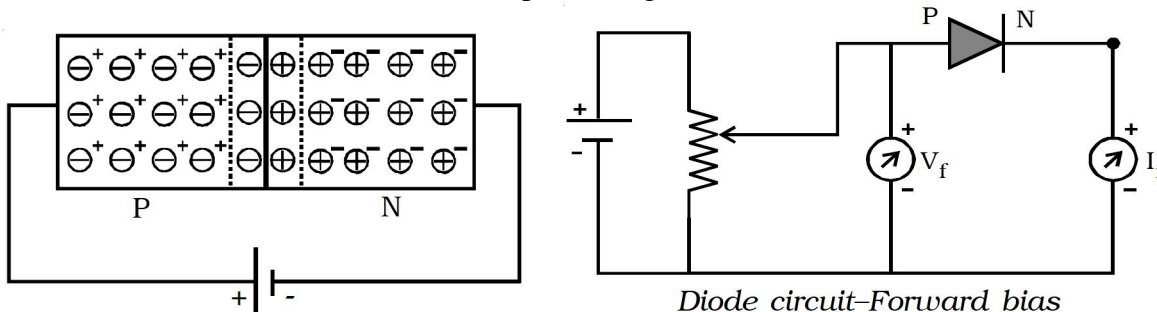
The diode symbol is shown in below figure. The P-type and N-type regions are referred to as P-end and N-end respectively. The arrow on the diode points the direction of conventional current.



FORWARD BIASED PN JUNCTION DIODE

When the positive terminal of the battery is connected to P-side and negative terminal to the N-side, so that the potential difference acts in opposite direction to the barrier potential, then the PN junction diode is said to be forward biased.

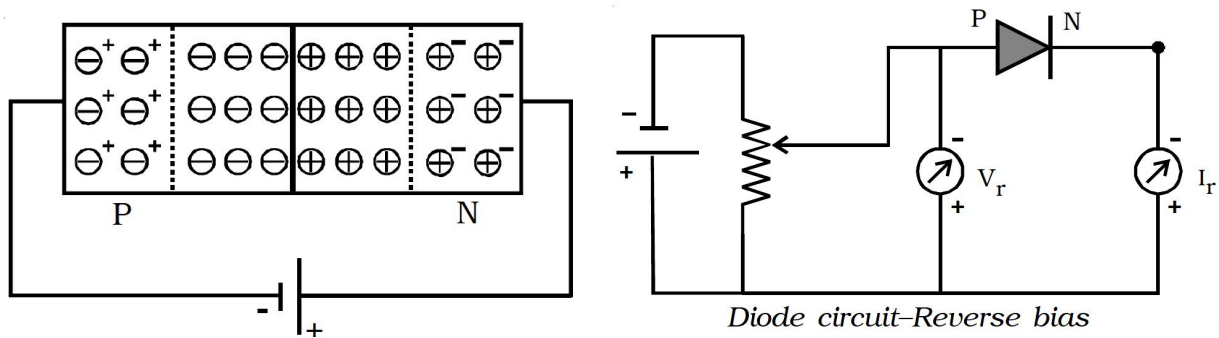
When the PN junction is forward biased (see the below Figure), the applied positive potential repels the holes in the P-region, and the applied negative potential repels the electrons in the N-region, so the charges move towards the junction. If the applied potential difference is more than the potential barrier, some holes and free electrons enter the depletion region.



Hence, the potential barrier as well as the width of the depletion region are reduced. The positive donor ions and negative acceptor ions within the depletion region regain electrons and holes respectively. As a result of this, the depletion region disappears and the potential barrier also disappears. Hence, under the action of the forward potential difference, the majority charge carriers flow across the junction in opposite direction and constitute current flow in the forward direction.

REVERSE BIASED PN JUNCTION DIODE

When the positive terminal of the battery is connected to the N-side and negative terminal to the P-side, so that the applied potential difference is in the same direction as that of barrier potential, the junction is said to be reverse biased.



When the PN junction is reverse biased (see the above Figure, electrons in the N region and holes in the P-region are attracted away from the junction. Because of this, the number of negative ions in the P-region and positive ions in the N-region increases. Hence the depletion region becomes wider and the potential barrier is increased. Since the depletion region does not contain majority charge carriers, it acts like an insulator. Therefore, no current should flow in the external circuit. But, in practice, a very small current of the order of few microamperes flows in the reverse direction. This is due to the minority carriers flowing in the opposite direction. This reverse current is small, because the number of minority carriers in both regions is very small. Since the major source of minority carriers is, thermally broken covalent bonds, the reverse current mainly depends on the junction temperature.

Rectifier

A device which convert alternating current or voltage into direct current or voltage IS known as rectifier. The process of converting AC into DC IS caned rectification.

Half-Wave Rectifier

A half-wave rectifier converts the half cycle of applied AC signal into DC signal. Ordinary transformer may be used here.

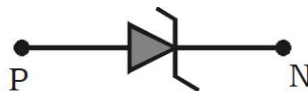
Full-Wave Rectifier

A full-wave rectifier converts the whole cycle of applied AC signal into DC signal. Centre top, transformer is used here.

[Half-wave rectifier converts only one-half of AC Into DC while full wave rectifier rectifies both halves of AC input.]

ZENER DIODE

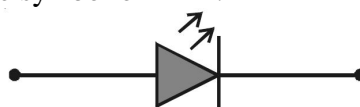
Zener diode is a reverse biased heavily doped semiconductor (silicon or germanium) PN junction diode, which is operated exclusively in the breakdown region. The symbol of a Zener diode is shown in below figure.



For normal operation of a Zener diode, in breakdown region, the current through the diode should be limited by an external circuit. Hence the power dissipated across the junction is within its power-handling capacity. Unless this precaution is observed, a large current will destroy the diode.

LIGHT EMITTING DIODE (LED)

A light emitting diode (LED) is a forward biased PN junction diode, which emits visible light when energized. The below figure shows the symbol of LED.



When a junction diode is forward biased, electrons from N-side and holes from P-side move towards the depletion region and recombination takes place. When an electron in the conduction band recombines with a hole in the valence band, energy is released.

If the semiconductor material is translucent, light is emitted and the junction becomes a light source (turned ON). The LED is turned ON, when it is forward biased and it is turned OFF, when it is reverse biased. The colour of the emitted light will depend upon the type of the material used. By using gallium arsenide phosphide and gallium phosphide, a manufacturer can produce LEDs that radiate red, green, yellow and orange. LEDs are used for instrument displays, calculators and digital watches.

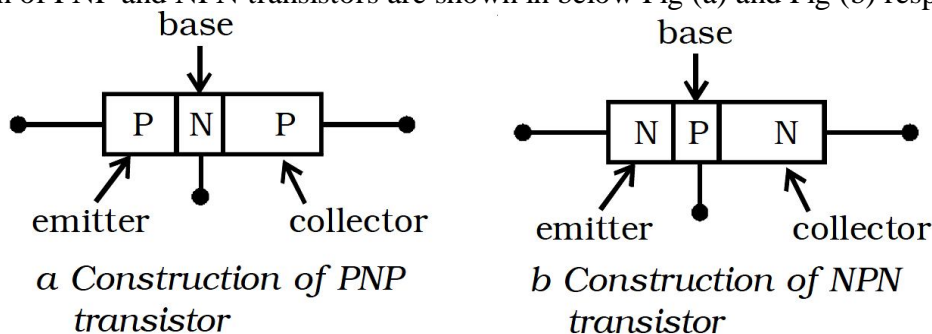
JUNCTION TRANSISTOR

A junction transistor is a solid state device. It consists of silicon or germanium crystal containing two PN junctions. The two PN junctions are formed between the three layers. These are called base, emitter and collector.

(i) Base (B) layer : It is a very thin layer, the thickness is about 25 microns. It is the central region of the transistor.

(ii) Emitter (E) and Collector (C) layers : The two layers on the opposite sides of B layer are emitter and collector layers. They are of the same type of the semiconductor. An ohmic contact is made to each of these layers. The junction between emitter and base is called emitter junction. The junction between collector and base is called collector junction.

The construction of PNP and NPN transistors are shown in below Fig (a) and Fig (b) respectively.



For a transistor to work, the biasing to be given are as follows :

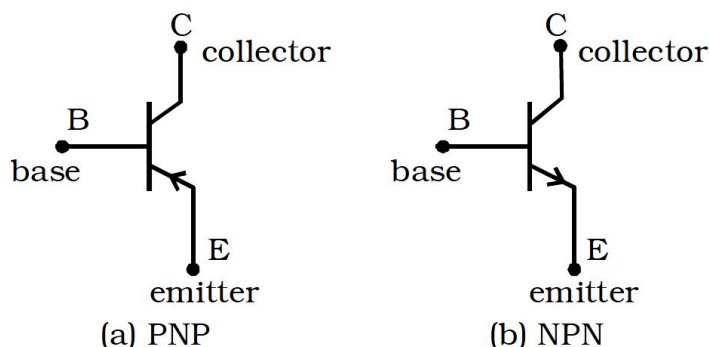
(i) The emitter-base junction is forward biased, so that majority charge carriers are repelled from the emitter and the junction offers very low resistance to the current.

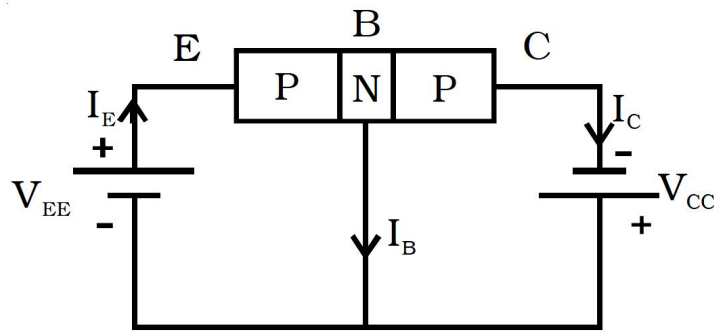
(ii) The collector-base junction is reverse biased, so that it attracts majority charge carriers and this junction offers a high resistance to the current.

Transistor circuit symbols

The circuit symbols for a PNP and NPN transistors are shown in below figure. The arrow on the emitter lead pointing towards the base represents a PNP transistor.

When the emitter-base junction of a PNP transistor is forward biased, the direction of the conventional current flow is from emitter to base. NPN transistor is represented by arrow on the emitter lead pointing away from the base. When the emitter base junction of a NPN transistor is forward biased, the direction of the conventional current is from base to emitter.





Transistor circuit configurations

There are three types of circuit connections (called configurations or modes) for operating a transistor. They are (i) common base (CB) mode (ii) common emitter (CE) mode and (iii) common collector (CC) mode.

The term common is used to denote the lead that is common to the input and output circuits. The different modes are shown in below figure for NPN transistor.

In a similar way, three configurations can be drawn for PNP transistor.

Transistor as an Amplifier

An amplifier is a device which is used for increasing the amplitude of variation of alternating voltage or current or power.

The amplifier thus produces an enlarged version of the input signal.

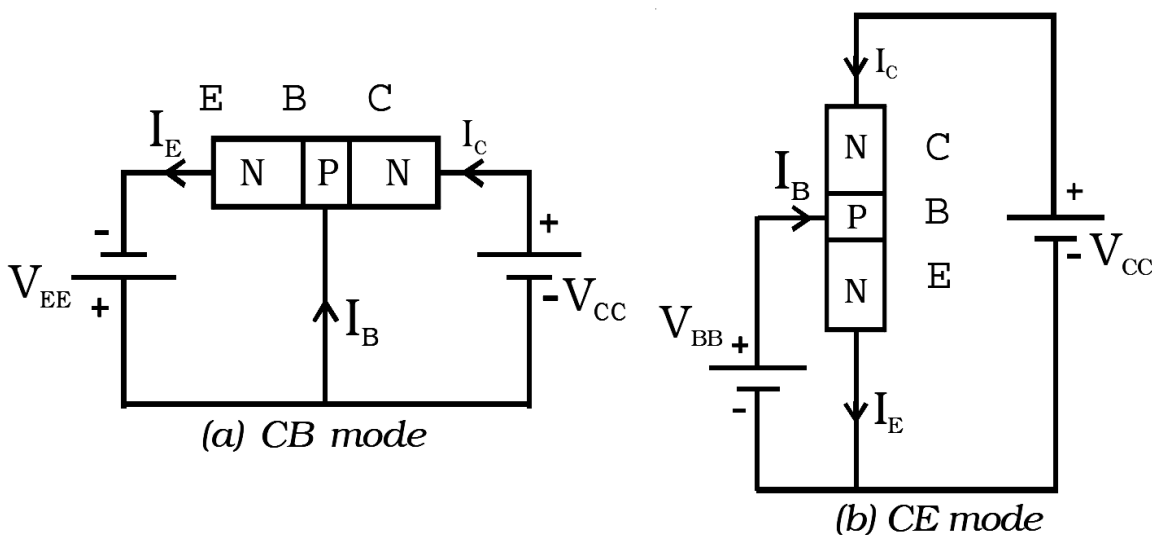
The general concept of amplification is represented in figure. There are two input terminals for the signal to be amplified and two output terminals for connecting the load; and a means of supplying power to the amplifier.

Current amplification factors α and β and the relation between them

The current amplification factor or current gain of a transistor is the ratio of output current to the input current. If the transistor is connected in common base mode, the current gain $\alpha = \frac{I_C}{I_E}$ and if the

transistor is connected in common emitter mode, the current gain $\beta = \frac{I_C}{I_B}$. The below figure shows a

NPN transistor connected in the common base and common emitter configurations. Since, 95% of the injected electrons reach the collector, the collector current is almost equal to the emitter current. Almost all transistors have α , in the range 0.95 to 0.99.



We know that

$$\alpha = \frac{I_C}{I_E} = \frac{I_C}{I_B + I_C} (\because I_E = I_B + I_C)$$

$$\Rightarrow \frac{1}{\alpha} = \frac{I_B + I_C}{I_C} = \frac{I_B}{I_C} + 1$$

$$\Rightarrow \frac{1}{\alpha} - 1 = \frac{I_B}{I_C} \Rightarrow \frac{1}{\alpha} - 1 = \frac{1}{\beta} \quad \left(\because \beta = \frac{I_C}{I_B} \right)$$

$$\Rightarrow \beta = \frac{\alpha}{1 - \alpha}$$

Usually β lies between 50 and 300. Some transistors have β as high as 1000.

DIGITAL SIGNAL AND LOGIC LEVELS

A digital signal (pulse) is shown in below figure. It has two discrete levels, 'High' and 'Low'. In most cases, the more positive of the two levels is called HIGH and is also referred to as logic 1. The other level becomes low and also called logic 0.

LOGIC GATES

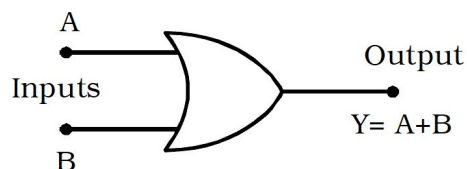
Circuits which are used to process digital signals are called logic gates. They are binary in nature. Gate is a digital circuit with one or more inputs but with only one output. The output appears only for certain combination of input logic levels. Logic gates are the basic building blocks from which most of the digital systems are built up.

Basic logic gates using discrete components

The basic elements that make up a digital system are 'OR', 'AND' and 'NOT' gates. These three gates are called basic logic gates. All the possible inputs and outputs of a logic circuit are represented in a table called TRUTH TABLE. The function of the basic gates are explained below with circuits and truth tables.

(i) OR gate

An OR gate has two or more inputs but only one output. It is known as OR gate, because the output is high if any one or all of the inputs are high. The logic symbol of a two input OR gate is shown in below figure.



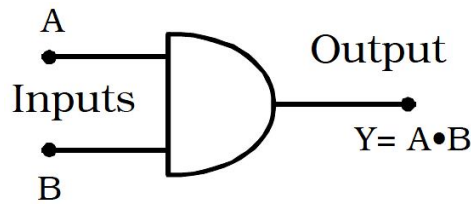
The Boolean expression to represent OR gate is given by $Y = A + B$ (+ symbol should be read as OR). The OR gate operations are shown in below Table.

Truth table of OR gate

Inputs		Output
A	B	$Y = A + B$
0	0	0
0	1	1
1	0	1
1	1	1

(ii) AND gate

An AND gate has two or more inputs but only one output. It is known as AND gate because the output is high only when all the inputs are high. The logic symbol of a two input AND gate is shown in below figure.



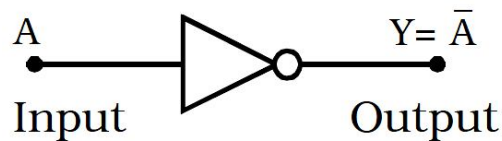
The Boolean expression to represent AND gate is given by $Y = A \cdot B$ (· should be read as AND). The AND gate operations are shown in below Table.

Truth table of AND gate

Inputs		Output
A	B	$Y = A \cdot B$
0	0	0
0	1	0
1	0	0
1	1	1

(iii) NOT gate (Inverter)

The NOT gate is a gate with only one input and one output. It is so called, because its output is complement to the input. It is also known as inverter. The below figure shows the logic symbol for NOT gate.



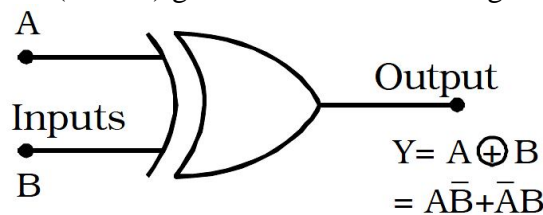
The Boolean expression to represent NOT operation is $Y = \bar{A}$. The NOT gate operations are shown in below Table.

Truth Table of NOT gate

Input	Output
A	$Y = \bar{A}$
0	1
1	0

Exclusive OR gate (EXOR gate)

The logic symbol for exclusive OR (EXOR) gate is shown in below figure.



The Boolean expression to represent EXOR operation is $Y = A \oplus B = A\bar{B} + \bar{A}B$. The EXOR gate operations are shown in below Table.

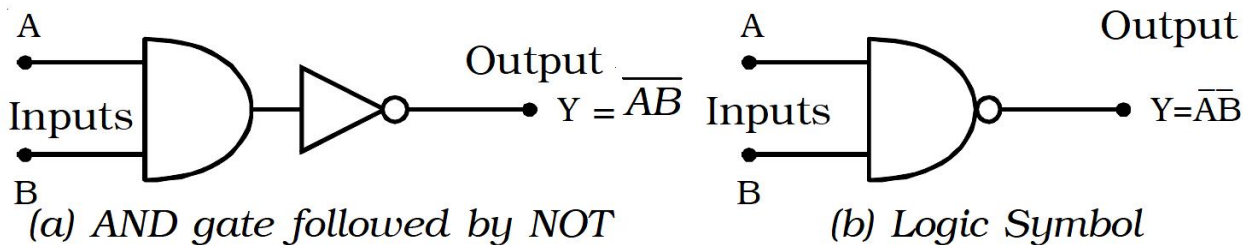
Truth table of EXOR gate

Inputs		Output
A	B	$Y = A \oplus B$
0	0	0
0	1	1
1	0	1
1	1	0

EXOR gate has an output 1, only when the inputs are complement to each other.

NAND gate

This is a NOT-AND gate. It can be obtained by connecting a NOT gate at the output of an AND gate. The logic symbol for NAND gate is shown in below figure.



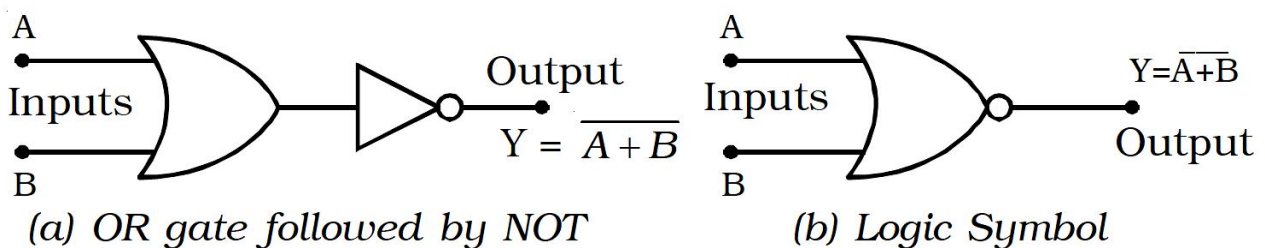
The Boolean expression to represent NAND Operation is $Y = \overline{AB}$. The NAND gate operations are shown in below Table.

Truth table of NAND gate

Inputs		Output
A	B	$Y = \overline{AB}$
0	0	1
0	1	1
1	0	1
1	1	0

NOR gate

This is a NOT-OR gate. It can be made out of an OR gate by connecting an inverter at its output. The logic symbol for NOR gate is given in below figure.



The Boolean expression to represent NOR gate is $Y = \overline{A+B}$. The NOR gate operations are shown in below Table.

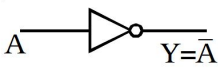
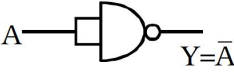
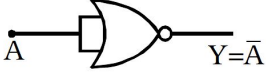
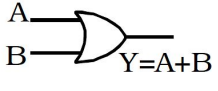
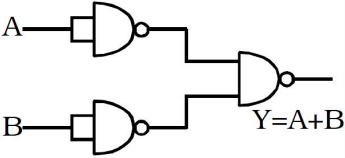
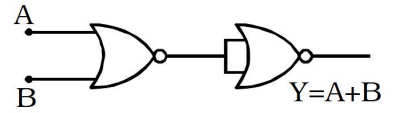
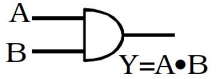
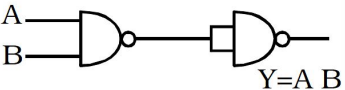
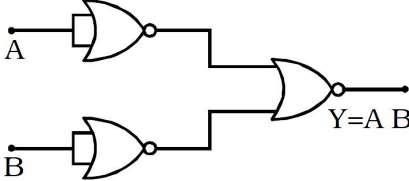
Truth table of NOR gate

Inputs		Output
A	B	$Y = \overline{A+B}$
0	0	1
0	1	0
1	0	0
1	1	0

NAND and NOR as Universal gates

NAND and NOR gates are called Universal gates because they can perform all the three basic logic functions. The below table gives the construction of basic logic gates NOT, OR and AND using NAND and NOR gates.

Substituting NAND / NOR gates

Logic function	Symbol	Circuits using NAND gates only	Circuits using NOR gates only
NOT			
OR			
AND			

Important Questions and Answers

VERY SHORT ANSWER TYPE QUESTIONS (1 MARK)

1. How is photodiode fabricated?

Ans: A photodiode is fabricated with a transparent window to allow light to fall on the diode.

2. State the reason, why GaAs is most commonly used in making of a solar cell. [AI 2008]

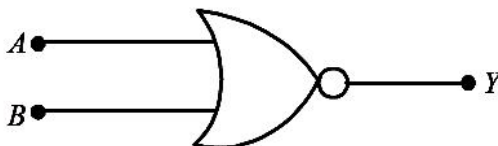
Ans: In solar radiations, intensity is maximum near 1.5 eV. In GaAs, $E_g \approx 1.53$ eV, so solar cell made of GaAs has high absorption coefficient of solar radiations.

3. Why should a photodiode be operated at a reverse bias? [AI 2008]

Ans: Because in reverse bias, the fractional change in minority carriers is much larger than the fractional change in majority carriers in forward bias. So, effect of intensity of light on the minority carrier dominated reverse bias current is more easily measurable than that in forward bias current.

4. Give the logic symbol of NOR gate. [AI 2009]

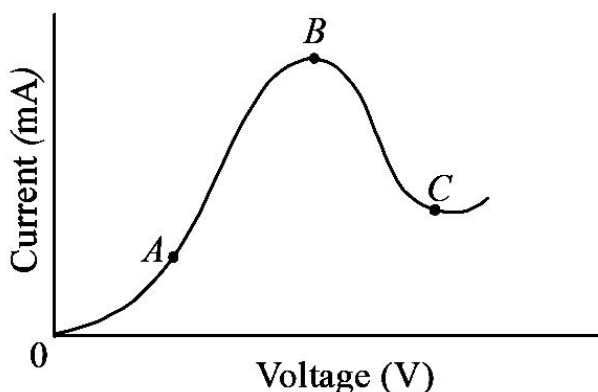
Ans:



5. In a transistor, doping level in base is increased slightly. How will it affect (i) collector current and (ii) base current? [AI 2011]

Ans: Collector current will decrease, as more of the majority carriers going from emitter to collector get neutralised in base by electron hole combination resulting increase of base current.

6. The graph shown in the figure represents a plot of current versus voltage for a given semiconductor. Identify the region, if any, over which the semiconductor has a negative resistance.



Ans: Region *BC* of the graph has a negative slope, hence in region *BC* semiconductor has a negative resistance.

7. State the factor, which controls : (i) wavelength of light, and (ii) intensity of light emitted by an LED.

Ans: (i) Wavelength of light emitted depends on the nature of semiconductor.

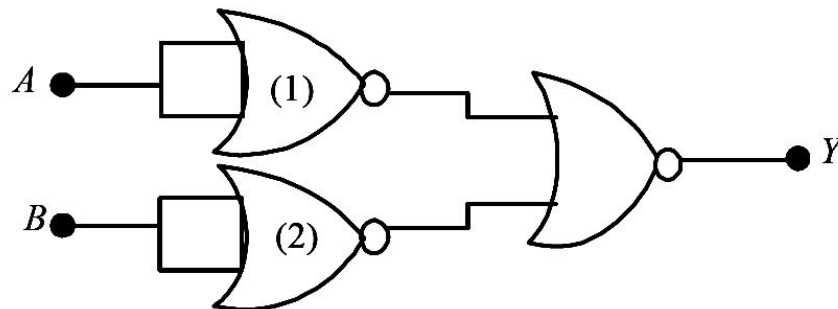
(ii) Intensity of light emitted depends on the **forward current**.

SHORT ANSWER TYPE QUESTIONS (2 MARKS/3 MARKS)

8. Why does the reverse current in pn-junction show a sudden increase at the critical voltage? Name any semiconductor device which operates under the reverse bias in the breakdown region. [AI 2013]

Ans: At critical voltage/breakdown voltage, a large number of covalent bonds break, resulting in availability of large number of charge carriers. Zener diode.

9. The inputs A and B are inverted by using two NOT gates and their outputs are fed to the NOR gate as shown below.



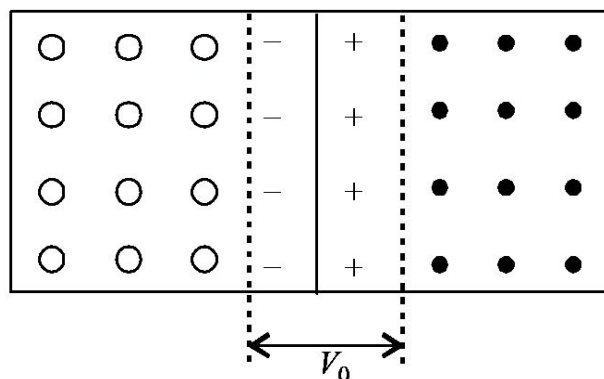
Analyse the action of the gates (1) and (2) and identify the logic gate of the complete circuit so obtained. Give its symbol and the truth table. [AI 2008]

Ans: $Y = \overline{\overline{A} + \overline{B}} = A.B$

So, the logic circuit is equivalent to AND gate.

10. With the help of a suitable diagram, explain the formation of depletion region in a pn junction. How does its width change when the junction is (i) forward biased, and (ii) reverse biased? [AI 2009]

Ans: When pn junction is formed, then at the junction, free electrons from n-type diffuse over to p-type, and hole from p-type over to n-type. Due to this a layer of positive charge is built on n side and a layer of negative charge is built on p side of the pn junction.



This layer sufficiently grows up within a very short time of the junction being formed, preventing any further movement of charge carriers (electron and holes) across the pn junction. This space charge region, developed on either side of the junction is known as depletion region as the electrons and holes taking part in the initial movement across the junction deplete, this region of its free charges. Width of depletion region layer decreases when the junction is forward biased and increases when it is reverse biased.

11. State briefly the underlying principle of a transistor oscillator. Draw a circuit diagram showing how the feedback is accomplished by inductive coupling. Explain the oscillator action. [AI 2008]

OR

12. Describe briefly with the help of a circuit diagram how an npn transistor is used to produce self sustained oscillations.

OR

13. Explain briefly the principle on which a transistor amplifier works as an oscillator. Draw the necessary circuit diagram and explain its working.

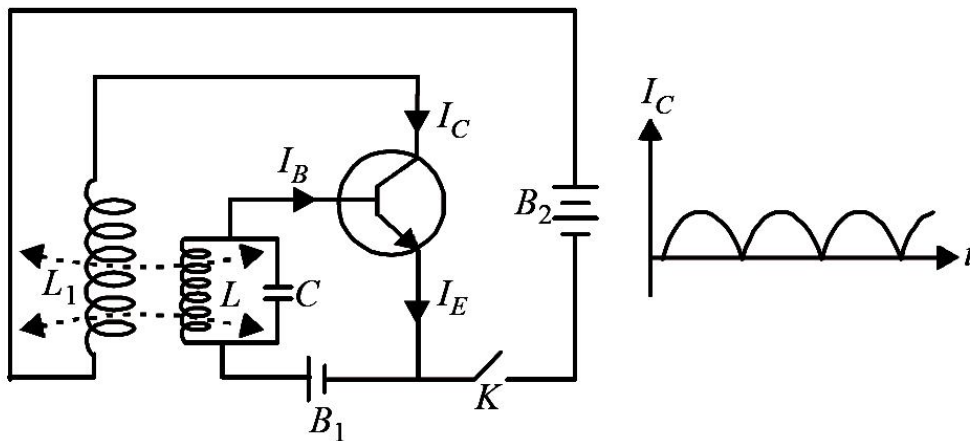
Ans: Transistor as an Oscillator : By using transistor as an oscillator we can convert d.c. into a.c. of desired frequency. It consists of Tank circuit which consists of an inductor 'L' and capacitor 'C' in parallel with each other producing the LC oscillations of charge with frequency

$$v = \frac{1}{2\pi\sqrt{LC}}$$

By changing the value of L, C or both oscillations of any frequency can be obtained.

Transistor Amplifier: The oscillations occurring in LC circuit are applied to input of transistor amplifier. Due to amplifying action of transistor, we get amplified output of these oscillations. A suitable fraction of the output of transistor is fed to LC circuit to meet the losses in LC circuit.

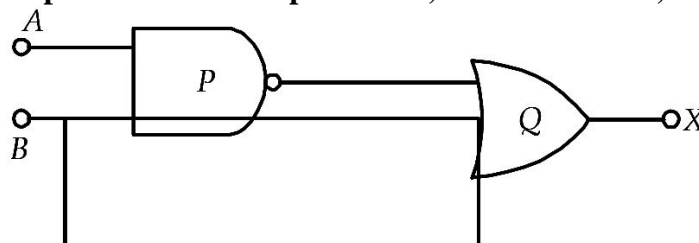
Feedback circuit: It is a circuit which receives the output of transistor amplifier and supplies correct amount of energy to LC circuit. When the key K is closed, the collector current I_C in the circuit starts increasing. The changing current through inductance L_1 induces an emf across the inductor L, which further increases the base current I_B and hence the emitter current I_E . The upper plate of capacitor gets positively charged.



As the current through inductor L_1 becomes steady, the mutual induction stops and induced emf across inductor L becomes zero and capacitor starts getting discharged through inductor L, thereby decreasing the base current I_B and hence emitter current I_E and collector current I_C till I_C becomes zero. Again the collector, base and emitter currents starts increasing and after attaining a maximum value starts decreasing. In this way collector current oscillates between maximum and zero values. In the oscillator, energy is supplied by the battery B_2 to the LC circuit at proper time and in proper phase, therefore the battery B_2 gets consumed in the oscillator. This means that in oscillator d.c. is converted into a.c.

14. (i) Identify the logic gates marked P and Q in the given logic circuit.

(ii) Write down the output at X for the inputs $A = 0, B = 0$ and $A = 1, B = 1$. [AI 2010]



Ans: (i) Gate P is a NAND gate, and gate Q is an OR gate.

(ii) Boolean expression for the above logic circuit is

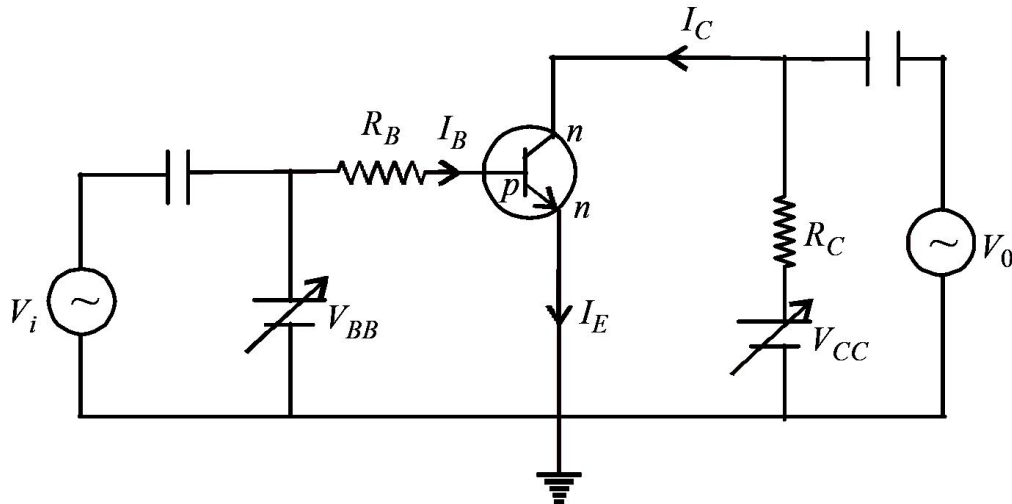
$$X = \overline{A \cdot B} + B = \overline{A} + \overline{B} + B = \overline{A} + 1$$

$$X = 1 \text{ [using boolean identities]}$$

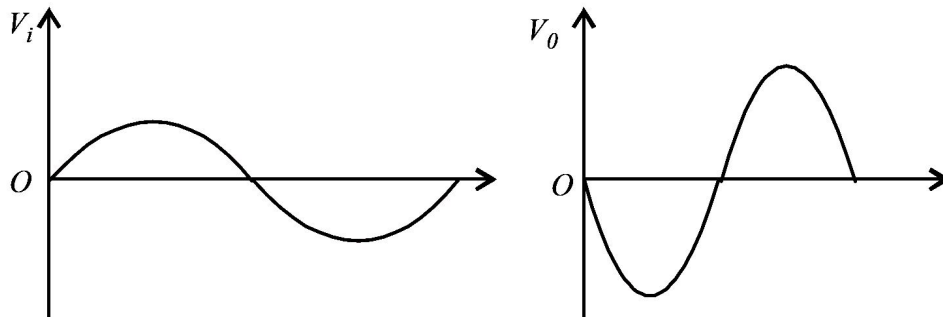
Thus output at X is going to be 1 for all the possible inputs at A and B.

15. Give a circuit diagram of a common emitter amplifier using an *nnp* transistor. Draw the input and output waveforms of the signal. Write the expression for its voltage gain. [AI 2009]

Ans:



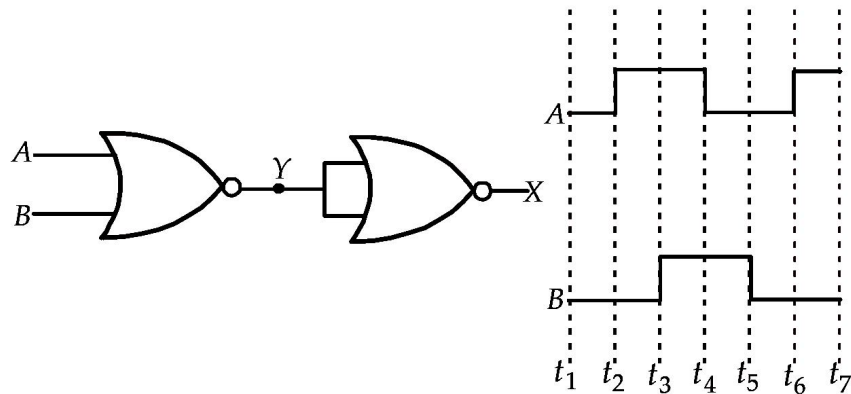
CE amplifier with npn transistor Input and output waveforms :



The voltage gain of amplifier is

$$A_v = \frac{\Delta V_o}{\Delta V_i} = \beta \frac{R_{out}}{R_{in}}$$

16. Draw the output waveform at X, using the given inputs A and B for the logic circuit shown below. Also, identify the logic operation performed by this circuit. [AI 2011]



Ans: Boolean expression of this combination is,

$$Y = \overline{A+B} \text{ and } X = \overline{\overline{A+B}} = A+B$$

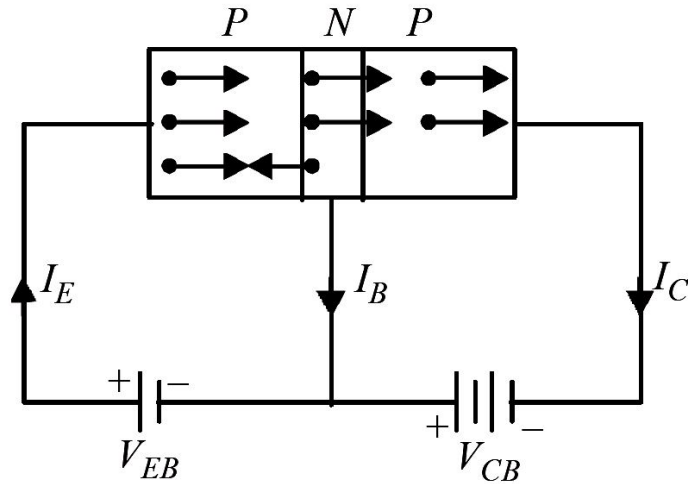
Therefore, the given logic circuit acts as OR gate. Hence, output is high when both or one of them is high. Accordingly the waveform of output is shown in figure.

17. Describe briefly with the help of a circuit diagram, how the flow of current carriers in a *pnp* transistor is regulated with emitter base junction forward biased and base collector junction reverse biased. [AI 2012]

Ans: Action of pnp Transistor

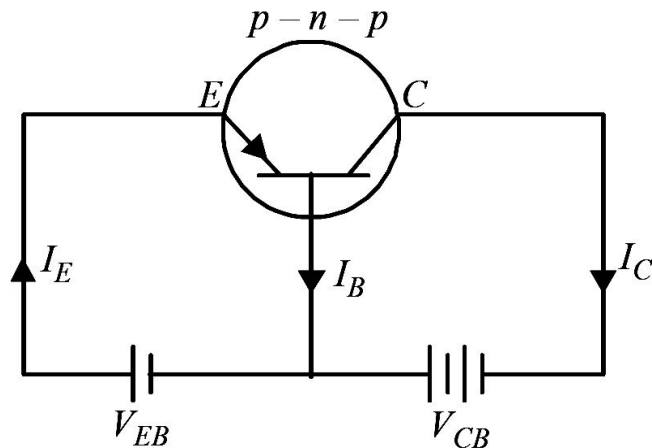
(a) The forward bias of the emitter base circuit repels the holes of emitter towards the base and electrons of base towards the emitter. As the base is very thin and lightly doped, most of the holes (\approx

95 %) entering it pass on to collector while a very few of them ($\approx 5\%$) recombine with the electrons of the base region.



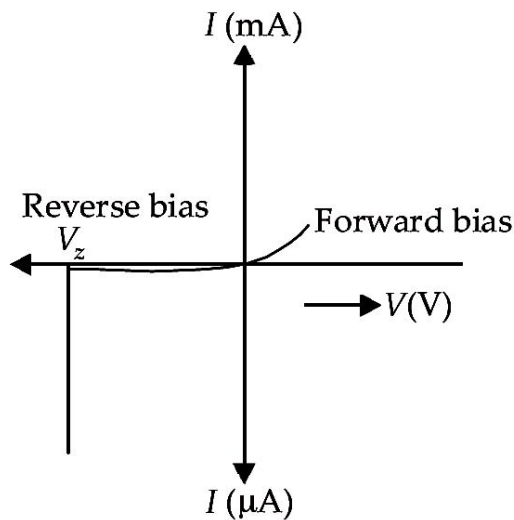
(b) As soon as a hole combines with an electron, an electron from the negative terminal of the battery V_{EB} enters the base. This sets up a small base current I_B . Each hole entering the collector region combines with an electron from the negative terminal of the battery V_{CB} and gets neutralised. This creates collector current I_C . Both the base current I_B and collector current I_C combine to form emitter current I_E

$$\therefore I_E = I_B + I_C$$



18. Name the semiconductor device that can be used to regulate an unregulated dc power supply. With the help of I V characteristics of this device, explain its working principle. [AI 2011]

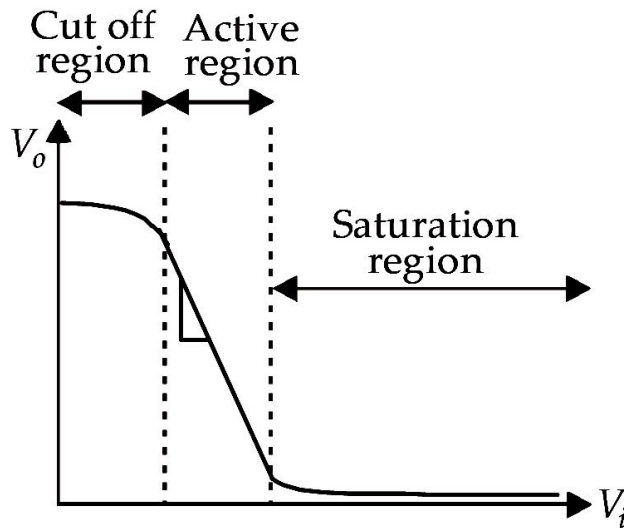
Ans: Zener diode



Working : The IV characteristics of a Zener diode is shown in the above figure. When the applied reverse bias voltage (V) reaches the breakdown voltage (V_z) of the Zener diode, there is a large change in the current. After the breakdown voltage V_z , a large change in the current can be produced by almost insignificant change in the reverse bias voltage. In other words, Zener voltage remains constant, even though current through the Zener diode varies over a wide range. This property of the Zener diode is used for regulating supply voltages so that they are constant.

19. Draw the transfer characteristic curve of a base biased transistor in CE configuration. Explain clearly how the active region of the V_o versus V_i curve in a transistor is used as an amplifier. [AI 2011]

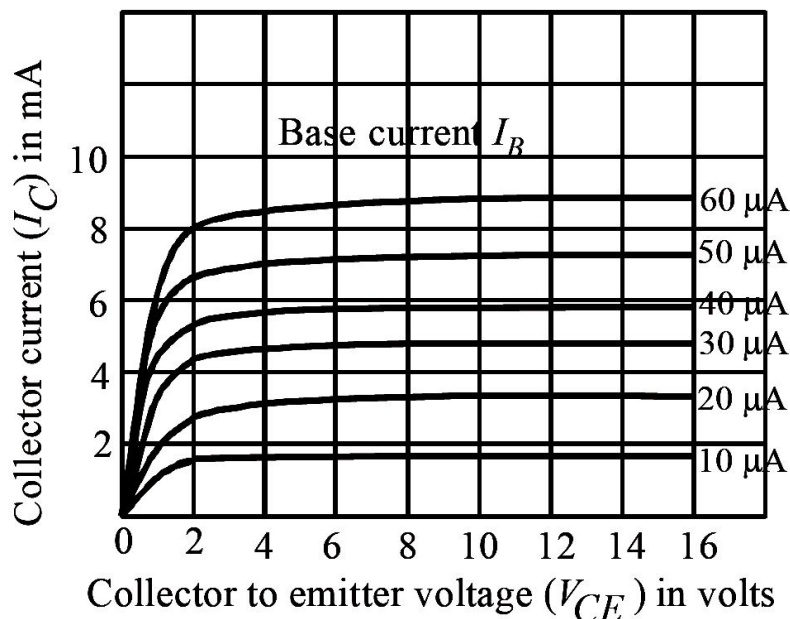
Ans: The transfer characteristic curve of a base biased transistor in CE configuration is shown below.



For using the transistor as an amplifier we will use the active region of the V_o versus V_i curve. The slope of the linear part of the curve represents the rate of change of the output with the input. If we consider ΔV_o and ΔV_i as small changes in the output and input voltages then $\Delta V_o / \Delta V_i$ is called the small signal voltage gain A_V of the amplifier.

20. Draw typical output characteristics of an npn transistor in CE configuration. Show how these characteristics can be used to determine output resistance. [AI 2013]

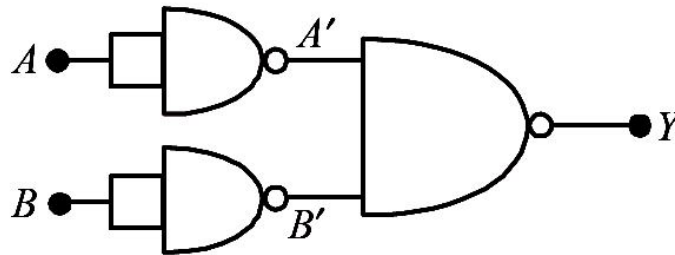
Ans:



Output resistance is the reciprocal of the slope of the linear part of the output characteristics.

$$r_o = \left(\frac{\Delta V_{CE}}{\Delta I_C} \right)_{I_B}$$

21. In the circuit shown in the figure, identify the equivalent gate of the circuit and make its truth table.



Ans: Here both the input terminals A and B are short circuited.

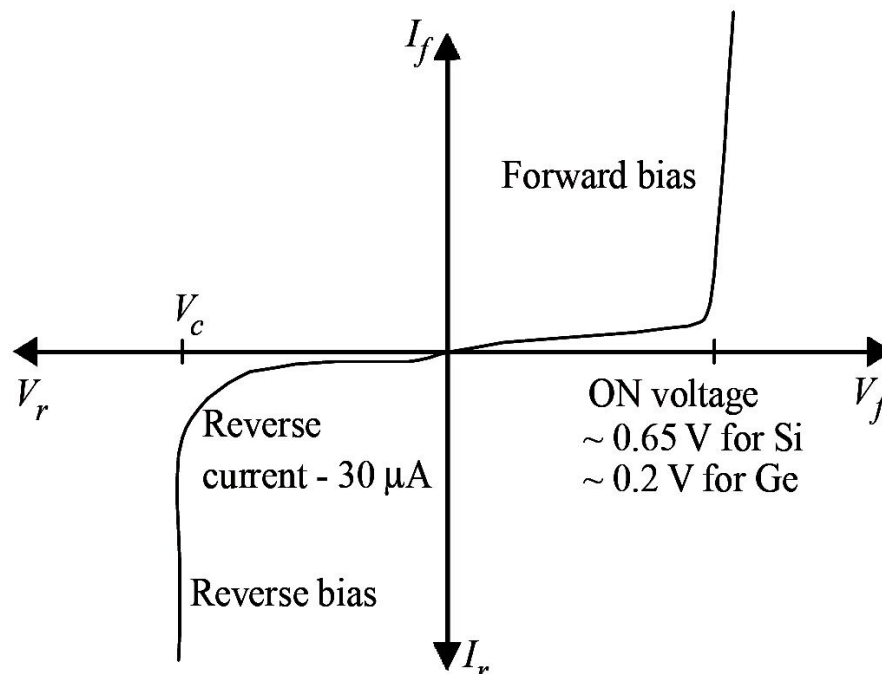
Truth Table

Inputs		Output
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

So, the equivalent gate is OR gate.

22. Draw VI characteristics of a pn junction diode. Why is the current under reverse bias almost independent of the applied potential upto a critical voltage?

Ans:

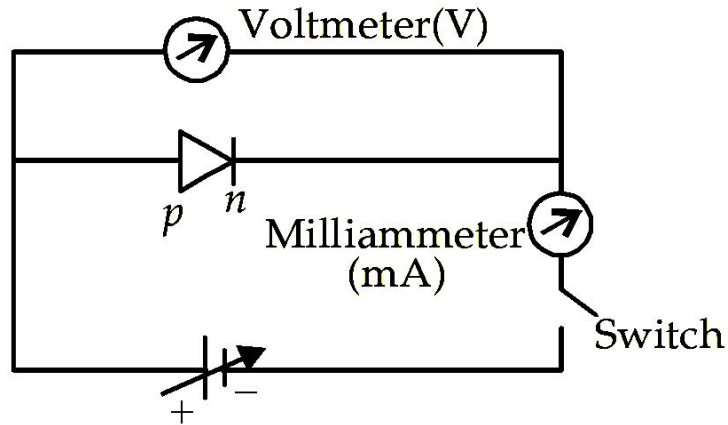


The reverse current is due to minority charge carriers and even a small voltage is sufficient to sweep the minority carriers from one side of the junction to the other side of the junction.

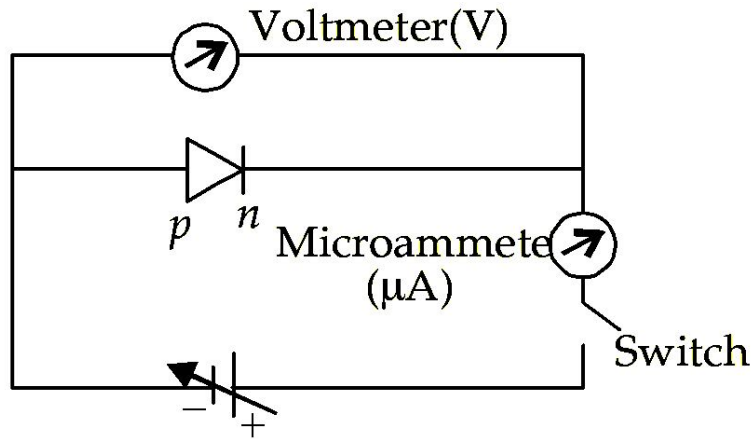
23. Draw the circuit diagrams of a pn junction diode in (i) forward bias, (ii) reverse bias. How are these circuits used to study the $V-I$ characteristics of a silicon diode? Draw the typical $V-I$ characteristics.

Ans: (a) Biasing of a pn junction diode:

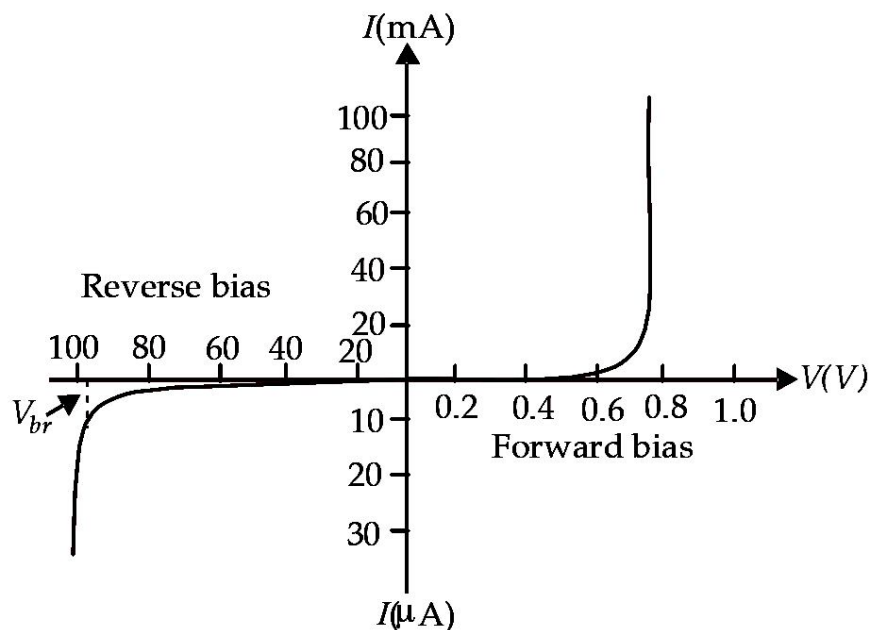
Forward Biasing: When an external voltage (V) is applied across the diode such that p side is connected with positive or at a higher potential and n side is connected with negative or at a lower potential, the diode is called “Forward Biased”



Reverse Biasing: When the external voltage (V) is applied across the diode such that p side is connected with negative or at a lower potential and n side is connected with positive or at a higher potential, the diode is called “Reverse Biased”.



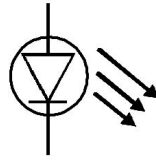
By changing the biasing voltage in both circuits above, corresponding readings of voltmeter and ammeter are observed, and graphs are plotted between them for both the circuits. These graphs are known as V - I characteristics.



V - I Characteristics of a Silicon diode

24. What is a light emitting diode (LED)? Mention two important advantages of LEDs over conventional lamps.

Ans: Light emitting diode (LED) is a junction diode made of gallium arsenide or indium phosphide in which when hole electron pairs recombine at forward biased *pn* junction, energy is released in the form of light.

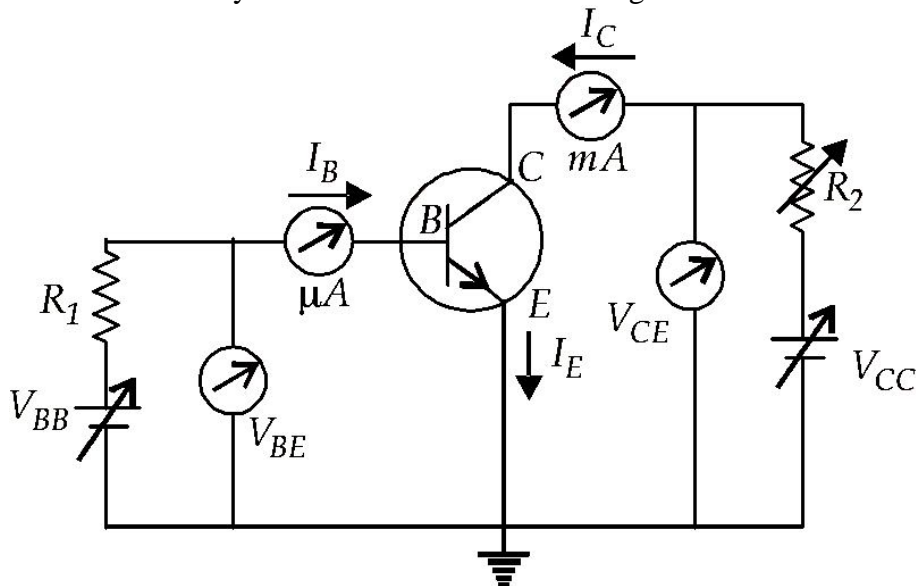


Two advantages of LED over conventional incandescent lamps are:

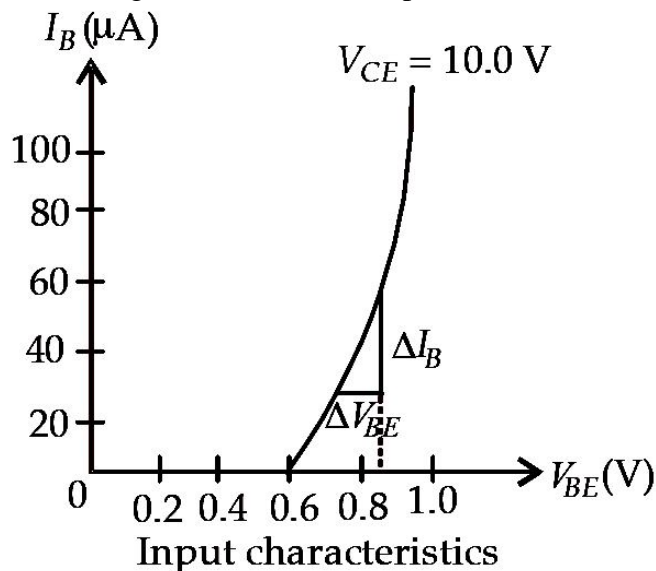
- (i) In LED energy is produced in the form of light only, whereas in incandescent lamp energy is produced in the form of heat and light. Thus, there is no energy loss in LED.
- (ii) To operate LED, very small voltage ($\approx 1\text{ V}$) is required, whereas for the incandescent lamp higher voltages are required.

25. Draw the circuit arrangement for studying the input and output characteristics of an *npn* transistor in *CE* configuration. With the help of these characteristics define (i) input resistance, (ii) current amplification factor.

Ans: Circuit arrangement for studying the input and output characteristics of an *npn* transistor in *CE* configuration is shown below. Symbols have their usual meaning.



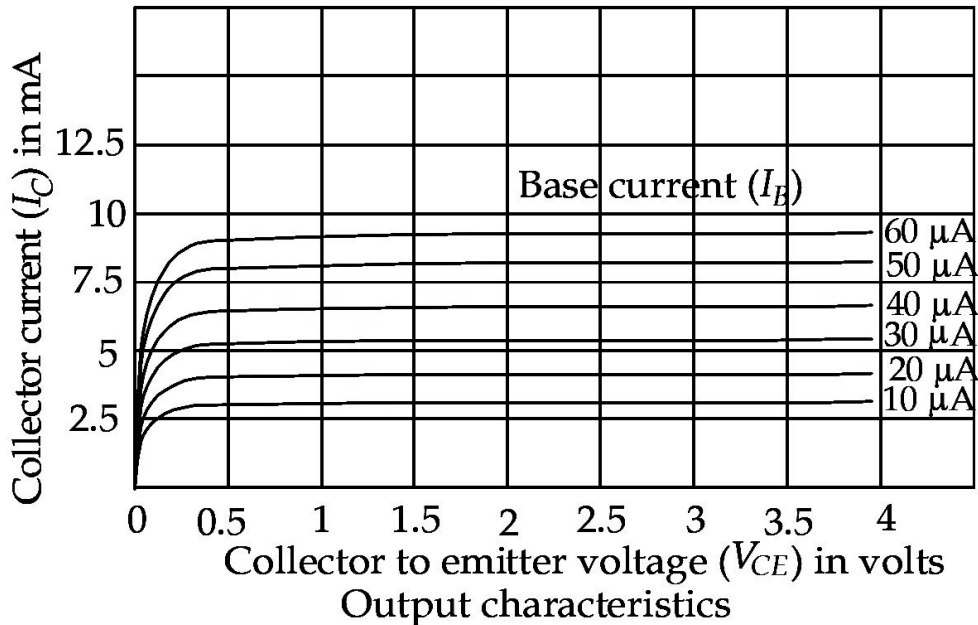
Input characteristics : A graph showing the variation of base current I_B with base emitter voltage V_{BE} at constant Collector emitter voltage V_{CE} is called the input characteristic of the transistor.



Input resistance (r_i): This is defined as the ratio of change in base emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔI_B) at constant collector emitter voltage (V_{CE}). This is dynamic (ac resistance) and as its value varies with the operating current in the transistor:

$$r_i = \left(\frac{\Delta V_{BE}}{\Delta I_B} \right)_{V_{CE}} = \frac{1}{\text{slope of input characteristics}}$$

Output characteristics : A graph showing the variation of collector current I_C with collector emitter voltage V_{CE} at constant base current I_B is called the output characteristic of the transistor.

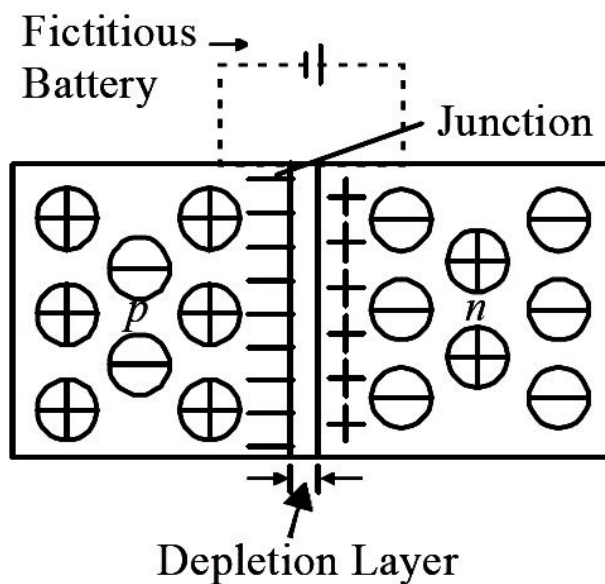


Current amplification factor (β): This is defined as the ratio of the change in collector current to the change in base current at a constant collector emitter voltage (V_{CE}) when the transistor is in active state.

26. Describe briefly, with the help of a diagram, the role of the two important processes involved in the formation of a pn junction.

Ans: The two processes are (i) Diffusion (ii) Drift

Diffusion : Holes diffuse from p side to n side ($p \rightarrow n$) and electrons diffuse from n side to p side ($n \rightarrow p$)

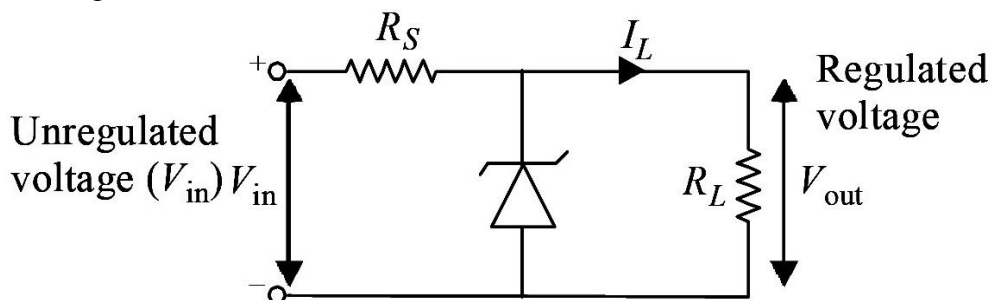


Drift : The motion of charge carriers, due to the applied electric field (\vec{E}) which results in drifting of holes along \vec{E} and of electrons opposite to that of electric field (\vec{E})

27. Name the device which is used as a voltage regulator. Draw the necessary circuit diagram and explain its working.

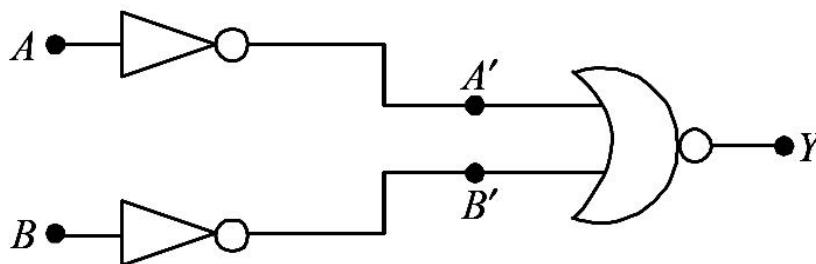
Ans: Zener Diode is used as a voltage regulator.

When applied reverse voltage V is less than zener voltage V_z i.e., $V < V_z$, then zener diode does not conduct any current, and is said to be in OFF state. When $V > V_z$ then zener diode conducts current at constant voltage V_z and is said to be in ON state.



Such zener diode is used in voltage stabilisation across a circuit. For this it is connected in parallel across the load resistor R_L in reverse bias. Suppose an unregulated d.c. input voltage V_{in} is applied to the zener diode of breakdown voltage V_z . When $V_{in} < V_z$ zener diode does not conduct any current and hence input voltage appears across the load R_L . When $V_{in} > V_z$, then the zener diode is in breakdown condition, and allows large reverse current to flow through it, keeping the voltage across it constant at V_z , which remains unaffected by value of load R_L . Thus, the output voltage across the zener diode is regulated voltage.

28. Identify the equivalent gate for the following circuit and write its truth table. [AI 2012]



Ans: AND Gate

A	B	$Y = A \cdot B$
0	0	0
0	1	0
1	0	0
1	1	1

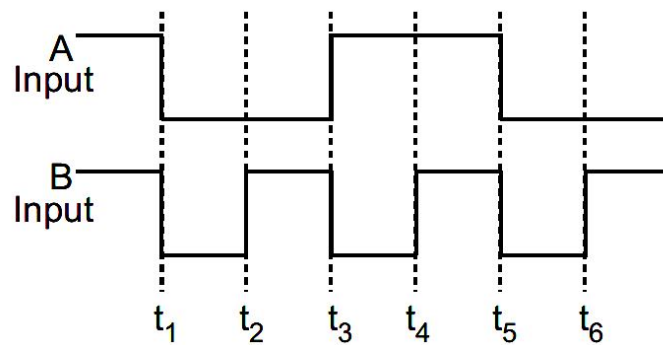
29. Distinguish between an intrinsic semiconductor and P-type semiconductor. Give reason, why a P type semiconductor crystal is electrically neutral, although $nh \gg ne$?

Ans:

Intrinsic semiconductor	P-type semiconductor
(i) It is a semiconductor in pure form.	(i) It is a semiconductor doped with p-type (like Al, In) impurity.
(ii) Intrinsic charge carriers are electrons and holes with equal concentration.	(ii) Majority charge carriers are holes and minority charge carriers are electrons.
(iii) Current due to charge carriers is feeble (of the order of μA).	(iii) Current due to charge carriers is significant (of the order of mA).

P-type semiconductor is electrically neutral because every atom, whether it is of pure semiconductor (Ge or Si) or of impurity (Al) is electrically neutral.

30. The given inputs A, B are fed to a 2-input NAND gate. Draw the output wave form of the gate.



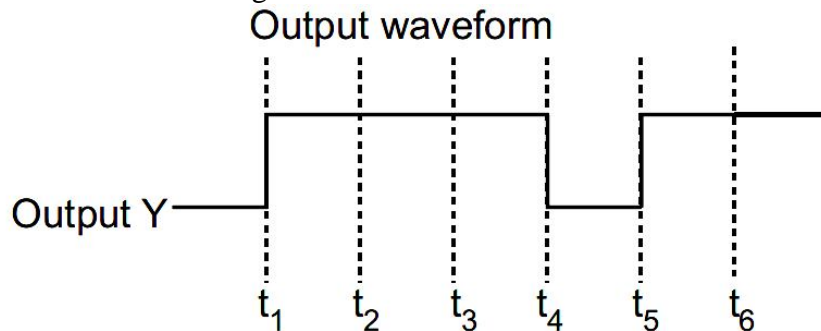
Ans: The output of NAND gate with inputs A and B is $Y = \overline{AB}$

i.e., output is obtained if either or both inputs are zero.

Accordingly the output waveform $Y = \overline{AB}$ is shown in fig.

i.e., output is zero between intervals 0 to t_1 and t_4 to t_5 and in all other intervals it is '1'.

The output waveform is shown in fig.



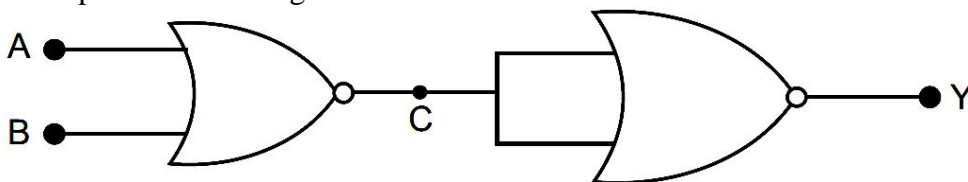
31. If the output of a 2 input NOR gate is fed as both inputs A and B to another NOR gate, write down a truth table to find the final output, for all combinations of A, B .

Ans: First gate is NOR gate, its output $C = \overline{A+B}$

Second gate is also NOR gate, its output

$$Y = \overline{C+C} = \overline{C.C} = \overline{C} = \overline{\overline{A+B}} = A+B$$

This is Boolean expression for OR gate.

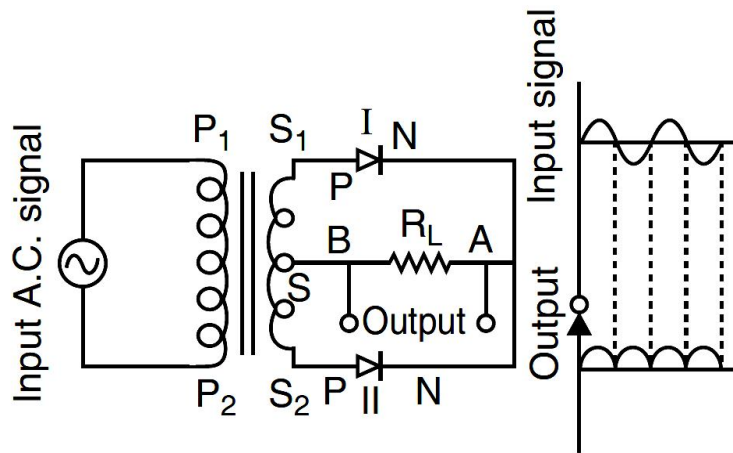


Its truth table is

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

32. Draw a labelled circuit diagram of a full-wave rectifier and briefly explain its working principle.

Ans: For full wave rectifier we use two junction diodes. The circuit diagram for full wave rectifier using two junction diodes is shown in figure.

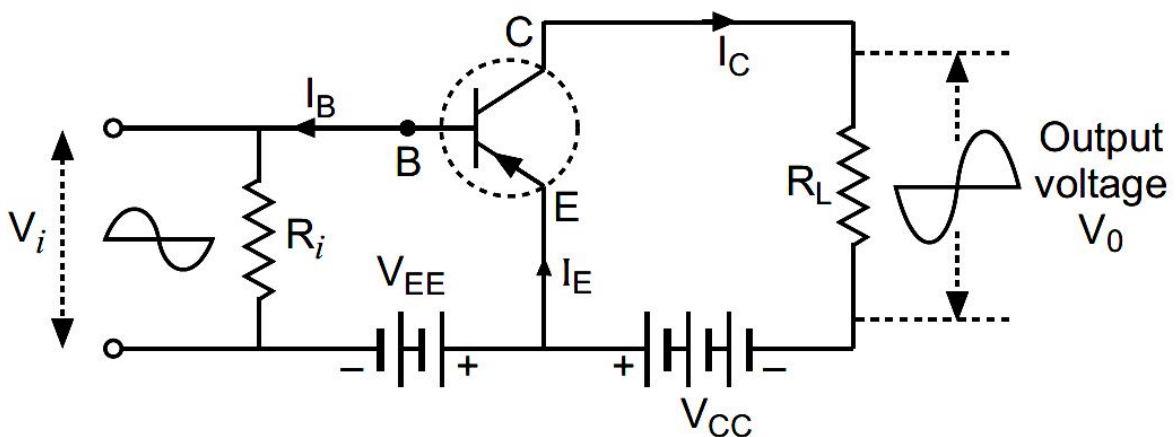


Suppose during first half cycle of input ac signal the terminal S_1 is positive relative to S and S_2 is negative relative to S , then diode I is forward biased and diode II is reverse biased. Therefore current flows in diode I and not in diode II. The direction of current i_1 due to diode I in load resistance R_L is directed from A to B. In next half cycle, the terminal S_1 is negative relative to S and S_2 is positive relative to S . Then diode I is reverse biased and diode I₁ is forward biased.

Therefore current flows in diode II and there is no current in diode I. The direction of current i_2 due to diode II in load resistance is again from A to B. Thus for input a.c. signal the output current is a continuous series of unidirectional pulses. This output current may be converted in fairly steady current by the use of suitable filters.

33. Draw a labelled circuit diagram of a p-n-p transistor amplifier in the common-emitter configuration. Briefly explain, how the input/output signals differ in phase by 180° .

Ans: Common-Emitter Transistor Amplifier: Common-emitter transistor amplifier gives the highest gain and hence it is the most commonly employed circuit. Fig. depicts the circuit for a p-n-p transistor. In this circuit, the emitter is common to both the input (emitter-base) and output (collector-emitter) circuits and is grounded. The emitter-base circuit is forward biased and the base-collector circuit is reverse biased.



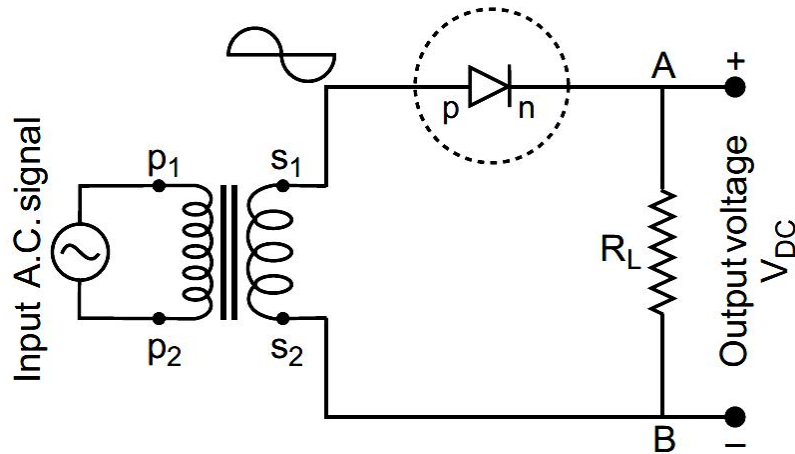
In a common-emitter circuit, the collector-current is controlled by the base-current rather than the emitter-current. Since in a transistor, a large collector-current corresponds to a very small base-current, therefore, when input signal is applied to base, a very small change in base-current provides a much larger change in collector-current and thus extremely large current gains are possible.

Referring to fig., when positive half cycle is fed to the input circuit, it opposes the forward bias of the circuit which causes the collector current to decrease. It decreases the voltage drop across load R_L and thus makes collector voltage more negative. Thus when input cycle varies through a positive half cycle, the output voltage developed at the collector varies through a negative half cycle and vice versa. Thus the output voltage in common-emitter amplifier is in antiphase with the input signal or the output and input voltages are 180° out of phase.

34. Explain briefly, with the help of a circuit diagram, how a $p-n$ junction diode works as a half wave rectifier.

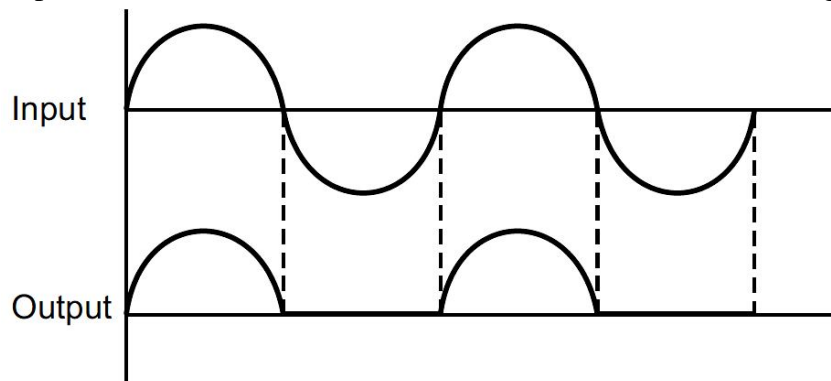
Ans:

Half Wave Rectifier: The circuit diagram for junction diode as half wave rectifier is shown in below Fig.



Let during first half the cycle the secondary terminal S_1 of transformer be positive relative to S_2 , then the junction diode is forward biased. Therefore the current flows and its direction in load resistance R_L is from A to B . In next half cycle the terminal S_1 is negative relative to S_2 then the diode is in reverse bias, therefore no current flows in diode and hence there is no potential difference across load R_L . Therefore the output current in load flows only when S_1 is positive relative to S_2 . That is during first half cycles of input a.c. signal there is a current in circuit and hence a potential difference across load resistance R_L while no current flows for next half cycle. The direction of current in load is always from A to B . Thus a *single $p-n$ junction diode acts as a half wave rectifier.*

The input and output waveforms of half wave rectifier are shown in the below figure.



35. Draw the logic symbol of the gate whose truth table is given below:

Input		Output
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

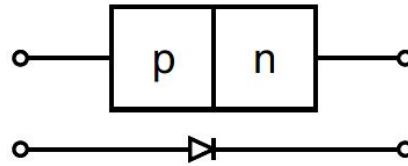
If this logic gate is connected to NOT gate, what will be output when (i) $A = 0, B = 0$ and (ii) $A = 1, B = 1$? Draw the logic symbol of the combination.

Ans:

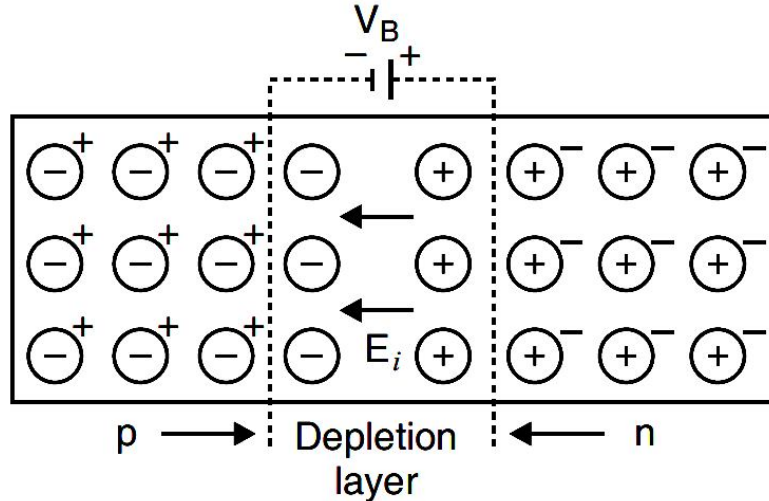
36. Explain the formation of 'depletion layer' and 'barrier potential' in a $p-n$ junction.

Ans: At the junction there is diffusion of charge carriers due to thermal agitation; so that some of electrons of n -region diffuse to p -region while some of holes of p -region diffuse into n -region. Some charge carriers combine with opposite charges to neutralise each other. Thus near the junction there is an

excess of positively charged ions in n -region and an excess of negatively charged ions in p -region. This sets up a **potential difference** called potential barrier and hence an internal electric field E_i across the junctions.



The field E_i is directed from n -region to p -region. This field stops the further diffusion of charge carriers. Thus the layers ($\approx 10^{-4}$ cm to 10^{-6} cm) on either side of the junction becomes free



Explain how a transistor in active state exhibits a low resistance at its emitter base junction and high resistance at its base collector junction.

37. Draw a circuit diagram and explain the operation of a transistor as a switch.

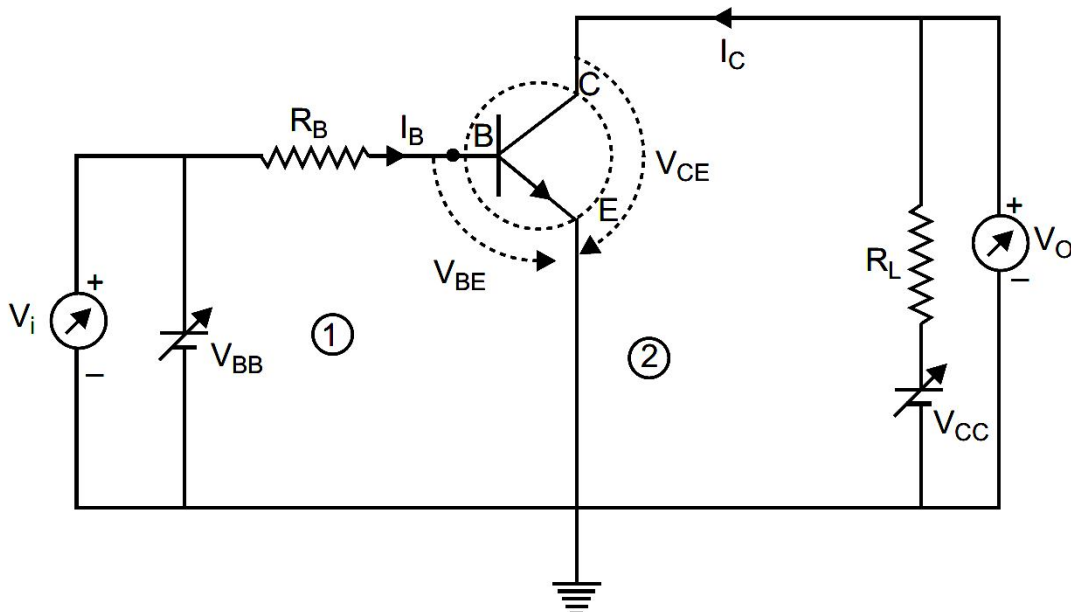
Ans:

A switch is a device which can turn ON and OFF current in an electrical circuit.

A transistor can be used to turn current ON or OFF rapidly in electrical circuits.

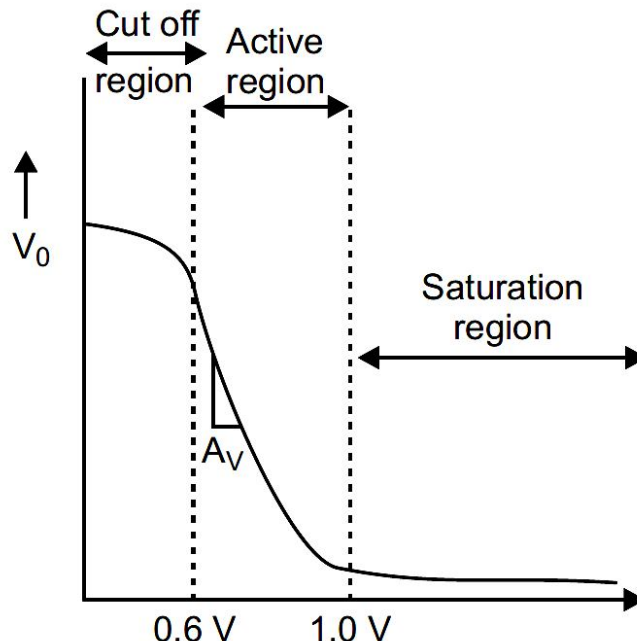
Operation: The circuit diagram of $n-p-n$ transistor in CE configuration working as a switch is shown in fig. V_{BB} and V_{CC} are two dc supplies which bias base-emitter and emitter collector junctions respectively.

Let V_{BB} be the input supply voltage. This is also input dc voltage (V_C). The dc output voltage is taken across collector-emitter terminals, R_L is the load resistance in output circuit.



If we plot V_0 versus V_i , we get the graph as shown in fig. [This characteristics curve is also called transfer characteristic curve of base biased transistor.]

The curve shows that there are non-linear regions. (i) between cut off state and active state and (ii) between active state and saturation state; thus showing that the transitions (i) from cut off to active state and from active to saturation state are not sharply defined.

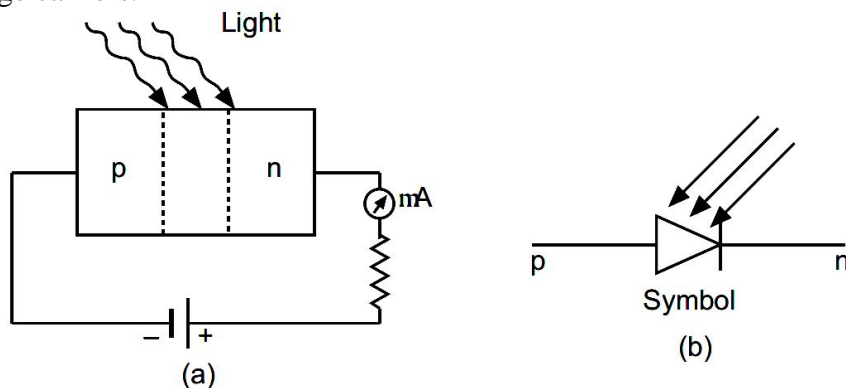


When transistor is non-conducting ($I_C = 0$), it is said to be ‘switched off’ but when it is conducting (I_C is not zero); it is said to be ‘switched ON’.

As long as input voltage V_i is low and unable to overcome the barrier voltage of the emitter base junction, V_0 is high ($I_C = 0$ and $V_0 = V_{CC}$), so the transistor is ‘switched OFF’ and if it is high enough to derive the transistor into saturation (I_C is high and so $V_0 (= V_{CC} - I_C R_L)$ is low, very near to zero, so the transistor is ‘switched ON’. Thus we can say low input switches the transistor is **OFF** state and high input switches it ON. The switching circuits are designed in such a way that the transistor does not remain in active state.

38. Draw the circuit diagram of an illuminated photodiode in reverse bias. How is photodiode used to measure light intensity?

Ans: It is a reversed biased p-n junction, illuminated by radiation. When p-n junction is reversed biased with no current, a very small reverse saturated current flows across the junction called the dark current. When the junction is illuminated with light, electron-hole pairs are created at the junction, due to which additional current begins to flow across the junction; the current is solely due to minority charge carriers.



39. Distinguish between a conductor, a semiconductor and an insulator on the basis of energy band diagrams.

Ans: If the valence and conduction bands overlap, the substance is referred as a *conductor*.

If the valence and conduction bands have a forbidden gap more than 3 eV, the substance is an insulator.

If the valence and conduction bands have a small forbidden gap (≈ 1 eV), the substance is a semiconductor.

40. How is forward biasing different from reverse biasing in a p-n junction diode?

Ans:

1. Forward Bias:

- (i) Within the junction diode the direction of applied voltage is opposite to that of built-in potential.
- (ii) The current is due to diffusion of majority charge carriers through the junction and is of the order of milliamperes.
- (iii) The diode offers very small resistance in the forward bias.

2. Reverse Bias:

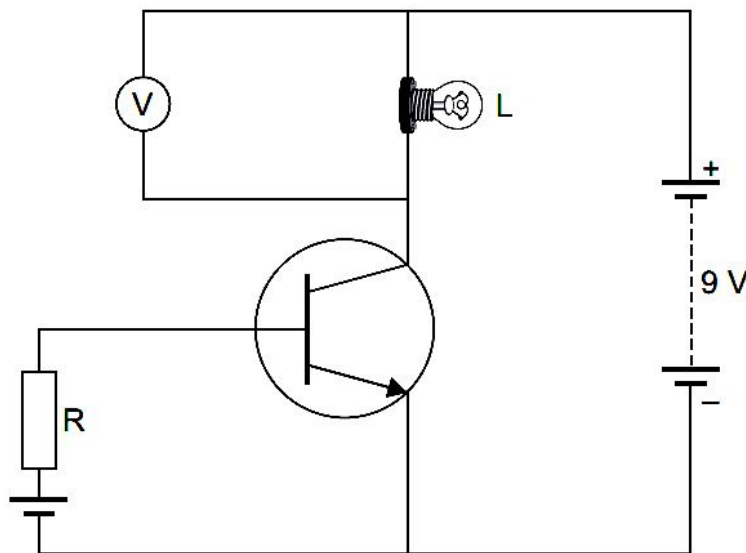
- (i) The direction of applied voltage and barrier potential is same.
- (ii) The current is due to leakage of minority charge carriers through the junction and is very small of the order of μA .
- (iii) The diode offers very large resistance in reverse bias.

41. Write two characteristic features to distinguish between n-type and p-type semiconductors.

Ans:

n- type Semiconductor	p- type Semiconductor
(i) It is formed by doping pentavalent impurities.	(i) It is doped with trivalent impurities.
(ii) The electrons are majority carriers and holes are minority carriers ($n_e \gg n_h$).	(ii) The holes are majority carriers and electrons are minority carriers ($n_h \gg n_e$).

42. In the given circuit diagram, a voltmeter 'V' is connected across a lamp 'L'. How would (i) the brightness of the lamp and (ii) voltmeter reading 'V' be affected, if the value of resistance 'R' is decreased? Justify your answer.



Ans:

- (i) If the value of the resistance R is reduced, the current in the forward biased input circuit increases. The emitter current I_E and the collector current $I_C (= I_E - I_B)$ both increase. Hence, the brightness of the lamp increases.
- (ii) Due to increase in I_C , the potential drop across lamp L increases and hence the voltmeter reading V increases.

43. Mention the important considerations required while fabricating a p-n junction diode to be used as a Light Emitting Diode (LED). What should be the order of band gap of an LED if it is required to emit light in the visible range?

Ans: Important consideration in the fabrication of LED:

(a) (i) light emitting diode is a heavily doped p-n junction.

(ii) The reverse breakdown voltages of LEDs are very low, typically around 5V.

(b) The order of band gap of an LED to emit light in the visible range is about 3 eV to 1.8 eV.

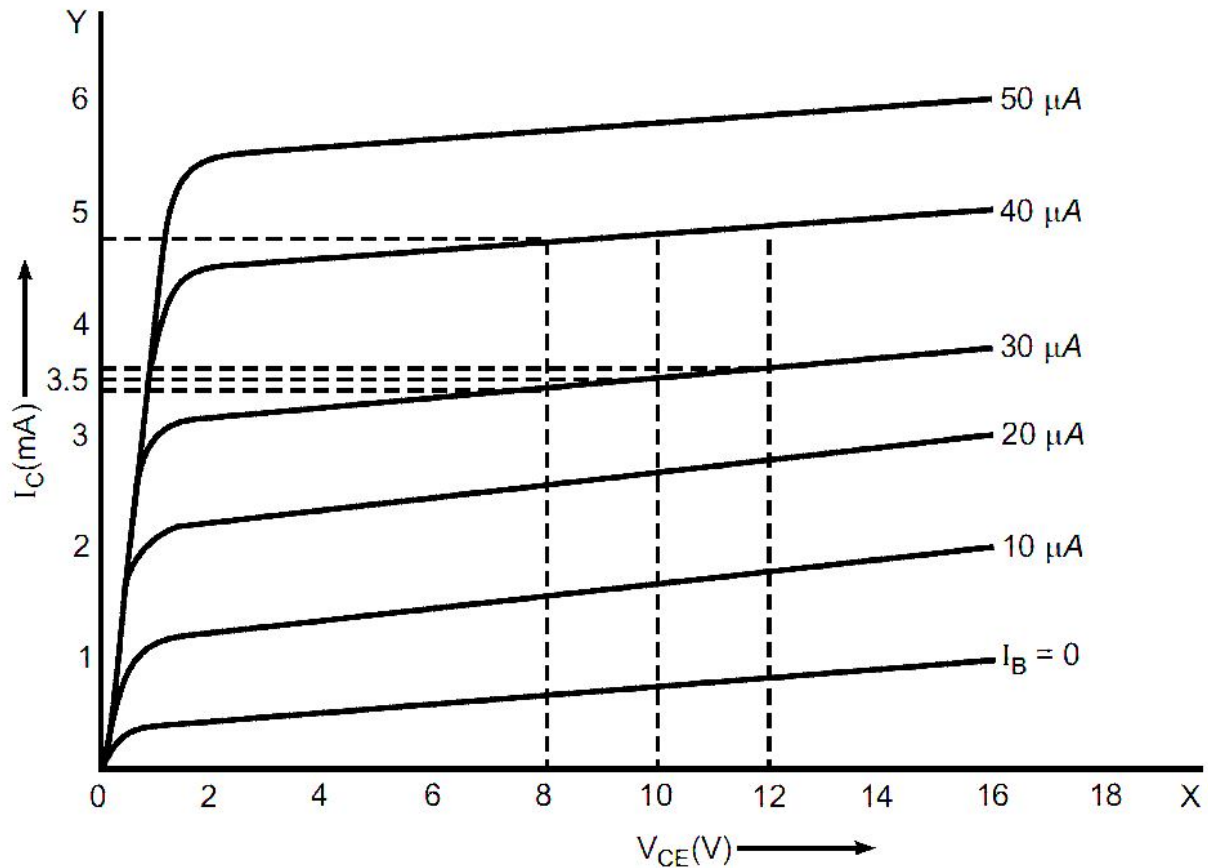
44. Output characteristics of an n-p-n transistor in CE configuration is shown in the figure.

Determine:

(i) dynamic output resistance

(ii) dc current gain and

(iii) ac current gain at an operating point $V_{CE} = 10$ V, $I_B = 30 \mu A$.



Ans:

(i) Dynamic output resistance is given by $r_o = \left(\frac{\Delta V_{CE}}{\Delta I_C} \right)_{I_B}$

For $I_B = 30 \mu A$, $\Delta V_{CE} = (12 - 8) = 4V$ and $\Delta I_C = (3.6 - 3.4) = 0.2mA$

$$r_o = \frac{0.4V}{0.2mA} = \frac{4}{0.2 \times 10^{-3}} = 2 \times 10^4 \Omega$$

(ii) dc current gain $\beta_{dc} = \frac{I_c}{I_b}$

At $V_{CE} = 10$ V and $I_b = 30 \mu A$, the value of $I_c = 3.5m A$

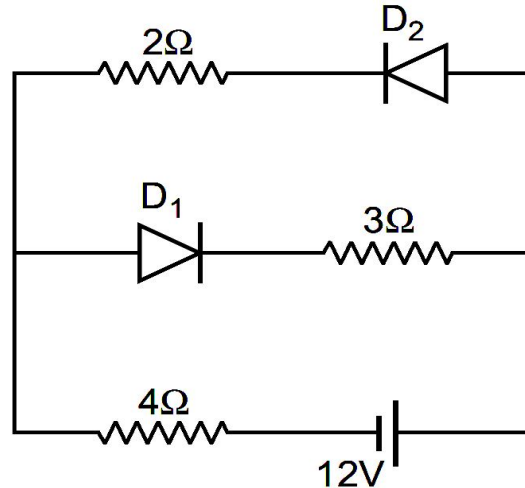
$$\beta_{dc} = \frac{3.5mA}{30\mu A} = \frac{3.5 \times 10^{-3}}{30 \times 10^{-6}} = 117$$

$$(iii) \text{ ac current gain } \beta_{dc} = \left(\frac{\Delta I_C}{\Delta I_B} \right)_{V_{CE}}$$

At $V_{CE} = 10 \text{ V}$, $\Delta I_C = (3.5 - 2.5) \text{ mA} = 1 \text{ mA}$ and $\Delta I_B = (30 \mu\text{A} - 20 \mu\text{A}) = 10 \mu\text{A}$

$$\beta_{dc} = \frac{1 \text{ mA}}{10 \mu\text{A}} = 100$$

45. The circuit shown in the figure has two oppositely connected ideal diodes connected in parallel. Find the current flowing through each diode in the circuit.

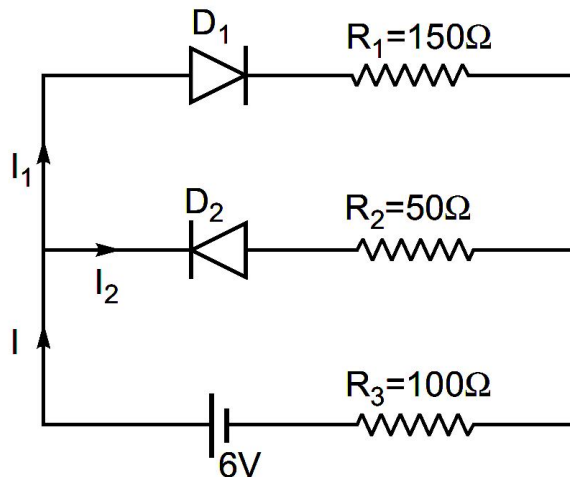


Ans: (i) Diode D_1 is reverse biased, so it offers an infinite resistance. So no current flows in the branch of diode D_1 .

(ii) Diode D_2 is forward biased, and offers no resistance in the circuit. So current in the branch

$$I = \frac{V}{R_{eq}} = \frac{12\text{V}}{2\Omega + 4\Omega} = 2\text{A}$$

46. The circuit shown in the figure contains two diodes each with a forward resistance of 50Ω and infinite backward resistance. Calculate the current in the 100Ω resistance?



Ans: Resistance of diode D_1 in forward biasing $R_Z = 50 \Omega$.

Resistance of diode D_2 in reverse biasing $= \infty$.

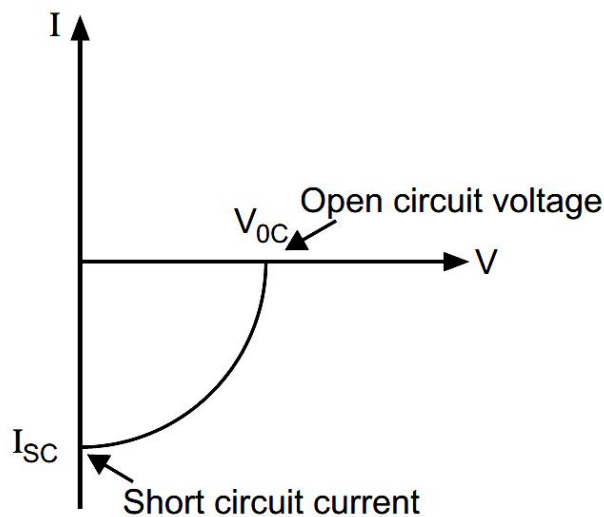
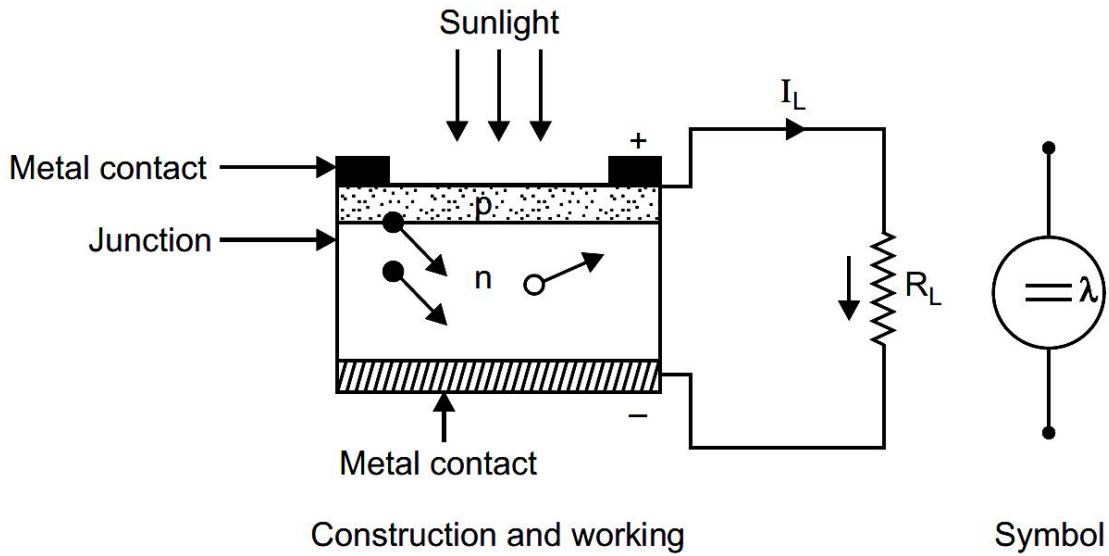
As no current flows through the diode D_2 , so current from the source flows through diode D_1 .

$$I = \frac{\varepsilon}{R_{net}} = \frac{6.0\text{V}}{50\Omega + 150\Omega + 100\Omega} = \frac{6.0}{300} = 0.02\text{A}$$

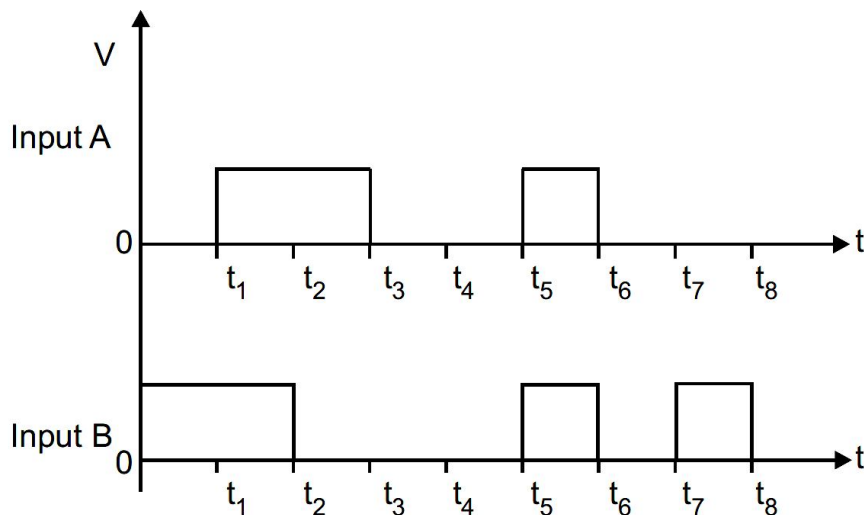
$I = 0.02 \text{ A}$ flows through 100Ω resistor.

47. Briefly explain its working. Draw its V-I characteristics for two different intensities of illumination.

Ans: When a reverse bias photodiode is illuminated with light of energy greater than the forbidden energy gap (E_g) of the semiconductor, then electron hole pair are generated in the depletion region. Due to electric field of the junction, electrons are collected on the n -side and holes on p -side, giving rise to an emf.



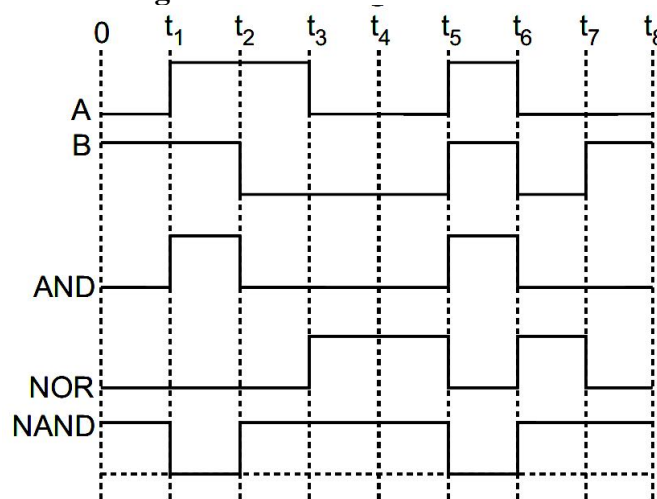
48. Two signals A, B as given below, are applied as input to (i) AND (ii) NOR and (iii) NAND gates. Draw the output wave-form in each case.



Ans:

Time Interval	Inputs		AND	NOR	NAND
	A	B	$Y = A.B$	$Y = \overline{A + B}$	$Y = \overline{A.B}$
$0 < t < t_1$	0	1	0	0	1
$t_1 < t < t_2$	1	1	1	0	0
$t_2 < t < t_3$	1	0	0	0	1
$t_3 < t < t_4$	0	0	0	1	1
$t_4 < t < t_5$	0	0	0	1	1
$t_5 < t < t_6$	1	1	1	0	0
$t_6 < t < t_7$	0	0	0	1	1
$t_7 < t < t_8$	0	1	0	0	1

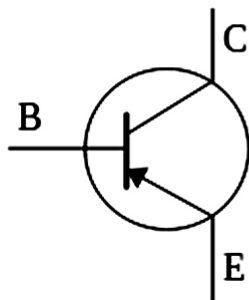
Output waveforms of the three gates:



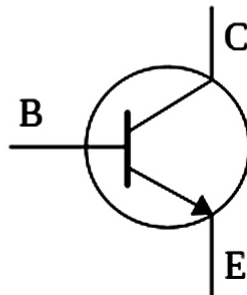
49. Draw the symbolic representation of a (a) p-n-p (b) p-n-p transistor, Why is the base region of transistor thin and lightly doped? With proper circuit diagram, show the biasing of a p-n-p transistor in common base configuration. Explain the movement of charge carriers through different parts of the transistor in such a configuration and show that $I_E = I_C + I_B$ [2007 D]

Ans:

Symbol of PNP transistor

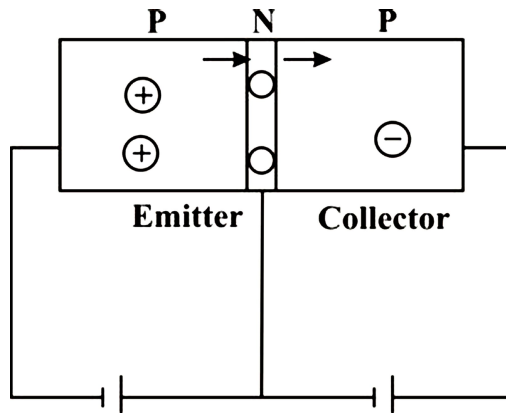


Symbol of NPN transistor



The thin and lightly doped base region offers lesser number of majority charge carrier in base region which reduces the possibility of combination of electron hole pair in base region and hence, reducing the base current.

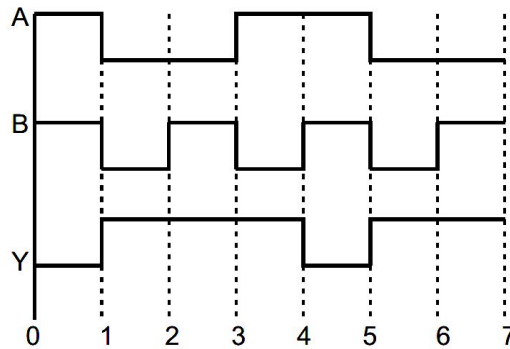
Also, this leads to increase collector current. Hence, current gain increase in transistor.



The forward bias of emitter-base circuit move holes towards collector. The base region is very thin and lightly doped, only 5% of holes combines with the electrons in base region and remains nearly 95% holes enters into the collector region under the influence of V_{EB} . The excess of holes (95%) in collector region get combined with the electron drawn from the negative terminal of V_{CB} and get annihilated.

$$I_E = I_C + I_B.$$

50. The following figure shows the input waveforms (A, B) and the output waveform (Y) of a gate. Identify the gate, write its truth table and draw its logic symbol.



Ans: The logic gate is NAND gate.



Truth Table

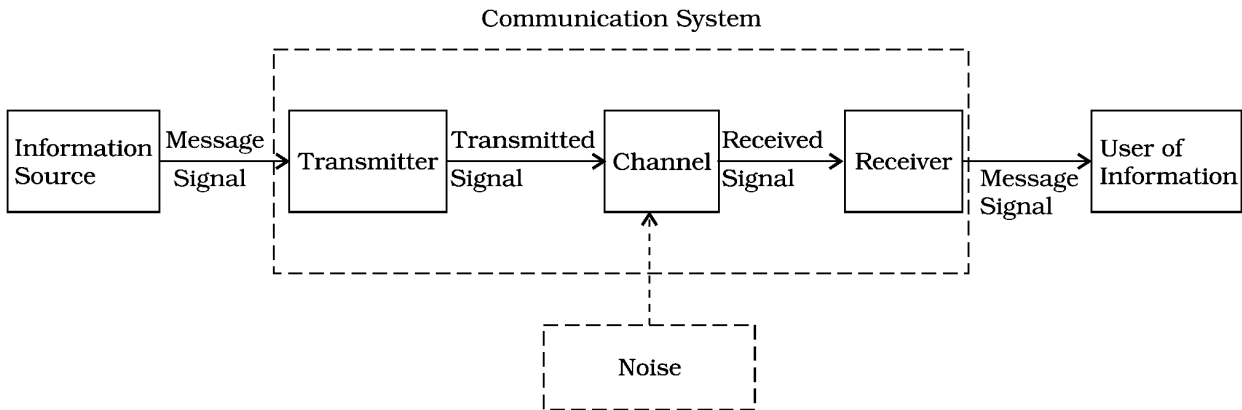
Inputs		Output
A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

COMMUNICATION SYSTEMS

QUICK REVISION (Important Concepts & Formulas)

Communication is the act of transmission of information. In electronics, the term 'communication' refers to sending, receiving and processing of information electronically.

Elements of Communication:



A communication system used electrical, electronic and optical modes for transmission of information from one place to another. It consists of the following three parts:

1. Transmitter
2. Communication channel
3. Receiver

Transmitter

A transmitter transmits the information or message signal after modifying it into a form suitable for transmission.

The message signal for communication can be analog signals or digital signals.

An analog signal is that in which current or voltage value varies continuously with time.

A digital signal is a discontinuous function of time. Such a signal is usually in the form of pulses.

An analog signal can be converted suitably into a digital signal and viceversa.

Modulation : The message signal cannot travel over long distances. They are superimposed on a high frequency wave known as carrier wave.

The power of modulated signal is boosted using a suitable amplifier.

The amplified signal is radiated into space with the help of transmitting antenna.

Communication channel

The communication channel carries the modulated wave from the transmitting antenna to the receiving antenna.

Receiver

In the wireless (radio) communication the receiver consists of the following parts:

- (i) A pick up antenna.
- (ii) A demodulator It is reverse of modulator.
- (iii) An amplifier
- (iv) The transducer- A transducer is a device which converts a message signal into electrical signal and viceversa. Broadly it converts one form of energy into another. A transducer has either input or output in electrical form.

Two Basic Modes of Communication:

- a) Point to point
- b) Broadcast

Point to Point Mode of Communication:

Here, communication takes place over a link between a single transmitter and a receiver. Telephony is an example of such a mode of communication.

Broadcast Mode of Communication:

Here, there are a large number of receivers corresponding to a single transmitter. Radio and television are examples of broadcast mode of communication.

Analog Mode of Transmission:

An analog message is physical quantity that varies with time usually in a smooth and continuous fashion.

Digital Mode of Transmission:

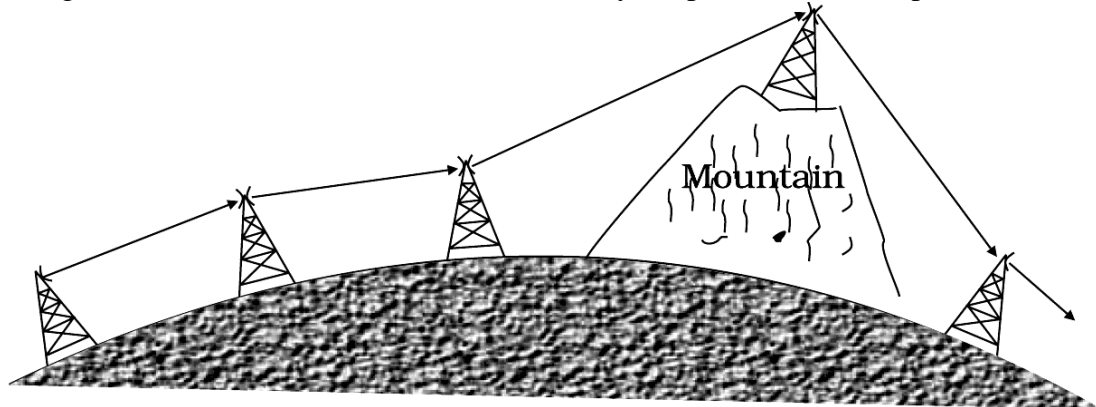
A digital message is an ordered sequence of symbols selected from a finite set of discrete elements.

Basic terminology used in Electronic Communication systems

- (i) *Transducer:* Any device that converts one form of energy into another can be termed as a transducer. An electrical transducer may be defined as a device that converts some physical variable (pressure, displacement, force, temperature, etc) into corresponding variations in the electrical signal at its output.
- (ii) *Signal:* Information converted in electrical form and suitable for transmission is called a signal. Signals can be either *analog or digital*. Analog signals are continuous variations of voltage or current. *They are essentially single-valued functions of time*. Sine wave is a fundamental analog signal. All other analog signals can be fully understood in terms of their sine wave components. Sound and picture signals in TV are analog in nature. Digital signals are those which can take only discrete stepwise values. Binary system that is extensively used in digital electronics employs just two levels of a signal. '0' corresponds to a low level and '1' corresponds to a high level of voltage/current. There are several coding schemes useful for digital communication. They employ suitable combinations of number systems such as the binary coded decimal (BCD). American Standard Code for Information Interchange (ASCII) is a universally popular digital code to represent numbers, letters and certain characters.
- (iii) *Noise:* Noise refers to the unwanted signals that tend to disturb the transmission and processing of message signals in a communication system. The source generating the noise may be located inside or outside the system.
- (iv) *Transmitter:* A transmitter processes the incoming message signal so as to make it suitable for transmission through a channel and subsequent reception.
- (v) *Receiver:* A receiver extracts the desired message signals from the received signals at the channel output.
- (vi) *Attenuation:* The loss of strength of a signal while propagating through a medium is known as attenuation.
- (vii) *Amplification:* It is the process of *increasing the amplitude* (and consequently the strength) of a signal using an electronic circuit called the amplifier (reference Chapter 14). Amplification is necessary to compensate for the attenuation of the signal in communication systems. The energy needed for additional signal strength is obtained from a DC power source. Amplification is done at a place between the source and the destination wherever signal strength becomes weaker than the required strength.
- (viii) *Range:* It is the largest distance between a source and a destination up to which the signal is received with sufficient strength.
- (ix) *Bandwidth:* Bandwidth refers to the frequency range over which an equipment operates or the portion of the spectrum occupied by the signal.
- (x) *Modulation:* The original low frequency message/information signal cannot be transmitted to long distances. Therefore, at the transmitter, information contained in the low frequency message signal is superimposed on a high frequency wave, which acts as a carrier of the information. This

process is known as modulation. As will be explained later, there are several types of modulation, abbreviated as AM, FM and PM.

- (xi) **Demodulation:** The process of retrieval of information from the carrier wave at the receiver is termed demodulation. This is the reverse process of modulation.
- (xii) **Repeater:** A repeater is a combination of a receiver and a transmitter. A repeater, picks up the signal from the transmitter, amplifies and retransmits it to the receiver sometimes with a change in carrier frequency. Repeaters are used to extend the range of a communication system as shown in below figure. A communication satellite is essentially a repeater station in space.



Earth's atmosphere

The various regions of earth's atmosphere are :

- **Troposphere** It extends upto a height of 12 km.
- **Stratosphere** It extends from 12 km to 50 km.
- There is an ozone layer in stratosphere.
- **Mesosphere** It extends from 50 km to 80 km.
- **Ionosphere** It extends from 80 km to 400 km. It is composed of ionised matter *i.e.* electrons and positive ions. It plays an important role in space communication.
- **Frequency ranges :** The various frequency ranges used in radiowaves or microwave communication system are shown below:
 - (i) Medium frequency band (M.F.) 300 to 3000 kHz.
 - (ii) High frequency band (H.F.) 3 to 30 MHz.
 - (iii) Very high frequency band (V.H.F.) 30 to 300 MHz.
 - (iv) Ultra high frequency band (U.H.F.) 300 to 3000 MHz.
 - (v) Super high frequency band (S.H.F.) 3000 to 30,000 MHz.
 - (vi) Extra high frequency band (E.H.F.) 30 to 300 GHz.

Propagation of electromagnetic waves

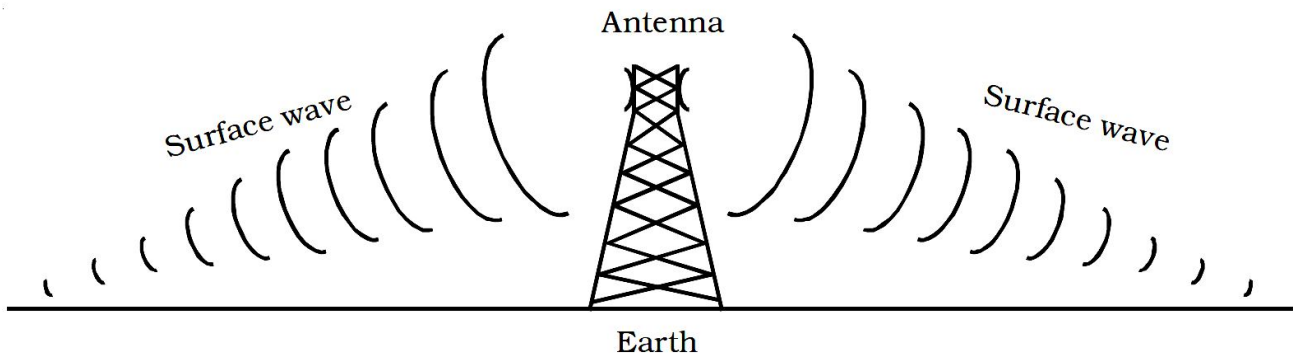
The propagation of electromagnetic waves depend on the properties of the waves and the environment. Radio waves ordinarily travel in straight lines except where the earth and its atmosphere alter their path.

Radio wave is propagated from the transmitting to the receiving antenna mainly in three different ways depending on the frequency of the wave. They are :

- (i) Ground (surface) wave propagation
- (ii) Space wave propagation
- (iii) Sky wave (or) ionospheric propagation

Ground (surface) wave propagation

Ground or surface waves are the radio waves which travel along the surface of the earth as shown in below figure. Ground wave propagation takes place when the transmitting and receiving antennas are close to the ground. Ground wave propagation is of prime importance only for medium and long wave signals. All medium wave signals received during the daytime use surface wave propagation.

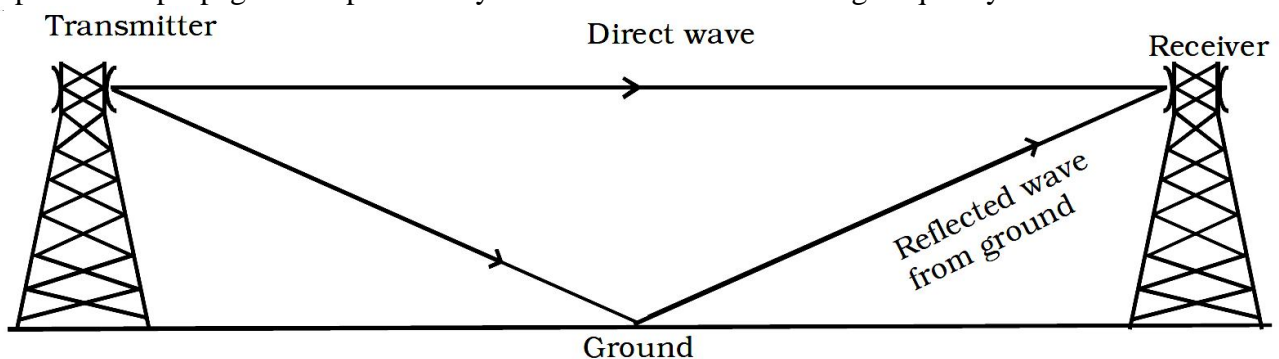


Space wave propagation

Radio waves propagated through the troposphere of the Earth are known as space waves. Troposphere is the portion of the Earth's atmosphere which extends upto 15 km from the surface of the Earth. Space wave usually consists of two components as shown in below figure.

- (i) A component which travels straight from the transmitter to the receiver.
- (ii) A component which reaches the receiver after reflection from the surface of the Earth.

Space wave propagation is particularly suitable for the waves having frequency above 30 MHz.

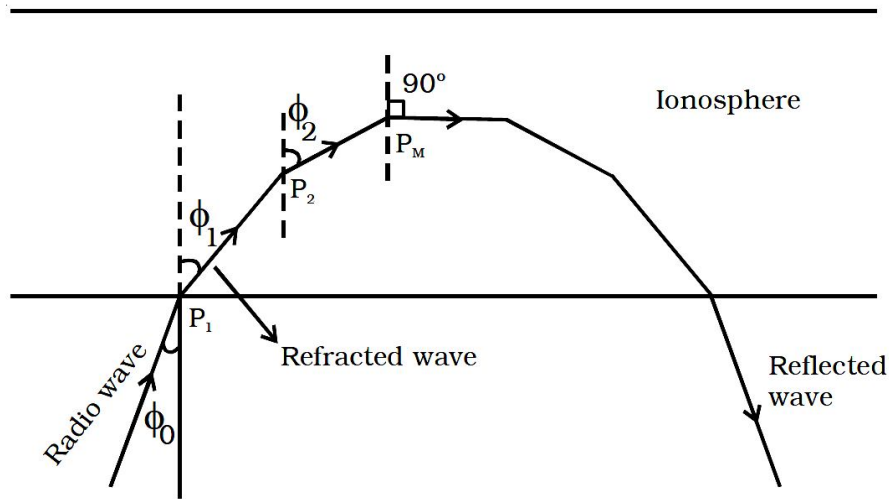


Sky wave (or) ionospheric propagation

The ionosphere is the upper portion of the atmosphere, which absorbs large quantities of radiant energy like ultra violet rays, cosmic rays etc., from the sun, becoming heated and ionised. This ionized region contains free electrons, positive and negative ions. Radio waves in the short wave band, radiated from an antenna at large angles with ground, travel through the atmosphere and encounters the ionised region in the upper atmosphere. Under favourable circumstances, the radiowaves get bent downwards due to refraction from the different parts of the ionised region and again reach the earth at a far distant point. Such a radio wave is called the sky wave and such a propagation of radio wave is known as sky wave propagation or ionospheric propagation. Long distance radio communication is thus possible through the sky wave propagation.

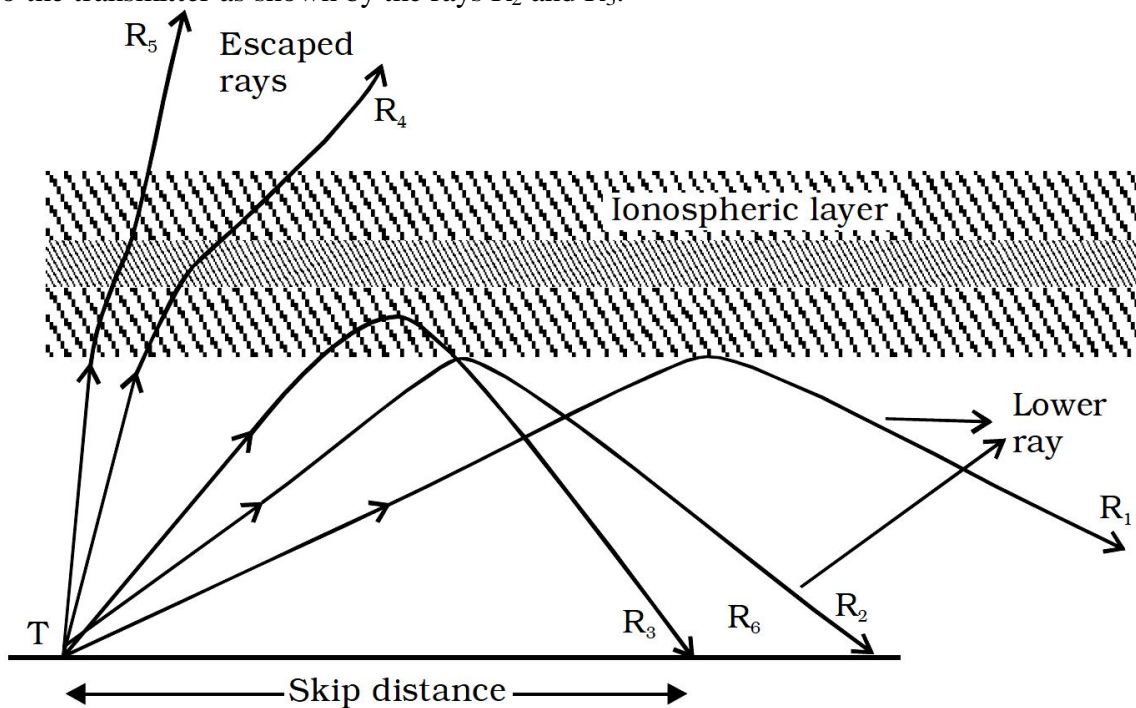
Reflection of electromagnetic waves by ionosphere

The electromagnetic waves entering into the ionosphere, are reflected by the ionosphere. In fact, the actual mechanism involved is refraction. The refractive indices of the various layers in the ionosphere do not remain constant and it varies with respect to electron density and the frequency of the incident wave. As the ionisation density increases for a wave approaching the given layer at an angle, the refractive index of the layer is reduced. Hence, the incident wave is gradually bent farther and farther away from the normal as shown in below figure until some point. When the electron density is large, the angle of refraction becomes 90° and the wave, then travel towards the Earth.



Skip distance and skip zone

In the skywave propagation, for a fixed frequency, the shortest distance between the point of transmission and the point of reception along the surface is known as the *skip distance*. When the angle of incidence is large for the ray R_1 as shown in below figure, the sky wave returns to the ground at a long distance from the transmitter. As this angle is slowly reduced, naturally the wave returns closer and closer to the transmitter as shown by the rays R_2 and R_3 .



If the angle of incidence is now made significantly less than that of ray R_3 , the ray will be very close to the normal to be returned to the Earth. If the angle of incidence is reduced further, the radio waves penetrate through the layer as shown by the rays R_4 and R_5 . For a particular angle of incidence, the distance between the point of transmission and the point of reception is minimum. The minimum distance between the transmitter and the ray like R_3 which strikes the Earth is called as the skip distance. As we move away from the transmitter, the ground wave becomes lesser and lesser significant. A stage comes when there is no reception due to the ground waves. This point lies somewhere in the skip distance. The region between the point where there is no reception of ground waves and the point where the sky wave is received first is known as skip zone. In the *skip zone*, there is no reception at all.

Modulation

In radio broadcasting, it is necessary to send audio frequency signal (eg. music, speech etc.) from a broadcasting station over great distances to a receiver. The music, speech etc., are converted into audio signals using a microphone. The energy of a wave increases with frequency. So, the audio frequency (20 – 20000 Hz) is not having large amount of energy and cannot be sent over long distances. Therefore, if

audio signal is to be transmitted properly, the audio signal must be superimposed on high frequency wave called carrier.

The resultant waves are known as modulated waves and this process is called as modulation. This high frequency wave (Radio frequency wave) is transmitted in space through antenna. At the receiver end, the audio signal is extracted from the modulated wave by the process called demodulation. The audio signal is then amplified and reproduced into sound by the loud speaker.

A high frequency radio wave is used to carry the audio signal. On adding the audio signal to carrier, any one of the characteristics namely amplitude or frequency or phase of the carrier wave is changed in accordance with the intensity of the audio signal. This process is known as modulation and may be defined as the process of changing amplitude or frequency or phase of the carrier wave in accordance with the intensity of the signal. Some of the modulation process namely, (i) amplitude modulation, (ii) frequency modulation and (iii) phase modulation.

Amplitude modulation (AM)

When the amplitude of high frequency carrier wave is changed in accordance with the intensity of the signal, the process is called *amplitude modulation*.

In the amplitude modulation, only the amplitude of the carrier wave is changed. The frequency and the phase of the carrier wave remains constant. The below figure shows the principle of amplitude modulation.

Fig. a shows the audio electrical signal of frequency f_s . Fig b shows a carrier wave of constant amplitude with frequency f_c . Fig c is the amplitude modulated wave. It is to be noted that the amplitudes of both positive and negative half cycles of carrier wave are changed in accordance with the signal. Thus the amplitude of the modulated wave possesses the frequency of the audio signal wave.

Modulation factor

An important term in amplitude modulation is modulation factor which describes the extent to which the amplitude of the carrier wave is changed by the audio signal. It is defined as the ratio of the change of amplitude in carrier wave after modulation to the amplitude of the unmodulated carrier wave.

modulation factor, $m = \frac{\text{Amplitude change of carrier wave after modulation}}{\text{Amplitude of carrier wave before modulation}}$

i.e. $m = \frac{\text{Signal amplitude}}{\text{Carrier amplitude}}$

Frequency modulation (FM)

When the frequency of carrier wave is changed in accordance with the intensity of the signal, the process is called frequency modulation. In frequency modulation, the amplitude and phase of the carrier wave remains constant. Only, the frequency of the carrier wave is changed in accordance with the signal.

The frequency variation of the carrier wave depends upon the instantaneous amplitude of the signal as shown in Fig (a). When the signal voltage is zero at A,C,E and G, the carrier frequency is unchanged. When the signal approaches its positive peaks at B and F, the carrier frequency is increased to maximum as shown by closely spaced cycles in Fig (c). But during the negative peak of signal as at D, the carrier frequency is reduced to minimum as shown by widely spaced cycles in Fig.(c). The louder signal causes greater frequency change in modulated carrier as indicated by increased bunching and spreading of the waves as compared with relatively weaker signal.

The frequency of an FM transmitter without signal input is called the *resting frequency or centre frequency (f_o)* and this is the allotted frequency of the transmitter. When the signal is applied, the carrier frequency deviates up and down from its resting value f_o .

Phase modulation (PM)

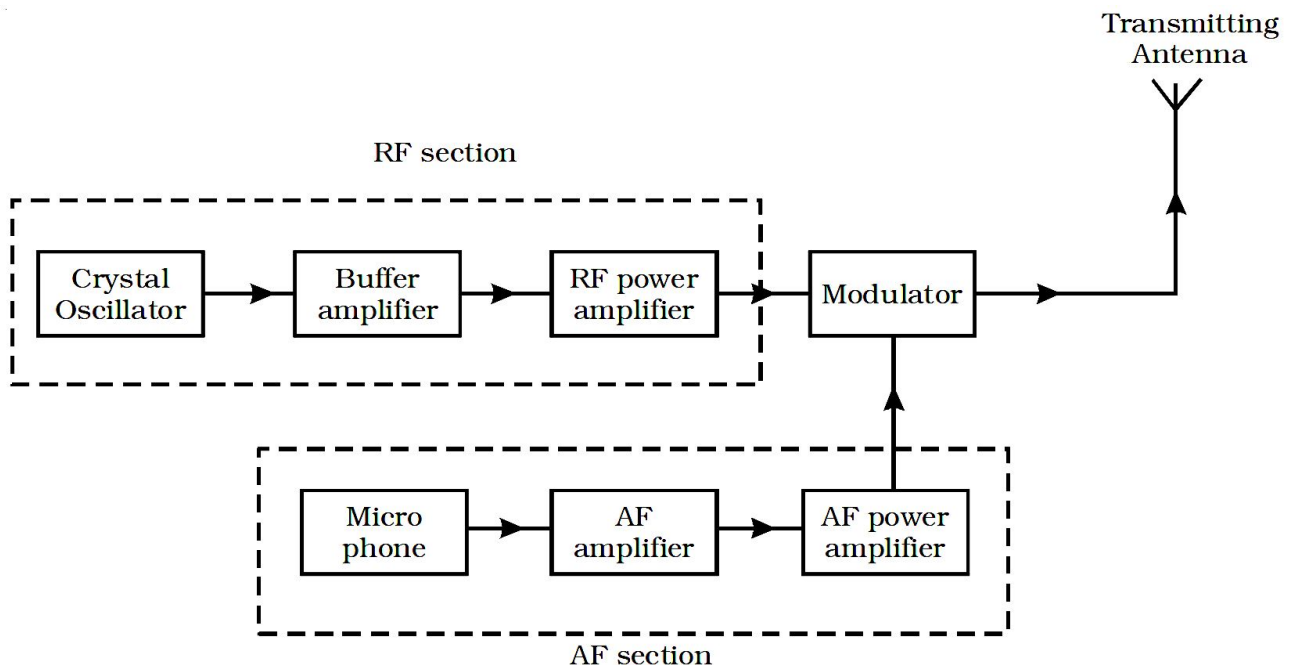
In phase modulation, the phase of the carrier wave is varied in accordance with the amplitude of the modulating signal and the rate of variation is proportional to the signal frequency. The waveform of the phase modulated wave is similar to that of FM wave. The phase modulation, generally uses a smaller bandwidth than FM. In other words, more information can be sent in a given bandwidth in phase modulation. Therefore, phase modulation facilitates highest transmission speeds on a given bandwidth. In phase modulation also, there is a frequency shift in the carrier wave frequency. The frequency shift depends on (i) amplitude of the modulating signal and (ii) the frequency of the signal. One great advantage of the phase modulation lies in the fact that the FM signal produced from PM signal is very stable. Also, the centre frequency called resting frequency is extremely stable.

Amplitude modulated (AM) transmitter

The below figure gives the block diagram of amplitude modulated radio transmitter. It consists of two sections (i) Audio frequency (AF) section and (ii) Radio frequency (RF) section.

AF section

The AF section of the transmitter generates the modulating wave (signal). The conversion of sound energy into electrical energy is performed by the microphone.



The electrical energy available from the microphone is very low. Hence, it is amplified through an amplifier. The output from the AF amplifier is fed to the AF power amplifier. The power amplifier provides the required audio frequency power. The output of the AF power amplifier is given to the modulator. A modulator is an electronic circuit with transistor and passive components, which performs the process of modulation.

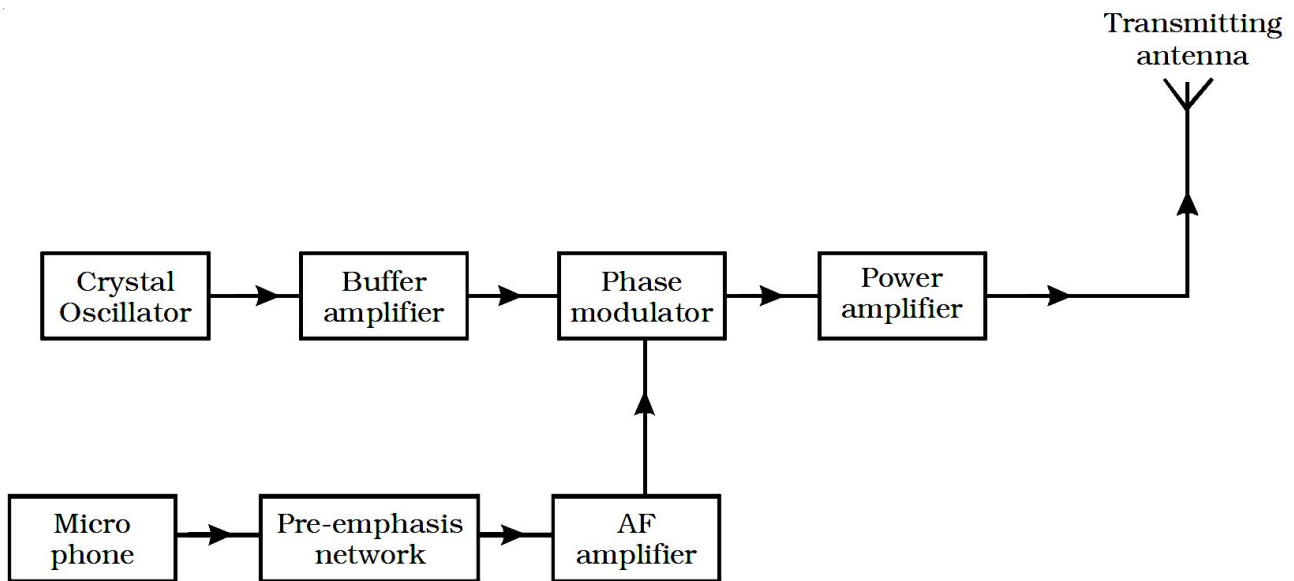
RF section

In the RF section, the high frequency carrier wave is generated by a crystal controlled oscillator. The output of the crystal controlled oscillator is power amplified by RF power amplifier. The buffer isolates the RF power amplifier from the oscillator. This arrangement keeps the frequency of the crystal controlled oscillator as a constant. In the modulator the RF wave and modulating AF signal are mixed to produce the amplitude modulated wave. The output of this section is fed to the antenna for transmission.

Frequency modulated (FM) transmitter

Frequency modulated systems are operated usually at a frequency above 40 MHz. Frequency modulated broadcasting is done in television sound, mobile radio etc. The functional block diagram of a FM

transmitter employing phase modulation is shown in below figure. The phase modulation is essentially a frequency modulation.

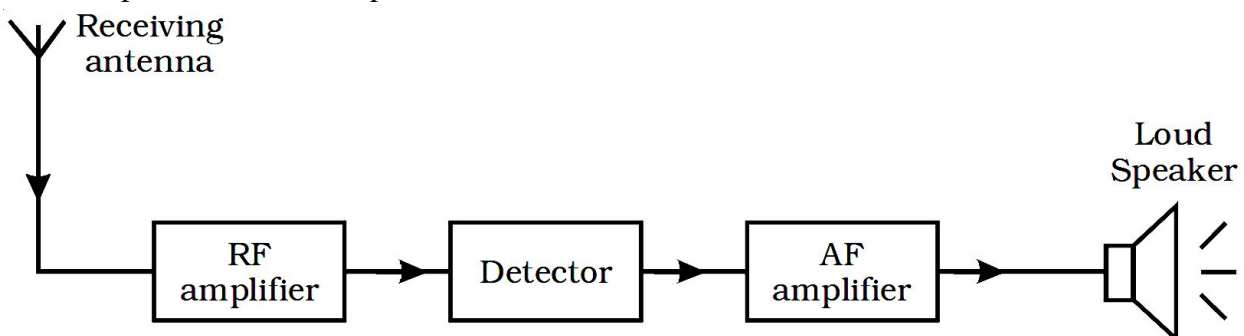


It consists of a crystal oscillator, which produces the carrier wave and the output of this is fed into the phase modulator. The buffer is a low frequency amplifier which isolates the crystal oscillator from the phase modulator.

The modulating signal is produced from a microphone. Since this AF modulating signal has uneven power, it is fed into a network called pre-emphasis network, where all the frequencies in the modulating signal are made to have equal power. The output of the pre-emphasis network is then amplified and sent for phase modulation. The modulated output is then power amplified using a power amplifier and then fed into the transmitting antenna for transmission.

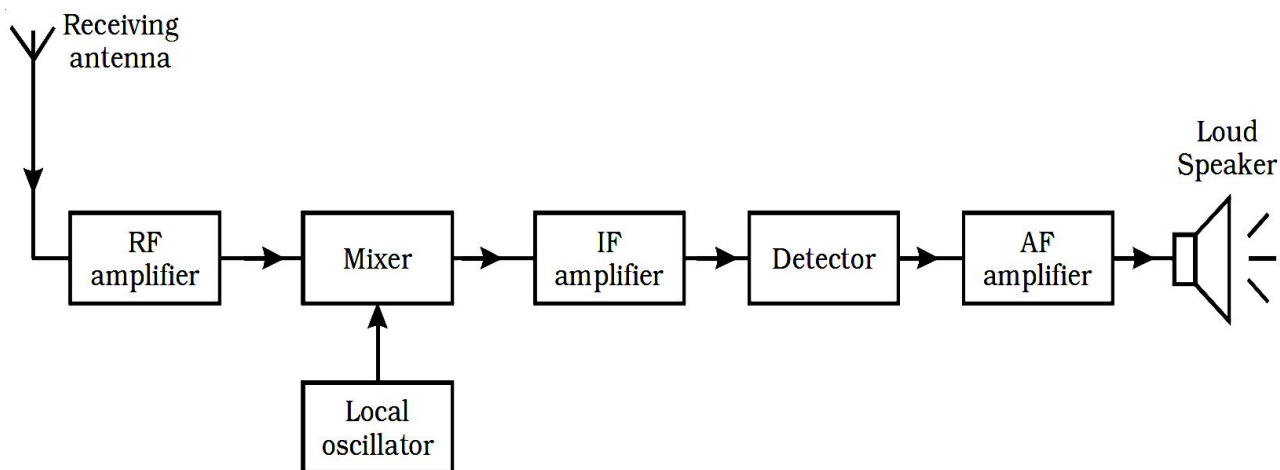
Radio receiver

The functional block diagram of a simple radio receiver is shown in below figure. The receiving antenna receives the radiowaves from different broadcasting stations. The desired radiowave is selected by the radio frequency amplifier, which employs a tuned parallel circuit. The tuned RF amplifier amplifies this selected radiowave. The amplified radiowave is fed to the detector circuit which consists of a PN diode. This circuit extracts the audio signal from the radiowave. The output of the detector is the audio signal, which is amplified by one or more stages of audio amplification. The amplified audio signal is given to the loud speaker for sound reproduction.



Superheterodyne AM receiver

The shortcomings of straight radio receiver were overcome by the invention of superheterodyne receiver. All the modern receivers utilise the superheterodyne circuit. The functional block diagram of AM receiving system of superheterodyne type is shown in below figure.



(i) RF amplifier

The RF amplifier uses a tuned parallel circuit. The radiowaves from various broadcasting stations are intercepted by the receiving antenna and are coupled to this stage. This stage selects the desired radiowave and enhances the strength of the wave to the desired level.

(ii) Mixer and local oscillator

The amplified output of RF amplifier is fed to the mixer stage, where it is combined with the output of a local oscillator. The two frequencies beat together and produce an intermediate frequency (IF). The intermediate frequency is the difference between oscillator frequency and radio frequency. The output of this section is always equal to the intermediate frequency 455 kHz. For example, if 600 kHz station is tuned, then local oscillator will produce a frequency of 1055 kHz and consequently the output from the mixer will have frequency of 455 kHz. By achieving this fixed intermediate frequency, the amplifier circuit in such receivers can be made to operate with maximum stability, selectivity and sensitivity.

(iii) IF amplifier

The output of the mixer circuit is fed to the tuned IF amplifier. This amplifier is tuned to one frequency (i.e. 455 KHz) and is amplified.

(iv) Detector

The output from the IF amplifier is coupled with input of a detector. The audio signals are extracted from the IF output. Usually a diode detector circuit is used because of its low distortion and excellent audio fidelity (reproducing ability).

(v) AF amplifier

The detected AF signal is usually weak and so it is further amplified by the AF amplifier. Then, the output signal from the amplifier is fed to the loud speaker, which converts the audio signal into sound waves corresponding to the original sound at the broadcasting station.

Satellite communication

- (i) A satellite communication is possible through geostationary satellites. At least three geostationary satellites are required which are 120° apart from each other, to cover the entire globe of earth.
- (ii) The satellite communication is a mode of communication and receiver through satellite.
- (iii) A communication satellite is a space craft, provided with microwave receiver and transmitter. It is placed in an orbit around the earth.

Remote sensing

- (i) Remote sensing is done through a satellite. The satellite moves in a fixed orbit around the earth in a way such that it passes over a given location on the earth at the same local time. The orbit of such a satellite is known as Sun synchronous orbit.
- (ii) Such satellites provide us with data critical to weather production, agriculture forecasting, resource exploration and environmental monitoring.
- (iii) The India remote sensing satellites are IRSIA, IRSIB and IRSIC.
- (iv) Such satellite takes repeated photographs of the particular location of the earth during its repeated journeys over that location. The comparative study of photographs leads to required results.

Optical fibres

An optical fibre is a long thread consisting of a central core of glass or plastic of uniform refractive index. It is surrounded by a cladding of material of refractive index less than that of the core and a protective jacket of insulating material.

There are three types of optical fibre configuration:

(i) Single mode step index fibre. (ii) Multimode step index fibre. (iii) Multimode graded index fibre.

➤ **Critical angle** : It is that angle of incidence in the denser medium for which the angle of refraction in rarer medium is 90° .

$$\therefore \frac{\mu_1}{\mu_2} = \frac{\sin \theta_c}{\sin 90^\circ} = \sin \theta_c$$

➤ If the rarer medium is air, $\mu_1 = 1$

$$\therefore \mu_2 = \frac{1}{\sin \theta_c}$$

➤ In optical fibre, critical angle is given by $\cos \theta_c = \frac{\sqrt{\mu_1^2 - \mu_2^2}}{\mu_1}$

➤ Optical fibres are used in optical communication.

➤ The optical communication system is more economical than other systems of communications and it has larger information carrying capacity and provides high quality service.

➤ Optical fibre cables are of small size and weight as compared to metallic cables and hence occupy small space for its operation.

➤ Optical fibres are most suitable for digital transmission and switching system.

LED and diode lasers in communication

Light emitting diode (LED) and diode lasers are preferred sources for optical communication links to the following features.

(i) Each produces light of suitable power required in optical communication.

(ii) Diode laser provides light which is monochromatic and coherent. This light is obtained as a parallel beam. It is used in very long distance transmission.

(iii) LED provides almost monochromatic light. This is suitable for small distance transmission. It is, infact, a low cost device as compared to diode lasers.

Line communication

Transmission lines are used to interconnect points separated from each other. For example interconnection between a transmitter and a receiver or a transmitter and antenna or an antenna and a receiver are achieved through transmission lines.

The most commonly used two wire lines are

(i) parallel wire lines

(ii) twisted pair wire lines

(iii) coaxial wire lines

Parallel wire lines are never used for transmission of microwaves. This is because at the frequency of microwaves, separation between the two wires approaches half a wavelength (*i.e.* $\lambda/2$). Therefore, radiation loss of energy becomes maximum.

Primary constants of a transmission line

(i) The four line parameters are resistance (R), inductance (L), capacitance (C) and conductance (G).

(ii) Series impedance (Z) = $R + j\omega L$

(iii) Shunt admittance (Y) = $G + j\omega C$.

Important Questions and Answers

VERY SHORT ANSWER TYPE QUESTIONS (1 MARK)

1. What is ground wave propagation?

Ans: Ground Wave Propagation: Ground wave propagation is one in which electromagnetic waves glide on the surface of earth between two antennas on the ground.

2. What is space wave propagation?

Ans: Space Wave Propagation: It is the straight line propagation of electromagnetic wave from transmitting antenna to receiving antenna both installed on the ground.

3. What is sky wave propagation?

Ans: Skywave propagation is a mode of propagation in which communication of radiowaves (in the frequency range 30 MHz–40 MHz) takes place due to reflection from the ionosphere.

4. Name three different types of modulation used for a message signal using a sinusoidal continuous carrier wave.

Ans: The three different modulation are : Amplitude modulation ,Frequency modulation ,Phase modulation

5. Write the range of frequencies suitable for space wave communication.

Ans: The range suitable is above 40 MHz.

6. Give reason - “For ground wave transmission, size of antenna (l) should be comparable to wavelength (λ) of signal i.e., $l = \lambda/4$.”

Ans: For high efficiency of signal radiation, the antennas should have a size of at least $\frac{\lambda}{4}$

7. What should be the length of dipole antenna for a carrier wave of frequency 5×10^8 Hz?

Ans :Length of dipole antenna = $\frac{\lambda}{4} = \frac{1}{4} \times \frac{c}{\nu} = \frac{3 \times 10^8}{4 \times 5 \times 10^8} = 0.15m$

8. Optical and radio telescopes are built on the ground while X-ray astronomy is possible only from satellites orbiting the Earth. Why?

Ans: The visible radiations and radiowaves can penetrate the earth's atmosphere but X-rays are absorbed by the atmosphere.

9. The small ozone layer on top of the stratosphere is crucial for human survival. Why?

Ans: The ozone layer absorbs ultraviolet and other low wavelength radiations which are harmful to living cells of human bodies and plants; hence ozone layer is crucial for human survival.

10. What is the line of sight communication?

Ans: The propagation of a radio wave in a straight line from transmitting to receiving antenna on the ground is called line of sight communication.

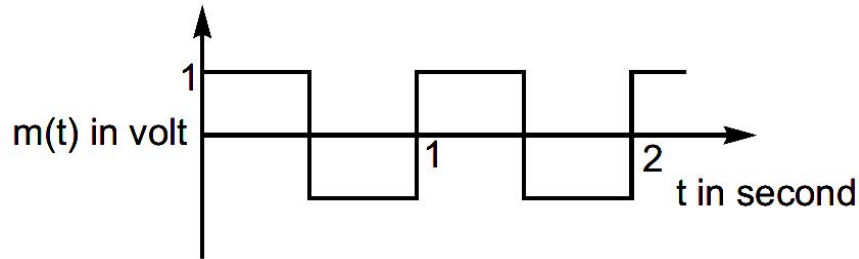
11. Why is it not possible to use sky wave propagation for transmission of TV signals?

Ans: TV signals have high frequency range 100 to 200 MHz. Ionospheric layers do not reflect back such high frequency signals. Hence, sky waves cannot be used for transmission of TV signals.

12. Why are broadcast frequencies (carrier waves) sufficiently spaced in amplitude modulated wave?

Ans: To avoid mixing up of signals from different transmitters. This can be done by modulating the signals on high frequency carrier waves, e.g. frequency band for satellite communication is 5.925–6.425 GHz.

13. The carrier wave is given by $C(t) = 2 \sin (8\pi t)$ volt. The modulating signal is a square wave as shown. Find modulation index.



Ans: Modulation index, $\mu = \frac{\text{Amplitude of modulated signal}}{\text{Amplitude of carrier waves}}$

$$\Rightarrow \frac{A_m}{A_c} = \frac{1m}{2m} = 0.5$$

14. Why is communication using line of sight mode limited to a frequencies above 40 MHz?

Ans: Line of sight mode is limited above 40 MHz, as these waves cannot propagate as sky waves.

15. What are the three basic units of a communication system?

Ans: The three basic units of communication are transmitter, medium /channel and receives.

16. What is the meaning of the term attenuation in communication system?

Ans: The loss of strength of a signal while propagating through a medium is known as attenuation.

17. What is the function of a transmitter in a communication system?

Ans: A transmitter processes the incoming message signal, makes it suitable for transmission.

18. What does the term transducer mean in an electronic communication system?

Ans: In electronic communication system a transducer is a device that converts signals (emw) to electrical form or vice-versa.

19. Name the mode of propagation of radio waves which travel in a straight line from the transmitting antenna to the receiving antenna.

Ans: Space Waves

20. Name the type of communication in which the signal is a discrete and binary coded version of the message or information.

Ans: Binary coded signals are in the form of pulse.

SHORT ANSWER TYPE QUESTIONS (2 MARKS/3 MARKS)

21. Explain the function of a repeater in a communication system.

Ans: A repeater is a combination of a receiver and a transmitter. Repeaters are used to increase the range of communication of signals. A repeater picks up the signal from the transmitter, amplifies and retransmits it to the receiver, sometimes with a change in carrier frequency. A typical example of repeater station is a communication satellite.

22. A TV tower is 80 tall. Calculate the maximum distance upto which the signal transmitted from the tower can be received.

Ans: Maximum coverage distance

$$d = \sqrt{2hR_e} = \sqrt{2 \times 6400 \times 10^3 \times 80} = 32 \times 10^3 \text{ m} = 32 \text{ km}$$

23. “A communication satellite is essentially a repeater station in space.” Justify this statement by analyzing the function of a repeater.

Ans: A repeater is a combination of a receiver and a transmitter. It picks up signals, amplifies and retransmits it. A satellite also receives signal, amplifies it and retransmits it to ground station. Thus the given statement is justified.

24. What is the range of frequencies used for TV transmission? What is common between these waves and light waves?

Ans: Range of frequencies for T.V. transmission are 54 MHz to 890 MHz. The common feature between these waves and light waves is that both travel at the same speed and both are electromagnetic waves.

25. Name any two types of transmission media that are commonly used for transmission of signals. Write the range of frequencies of signals for which these transmission media are used.

Ans: Sky waves and ground waves.

Sky waves – Range few MHz up to 30 to 40 MHz

Ground waves - < few MHz

26. Distinguish between ‘Analog and Digital signals’.

Ans:

Analog signals: They are the continuous variations of voltage or current.

Digital signals: They are the signals which can take only discrete values

27. Mention the function of any two of the following used in communication system: (i) Transmitter (ii) Bandpass Filter

Ans:

(i) Transmitter: A device which processes the incoming message signal so as to make it suitable for transmission through a channel and for its subsequent reception.

(ii) Bandpass filter: A bandpass filter blocks lower and higher frequencies and allows only a band of frequencies to pass through.

28. Why is sky wave mode propagation restricted to frequencies upto 40 MHz?

Ans: Sky wave propagation is restricted to frequency upto 40 MHz, because the radio waves of frequencies more than 40 MHz penetrate into the ionosphere.

29. Give three examples where space wave mode of propagation is used.

Ans: Space wave propagation (LOS) is used in

(i) Television broadcast

(ii) Microwave link

(iii) Satellite communication

30. What is the ground wave communication? On what factors does the maximum range of propagation in this mode depend?

Ans: When the waves propagate near to the surface, the waves glide over the surface of the earth, they are called ground waves. The maximum range of coverage depends on the transmitted power and frequency.

31. Distinguish between sinusoidal and pulse shaped signals.

Ans: When the signal is in the form of continuous variation of amplitude and can be written in the sinusoidal form, it is called a sinusoidal signal. When the signal is in the form of discrete variations or pulse, it is called a pulse signal.

32. What is the length of a dipole antenna to transmit signals of frequency 200 MHz?

Ans: The length of the antenna should be at least $\frac{\lambda}{4}$

For a carrier frequency $5 \times 10^8 \text{ Hz}$

$$\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{5 \times 10^8} = 0.6 \text{ m}$$

Therefore Length of antenna = $\frac{0.6}{4} = 0.15 \text{ m}$

33. Why is frequency modulation preferred over amplitude modulation for transmission of music?

Ans: In frequency modulation, naturally occurring noise is reduced, whereas in amplitude modulation, due to attenuation the signal is distorted and causes noise or disturbance in the signal.

34. Why are audio signals, converted into an electromagnetic wave, not directly transmitted.

Ans: Audio signal if converted to electromagnetic signal will require an antenna of at least size 15 km, which is impractical and signals of different transmitters would mix up.

35. Why is the amplitude of a modulating signal kept less than the amplitude of the carrier wave.

Ans: The amplitude of the modulating signal is kept less than the carrier waves so that no distortion occurs in the modulated wave.

36. In standard AM broadcast, what mode of propagation is used for transmitting a signal? Why is this mode of propagation limited to frequencies up to a few MHz?

Ans: In standard AM broadcast, ground wave is used as the mode of propagation. This mode is limited up to a few MHz, because the attenuation of surface waves increases very rapidly with increase in frequency.

37. Why do we need a higher bandwidth for transmission of music compared to that for commercial telephonic communication?

Ans: Higher bandwidth is required for transmission of music because of the high frequencies produced by the musical instruments of the range 20 Hz – 20 KHz. Speech signals range from 300 Hz - 3100 Hz.

38. Distinguish between frequency modulation and amplitude modulation. Why is an FM signal less susceptible to noise than an AM signal?

Ans: In frequency modulation the frequency of the carrier wave is modulated. In amplitude modulation, amplitude of the carrier wave is modulated. Due to attenuation, amplitude decrease affects the amplitude modulation. Thus AM is more susceptible to noise than FM.

39. Write the function of (i) Transducer and (ii) Repeater in the context of a communication system.

Ans: (i) **Transducer** : Any device that converts one form of energy into another is called a transducer. Like a phone converts electrical signal into sound and hence is a transducer.

(ii) **Repeater** : A repeater picks up the signal from the transmitter, amplifies it and retransmits it to the receiver sometimes with a change in carrier frequency. Thus, a repeater compensates the loss in energy during transmission of signals.

40. Write two factors justifying the need of modulation for transmission of a signal. [AI 2009]

Ans: Two factors justifying the need of modulation for transmission of a signal are :

(a) **Manageable size of the antenna** : Audio signals when converted into electromagnetic waves have low frequency and large wavelength λ , so an antenna of large length $L = \frac{\lambda}{4} \approx 3.75 \text{ km}$ is required, which is impractical.

However for modulating audio signals with carrier waves of large frequencies, antenna of small manageable size is required.

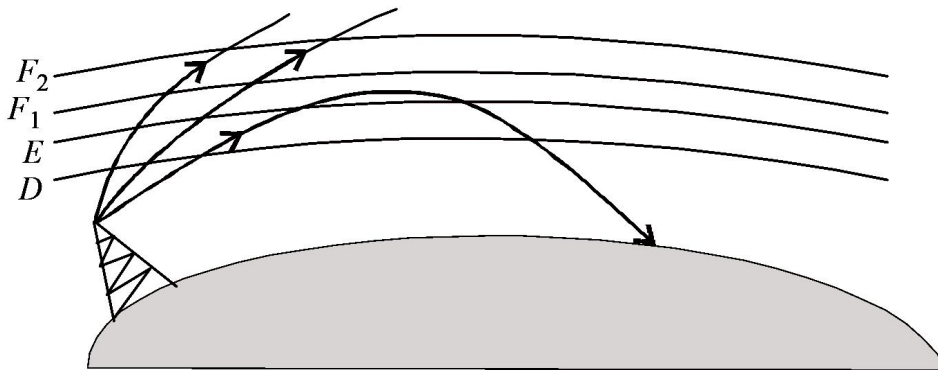
(b) **More effective power radiated by antenna** : Power radiated by antenna is $P \propto \frac{l^2}{\lambda^2}$

This shows that there is a need of higher frequency conversion for effective power transmission by the antenna.

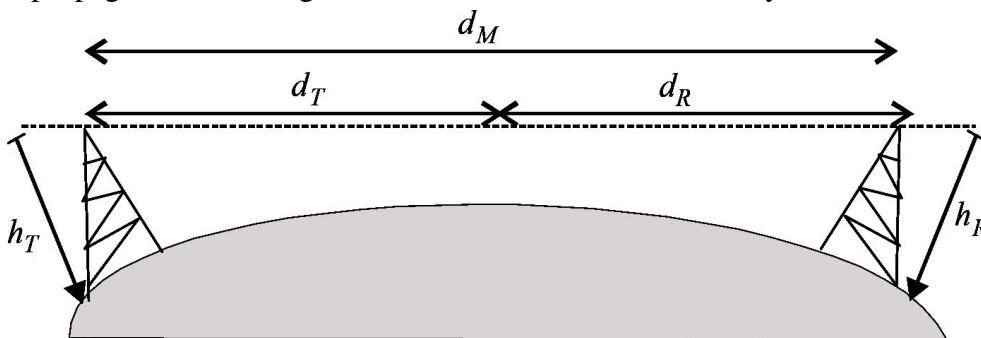
41. Distinguish between sky wave and space wave propagation. Give a brief description with the help of suitable diagrams indicating how these waves are propagated. [AI 2009]

Ans: In sky wave propagation, the transmitted radio waves reach the receiving antenna after reflection from the ionosphere. Whereas, in space wave propagation or line of sight propagation, radio waves travel in straight line from transmitting to receiving antenna.

(i) Sky wave propagation : Here the radio waves reach the receiving antenna from transmitting antenna after reflection from ionosphere.



(ii) Space wave propagation : Here the transmitted radio waves reach the receiver through a 'line of sight' straight propagation. The range of such a transmission is limited by the curvature of the earth.



42. Write two factors justifying the need of modulating a signal. A carrier wave of peak voltage 12 V is used to transmit a message signal. What should be the peak voltage of the modulating signal in order to have a modulation index of 75%? [AI 2010]

Ans: Need of modulation :

(i) audio/video signals do not have sufficiently high energy to travel upto long distances, because of their lower frequency.

(ii) For effective transmission, the size of the antenna should be at least of the size $\frac{\lambda}{4}$, where λ is wavelength of signal to be sent. For an e.m. wave of the frequency of the order of audio signal, we need an antenna of size 3.75 km, which is practically impossible.

Hence these low frequency base band signals are first converted into high frequencies, through modulation.

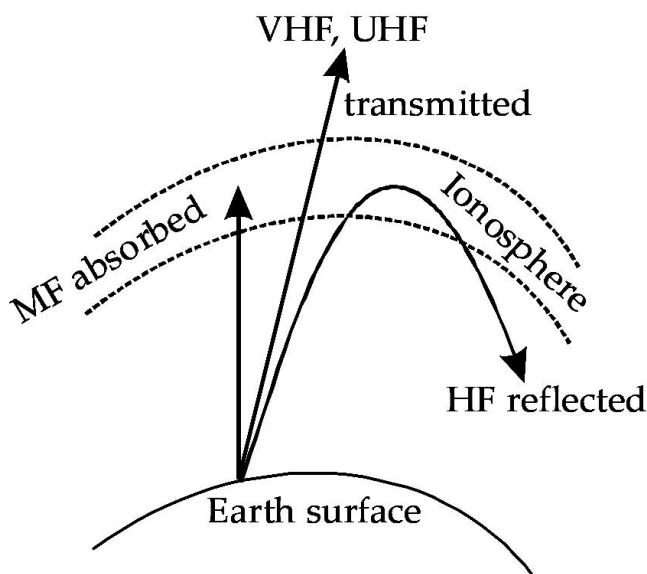
$$\text{Modulation index, } \mu = \frac{A_m}{A_c}$$

So peak voltage of modulating signal, $A_m = \mu A_c$

$$\therefore A_m = 0.75 \times 12 = 9 \text{ V}$$

43. Which mode of propagation is used by short wave broadcast services having frequency range from a few MHz upto 30 MHz? Explain diagrammatically how long distance communication can be achieved by this mode. Why is there an upper limit to frequency of waves used in this mode? [AI 2010]

Ans: Sky wave propagation is used by short wave broadcast services having frequency range from a few MHz upto 30 MHz.



Sky waves are used for long distance radio communication. The successive reflection of these radiowaves at the earth's surface and the ionosphere make it possible to transmit these waves from one part to another part of the earth.

These waves are reflected by ionosphere by means of total internal reflection, which arises due to change in refractive indices of different layers of ionosphere. Critical frequency of reflection for a particular layer is given by $f_c = 9\sqrt{N_{\max}}$ where N_{\max} = maximum electron density in the given layer.

For any frequency greater than f_c ionosphere is not able to reflect the radiowave. Hence there exists an upper limits to frequency of waves used in this mode.

44. (i) Define modulation index. (ii) Why is the amplitude of modulating signal kept less than the amplitude of carrier wave? [AI 2011]

Ans: (i) Modulation index : The modulation index of an amplitude modulated wave is defined as the ratio of the amplitude of modulating signal (A_m) to the amplitude of carrier wave (A_c).

i.e., Amplitude modulation index, $\mu_a = \frac{A_m}{A_c}$

(ii) The amplitude of modulating signal is kept less than the amplitude of carrier wave to avoid distortion.

45. Draw a schematic diagram showing the (i) ground wave (ii) sky wave and (iii) space wave propagation modes for em waves. Write the frequency range for each of the following :

(i) Standard AM broadcast

(ii) Television

(iii) Satellite communication [AI 2011]

Ans: The diagram below is showing various propagation modes for em waves.

(i) 540 – 1600 KHz

(ii) 54 – 72 MHz

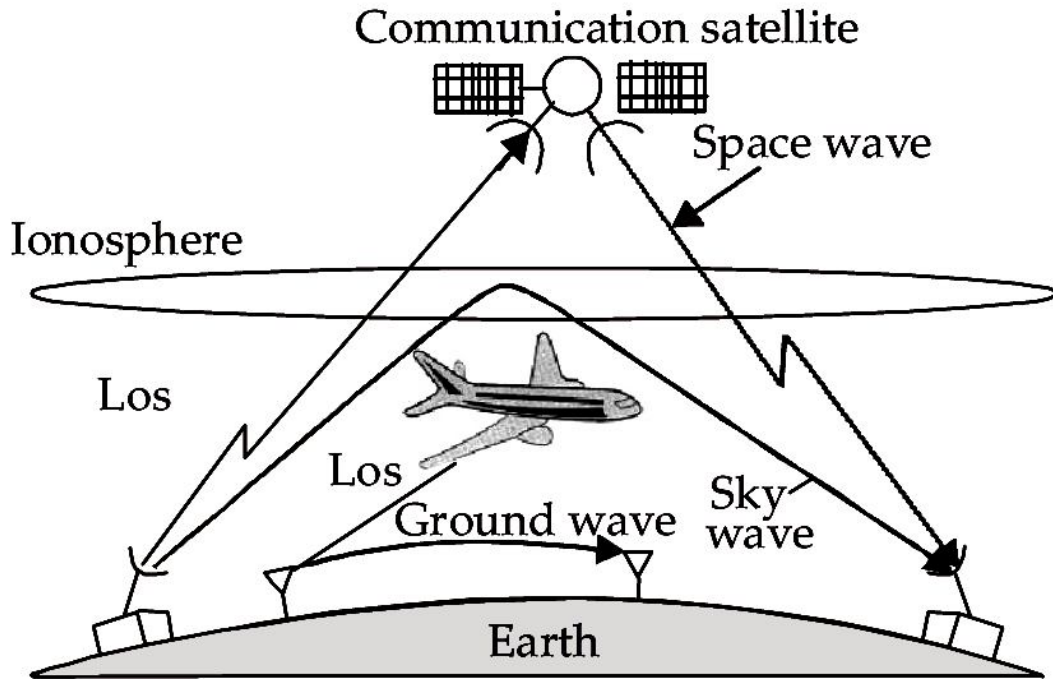
76 – 88 MHz

174 – 216 MHz

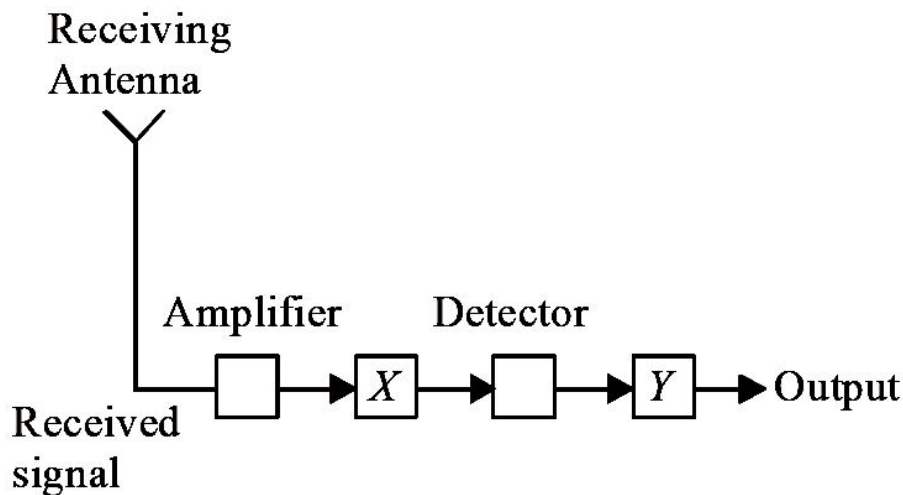
420 – 890 MHz

(iii) 5.925 – 6.425 GHz

3.7 – 4.2 GHz



46. In the given block diagram of a receiver, identify the boxes labelled as X and Y and write their functions. [AI 2012]



Ans: X = Intermediate frequency (IF) stage

Y = Amplifier/Power Amplifier

IF Stage : IF stage changes the carrier frequency to a lower frequency.

Amplifier: increases the strength of signals.

47. Name the type of waves which are used for line of sight (LOS) communication. What is the range of their frequencies? A transmitting antenna at the top of a tower has a height of 20 m and the height of the receiving antenna is 45 m. Calculate the maximum distance between them for satisfactory communication in LOS mode. (Radius of the Earth = 6.4×10^6 m) [AI 2013]

Ans: Space waves/radio wave/ micro wave

Frequency range above 40 MHz

Maximum distance, $d_m = \sqrt{2h_t R} + \sqrt{2h_r R}$

$$\Rightarrow d_m = \sqrt{2 \times 6400 \times 10^3 \times 45} + \sqrt{2 \times 6400 \times 10^3 \times 20}$$

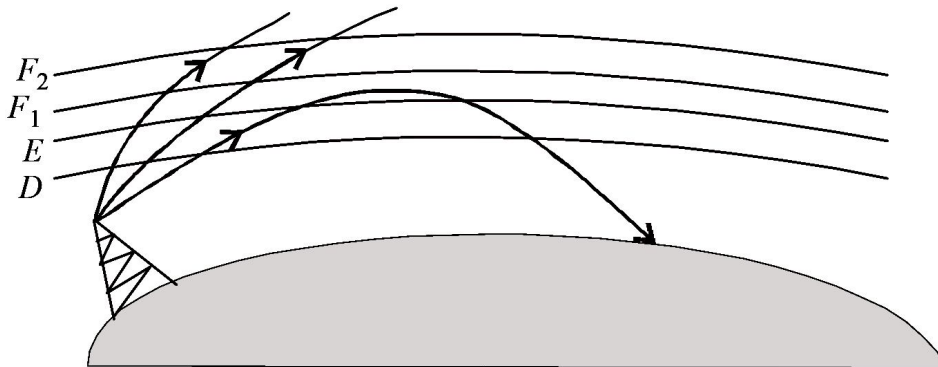
$$= (24 + 16) \times 10^3 \text{ m} = 40 \times 10^3 \text{ m}$$

48. Mention three different modes of propagation used in communication system. Explain with the help of a diagram how long distance communication can be achieved by ionospheric reflection of radio waves. [AI 2012]

- Ans: (i) Ground wave or surface wave propagation
 (ii) Sky wave propagation or ionospheric propagation
 (iii) Space wave propagation/Line of sight propagation

Sky wave propagation: The radio waves which are reflected back to earth by ionosphere are known as sky waves and mode of propagation of sky waves is known as sky wave propagation. Sky waves are also amplitude modulated waves and are for long distance radio communication. In sky wave propagation, radio waves transmitted by transmitting antenna are directed towards the ionosphere. The radiowaves having frequency range 2 MHz to 30 MHz are reflected back by the ionosphere. The successive reflection of these radiowaves at the earth's surface and the ionosphere make it possible to transmit these waves from one part to another part to another part of the earth.

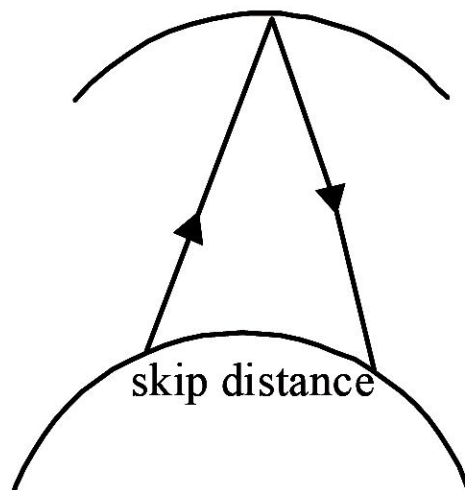
Ionosphere is a layer of atmosphere having charged particles, ions and electrons, which extends from about 60 to 350 kms from the surface of earth.



Ionosphere is subdivided into layer as C, D, E, f₁ and F₂.

These different layer of ionosphere reflect the radio waves of different frequencies.

- (i) Medium frequencies (MF) of frequencies up to 3 MHz are absorbed by ionosphere.
- (ii) High frequencies (HF) of frequencies up to 30 MHz are reflected back by ionosphere.
- (iii) Very high and ultra high frequencies (VHF and UHF) of frequencies above 40 MHz are only bend by ionosphere, but are not reflected back towards earth.



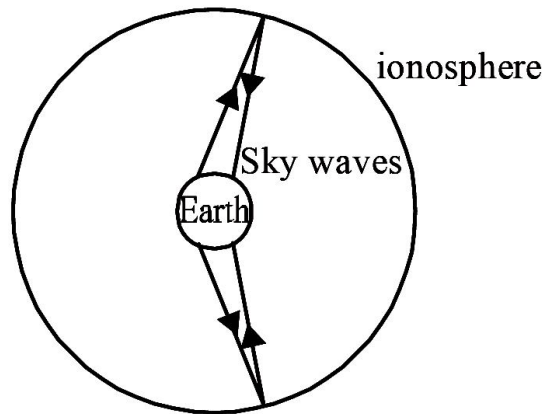
The ionosphere consists of positively charged ions and electrons. Such a system is known as 'plasma', which has a characteristic frequency called 'Plasma frequency' given by $f_p = 9\sqrt{N}$ where N is the electron density (in m^{-3}) in the concerned layer of ionosphere.

When any radiation reaches the region of electron density N at normal incidence, it will be reflected.

The 'critical frequency' for reflection is therefore given by $f_p = 9\sqrt{N_{max}}$

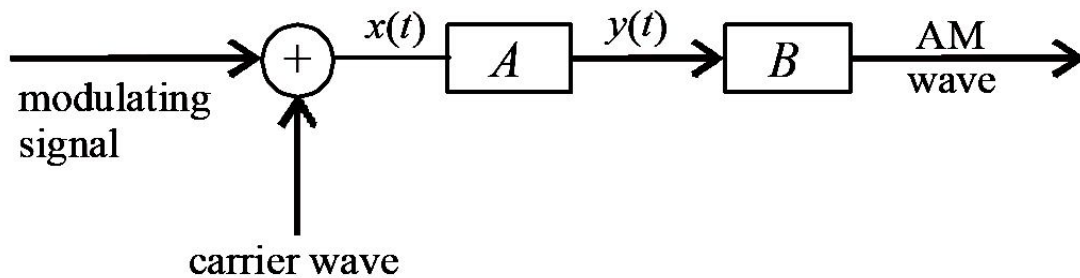
f_c turns out to be 4 MHz, 5 MHz and 8 MHz for E, F₁ and F₂ layers respectively.

Any wave directed at a certain angle gets reflected by ionosphere and returns to earth. The distance from the transmitter, measured along the surface of earth, to the point where sky wave returns after reflection from ionosphere is called skip distance for a single hop. Using multiple hops or beaming at different angles, we can increase the propagation range.



In sky wave propagation, radio signals can be transmitted to the stations which otherwise become inaccessible to the ground due to curvature of earth. Thus due to reflection by ionosphere, radio wave signals can be transmitted virtually from any one place to the other on surface of earth. So it is useful for very long distance radio communication. Thus for long distance radio broadcasts through sky wave propagation, we use short wave bands.

49. In the block diagram of a simple modulator for obtaining an AM signal shown in the figure, identify the boxes A and B. Write their functions. [AI 2013]



Ans: **Identification:**

A is the square law device.

B is the bandpass filter.

Functions:

Square law device is a non linear device and produces the output.

Bandpass filter rejects dc and sinusoidal frequencies $\omega_m, 2\omega_m, 2\omega_c$ and gives the AM wave as its output.

50. A transmitting antenna at the top of a tower has a height of 36 m and the height of the receiving antenna is 49 m. What is the maximum distance between them, for satisfactory communication in the LOS mode ? (Radius of earth = 6400 km).

Ans:

Given $h_T = 36$ m, $h_R = 49$ m, and $R_e = 6400$ km = 6.4×10^6 m.

Maximum LOS distance, $d_m = \sqrt{2h_T R_e} + \sqrt{2h_R R_e}$

$$\Rightarrow d_m = \sqrt{2 \times 6.4 \times 10^6 \times 36} + \sqrt{2 \times 6.4 \times 10^6 \times 49}$$

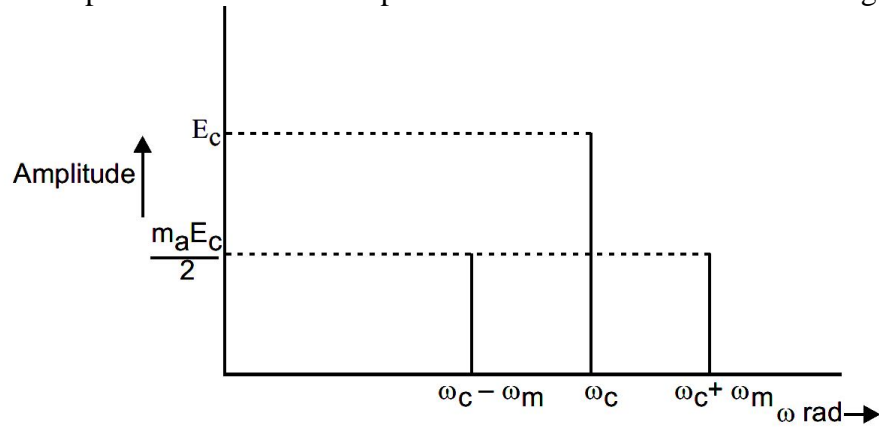
$$= 3.578 \times 10^3 (6 + 7) = 3.578 \times 10^3 \times 13 \text{ m}$$

$$= 46.5 \times 10^3 \text{ m} = \mathbf{46.5 \text{ km}}$$

51. Draw a plot of the variation of amplitude versus ω for an amplitude modulated wave. Define modulation index. State its importance for effective amplitude modulation.

Ans:

Plot of variation of amplitude versus ω for amplitude modulated wave is shown in fig.



Modulation Index: The ratio of amplitude of modulating signal to the amplitude of carrier wave is called modulation index *i.e.*, $m_a = \frac{E_m}{E_c}$

For effective amplitude modulation the modulation index determines the distortions, so its value is kept ≤ 1 for avoiding distortions.

52. By what percentage will the transmission range of a T.V. tower be affected when the height of the tower is increased by 21 %?

Ans: Transmission range of a TV tower

$$d = \sqrt{2hR}$$

If height is increased by 21 %, new height, $h' = h + \frac{21}{100}h = 1.21h$

If d' is the new range, then $\frac{d'}{d} = \sqrt{\frac{h'}{h}} = \sqrt{1.21} = 1.1$

$$\% \text{ increase in range, } \frac{\Delta d}{d} \times 100\% = \frac{d' - d}{d} \times 100\%$$

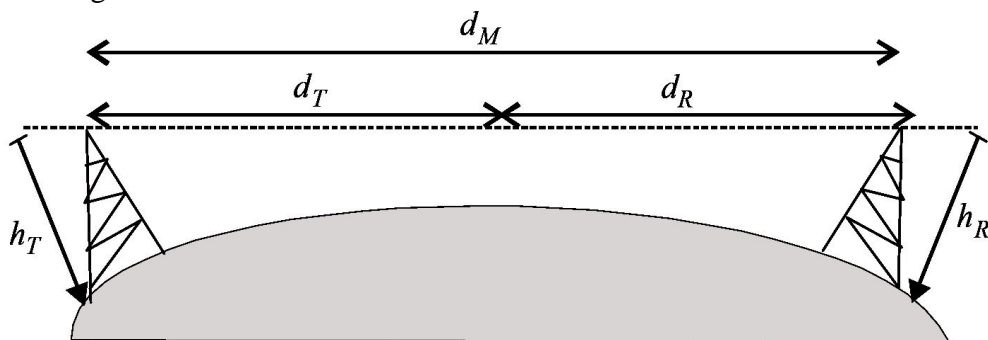
$$= \left(\frac{d'}{d} - 1 \right) \times 100\% = (1.1 - 1) \times 100\% = 10\%$$

53. What does the term ‘LOS communication’ mean ? Name the types of waves that are used for this communication. Give typical examples, with the help of a suitable figure, of communication systems that use space wave mode propagation.

Ans: LOS Communication: It means “Line of sight communication”.

Space waves are used for LOS communication.

In this communication the space waves (radio or microwaves) travel directly from transmitting antenna to receiving antenna.



Communication System using Space wave mode propagation are (i) LOS communication and Fig. shows LOS communication system.

If transmitting antenna and receiving antenna have heights h_T and h_R respectively, then Radio horizon of transmitting antenna,

$$d_T = \sqrt{2h_T R_e}$$

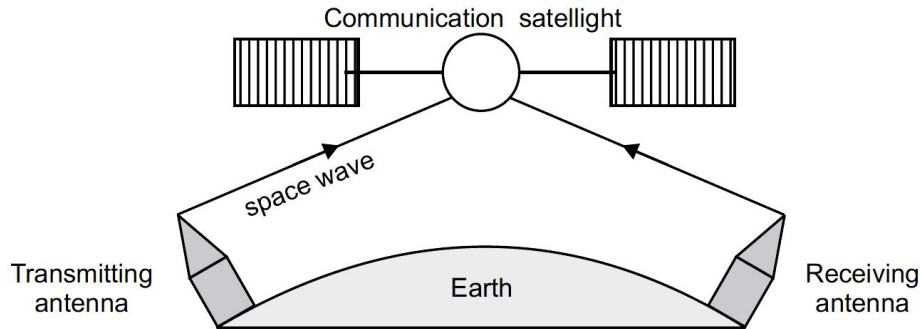
where R_e is radius of earth and radio horizon of receiving antenna.

$$d_R = \sqrt{2h_R R_e}$$

\therefore Maximum line of sight distance, $d_M = d_T + d_R = \sqrt{2h_T R_e} + \sqrt{2h_R R_e}$

(ii) Television, broadcast, microwave links and satellite communication

The satellite communication is shown in fig. The space wave used is microwave.



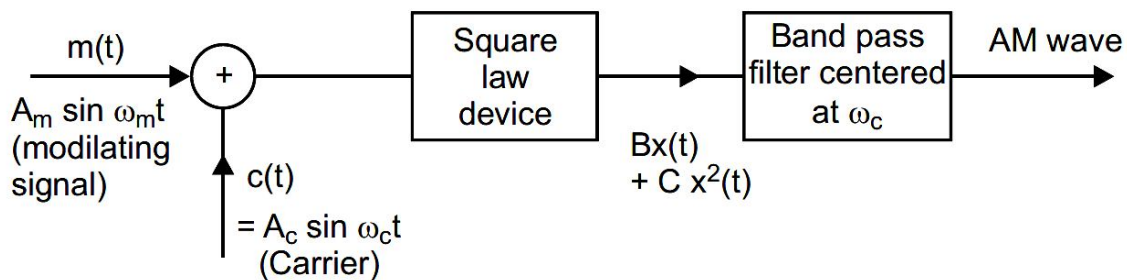
54. Why are high frequency carrier waves used for transmission?

Ans: Use of high frequency carrier wave in transmission of signals:

- (i) High frequency carrier wave reduces the size of antenna as $h = \frac{\lambda}{2}$ or $\frac{\lambda}{4}$
- (ii) High frequency carrier wave radiates more power in space as $P \propto v^2$
- (iii) High frequency carrier wave avoids mixing up of message signals.

55. What is meant by term ‘modulation’? Draw a block diagram of a simple modulator for obtaining an AM signal.

Ans: Meaning of Modulation: The original low frequency message/information signal cannot be transmitted over long distances. Therefore, at the transmitter end, information contained in the low frequency message signal, is superimposed on a high frequency carrier signal by a process known as modulation.



Block diagram of simple modulator

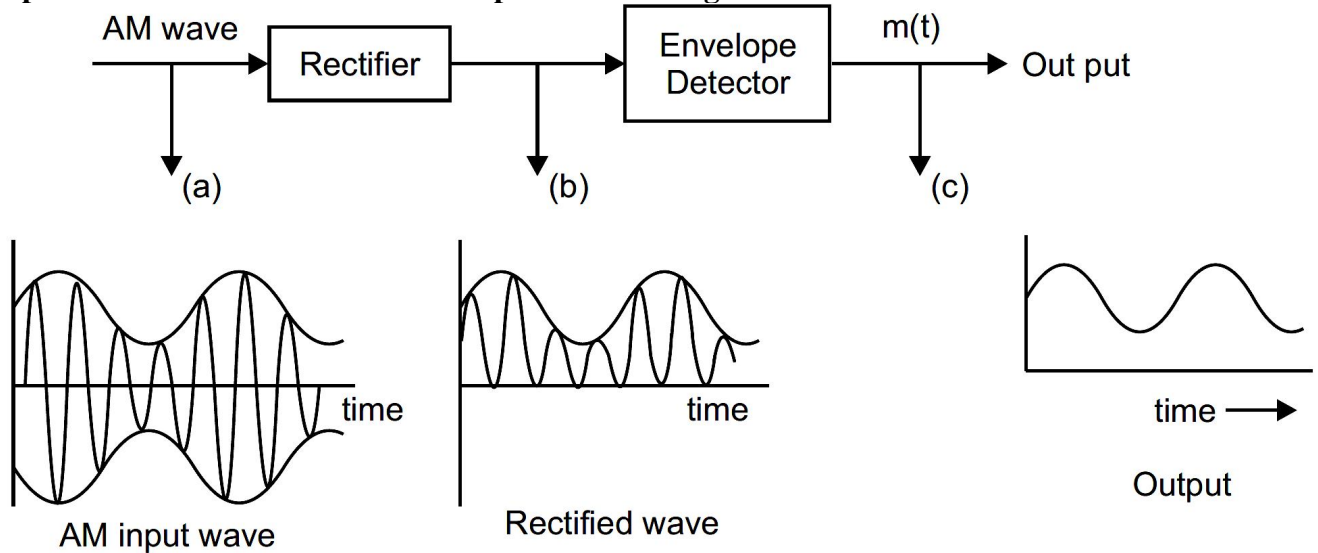
56. Define the terms ‘amplitude modulation’

Ans: In amplitude modulation, the amplitude of modulated (carrier) wave varies in accordance with amplitude of information (signal) wave. When amplitude of information increases, the amplitude of modulated wave increases and vice versa. In this case the amplitude of modulated wave is not constant.

57. What is meant by detection of a signal in a communication system? With the help of a block diagram explain the detection of AM signal.

Ans: Detection is the process of recovering the modulating signal from the modulated carrier wave.

Explanation of Detection with the help of a block diagram:



The modulated carrier wave contains frequencies $w_c \pm w_m$. The detection means to obtain message signal $m(t)$ of frequency w_m . The method is shown in the form of a block diagram.

The modulated signal is passed through a rectifier. It produces rectified wave [fig. (b)]; the envelope of which is the message signal.

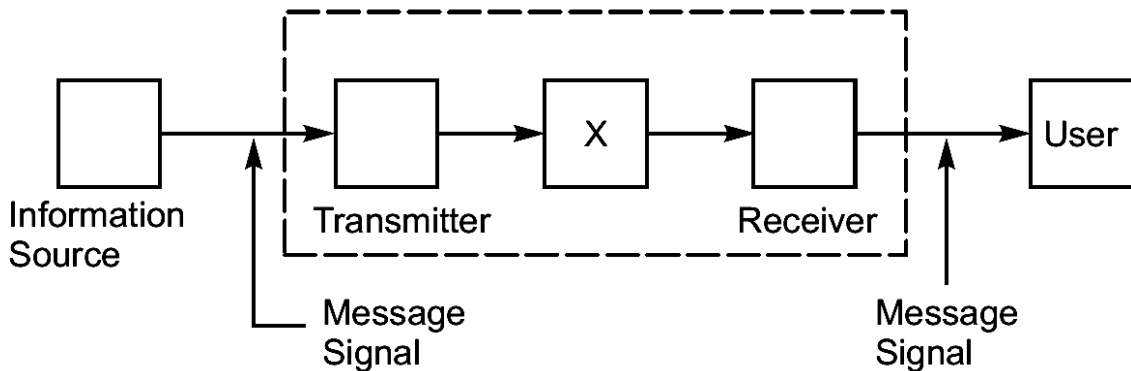
The rectified wave is passed through an envelope detector, whose output is the required message signal $m(t)$.

58. If a low frequency signal in the audio frequency range is to be transmitted over long distances, explain briefly the need of translating this signal to high frequencies before transmission.

Ans: The modulation is needed due to

- (i) Transmission of audio frequency electrical signals need long impracticable antenna.
- (ii) The power radiated at audio frequency is quite small, hence transmission is quite lossy.
- (iii) The various information signals transmitted at low frequency get mixed and hence can not be distinguished.

59. The figure given below shows the block diagram of a generalised communication system. Identify the element labelled 'X' and write its function.



Ans: X represents communication channel.

Function: It connects the transmitter to the receiver.

60. What is ground wave communication? On what factors does the maximum range of propagation in this mode depend?

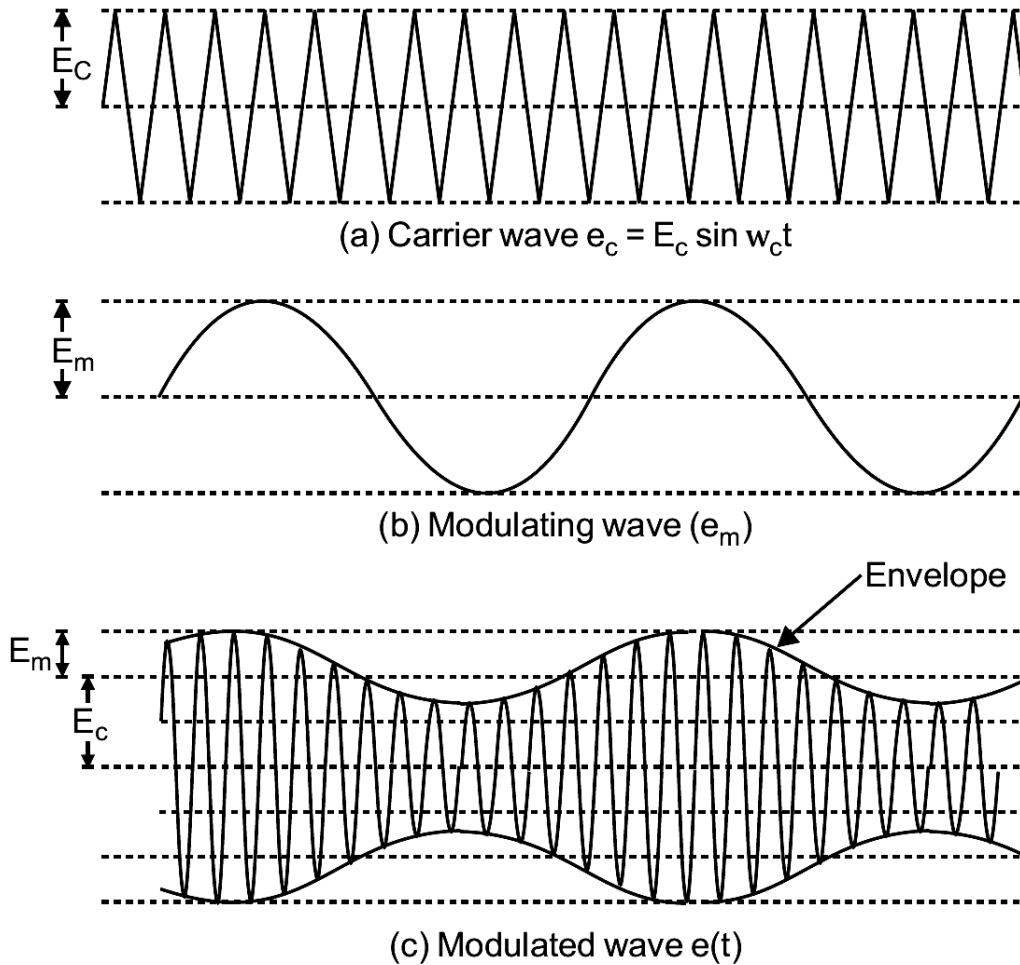
Ans: The mode of wave propagation in which wave glides over the surface of the earth is called ground wave communication.

The maximum range of propagation in this mode depends on

- (i) transmitted power and
- (ii) frequency (less than a few MHz)

61. Draw a suitable diagram to show amplitude modulation using a sinusoidal signal as the modulating signal.

Ans:



62. For an amplitude modulated wave, the maximum amplitude is found to be 10 V while the minimum amplitude is 2V. Calculate the modulation index. Why is modulation index generally kept less than one?

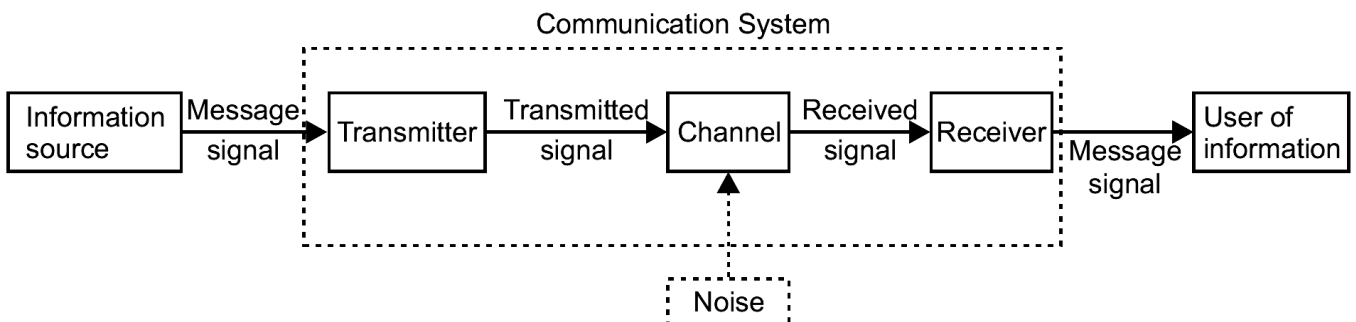
Ans: Here, $A_{max} = 10V$ and $A_{min} = 2 V$

$$\text{Modulation index} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}} = \frac{10 - 2}{10 + 2} = \frac{8}{12} = 0.67$$

Generally, the modulation index is kept less than one to avoid distortion.

63. Draw a block diagram showing the important components in a communication system. What is the function of a transducer?

Ans: Block diagram of communication system:



Function of a transducer is to convert one form of energy into another form.

ELECTROMAGNETIC WAVES

ELECTROMAGNETIC WAVES

MARKS WEIGHTAGE – 3 marks

QUICK REVISION (Important Concepts & Formulas)

- **Electromagnetic radiation** is the radiation in which associated electric and magnetic field oscillations are propagated through space. The electric and magnetic fields are at right angle to each other and to the direction of propagation.
- Propagation of electromagnetic wave through space is fully described in terms of wave theory but interaction with matter depends on quantum theory.
- Maxwell showed that the changing electric field intensity is equivalent to a current through the capacitor. This current through the capacitor is known as displacement current.

$$I_d = \frac{\epsilon_0 d\phi_E}{dt}$$

- Maxwell was first to provide the mathematical structure of the laws of electromagnetism.
- The basic principle of electromagnetism can be formulated in terms of four fundamental equations called Maxwell's equations.
- Four Maxwell's equations are –
- Gauss's law for electrostatics

$$\oiint \vec{E} \cdot d\vec{S} = \frac{q}{\epsilon_0} \text{ which describes the charge and the electric field.}$$

- Gauss's law for magnetism

$$\oiint \vec{B} \cdot d\vec{S} = 0 \text{ which describes the magnetic field.}$$

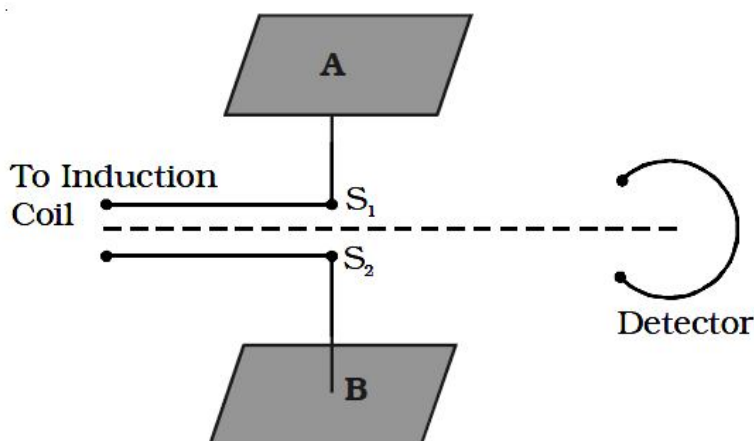
- Faraday's law of induction

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\phi_B}{dt} \text{ which describes the electrical effect of a changing magnetic field.}$$

- Ampere's law of induction (as extended by Maxwell)

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 i + \mu_0 \epsilon_0 \frac{d\phi_E}{dt} \text{ which describes the magnetic effect of a current or a changing electric field.}$$

- Maxwell's equations apply to electric and magnetic fields in vacuum. They may also be generalised to include fields in matter.
- Hertz was first to demonstrate the production of electromagnetic waves in the laboratory which is based on principle that a vibrating charge radiates electromagnetic waves.
- Hertz produced electromagnetic waves, with the aid of oscillating circuits. To receive and detect these waves, the other circuits, tuned to same frequency, were used.



Hertz experiment

- The frequency of oscillation, $\nu = \frac{1}{2\pi\sqrt{LC}}$
- Hertz from his experiment produced standing electromagnetic waves and measured the distance between adjacent nodes, to measure the wavelength.
- Knowing the frequency of his resonators, he then found the velocity of the wave from the fundamental wave equation $c = \nu\lambda$ and verified that it was the same as that of light, as given by Maxwell.
- The unit of frequency, one cycle per second is named one hertz (1 Hz) in honour of Hertz.
- The plane progressive electromagnetic wave has the following characteristics.
 1. The electric vector, the magnetic vector and the direction of propagation are mutually perpendicular to each other. i.e. the electromagnetic wave is a transverse wave.
 2. The equation of plane progressive electromagnetic wave can be written as

$$E = E_0 \sin \omega \left(t - \frac{x}{c} \right), B = B_0 \sin \omega \left(t - \frac{x}{c} \right), \text{ where } \omega = 2\pi\nu$$

This shows that both the electric and magnetic fields oscillate with the same frequency ν and there is no phase difference between them.

Both these fields have varying time and space and have the same frequency.

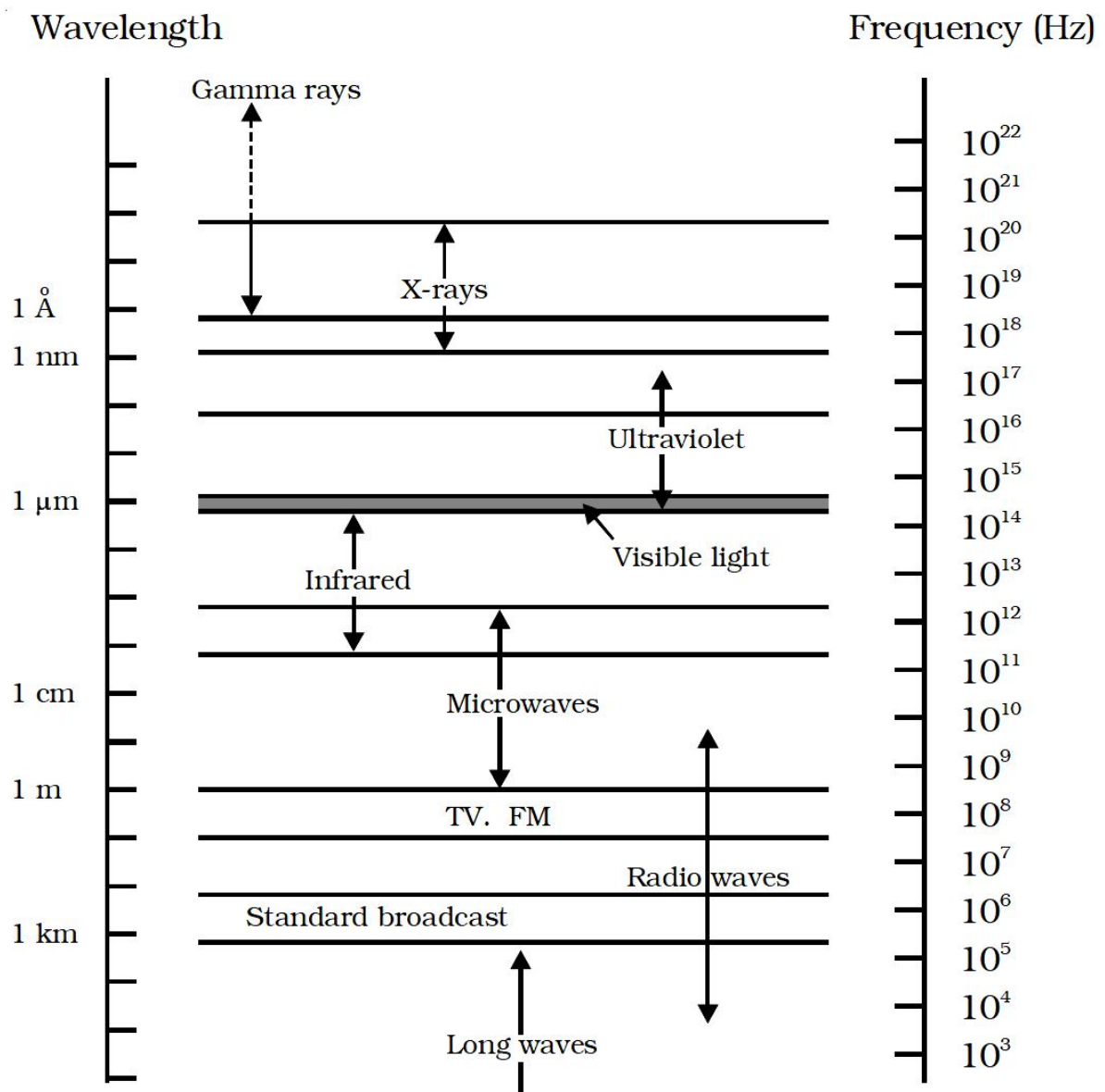
- **Velocity** of electromagnetic waves in free space is given by $c = \frac{1}{\sqrt{\mu_0\epsilon_0}} = 3 \times 10^8$ m/s
- The instantaneous magnitude of the electric and magnetic field vectors in electromagnetic wave are related as $\frac{|E|}{|B|} = c$ or $E = Bc$.
- In a medium of refractive index n , the velocity v of an electromagnetic wave is given by $v = \frac{c}{n} = \frac{1}{n} \cdot \frac{1}{\sqrt{\mu_0\epsilon_0}}$. Also, $v = \frac{1}{\sqrt{\mu\epsilon}}$
- So that $n = \sqrt{\frac{\mu\epsilon}{\mu_0\epsilon_0}}$
- The energy is equally shared between electric field and magnetic field vectors of electromagnetic wave. Therefore the energy density of the electric field, $u_E = \frac{1}{2} \epsilon_0 E^2$; the energy density of magnetic field, $u_B = \frac{1}{2} \frac{B^2}{\mu_0}$
- Average energy density of the electric field, $\langle u_E \rangle = \frac{1}{4} \epsilon_0 E_0^2$ and average energy density of the magnetic field $\langle u_B \rangle = \frac{1}{2} \mu_0 B_0^2 = \frac{1}{4} \epsilon_0 E_0^2$
- Average energy density of electromagnetic wave is $\langle u \rangle = \frac{1}{2} \epsilon_0 E_0^2$
- **Intensity** of electromagnetic wave is defined as energy crossing per unit area per unit time perpendicular to the directions of propagation of electromagnetic wave. The intensity I is given by the relation $I = \langle u \rangle c = \frac{1}{2} \epsilon_0 E_0^2 c$
- The electromagnetic wave also carries linear momentum with it. The linear momentum carried by the portion of wave having energy U is given by $p = U/c$.

- If the electromagnetic wave incident on a material surface is completely absorbed, it delivers energy U and momentum $p = U/c$ to the surface.
 - If the incident wave is totally reflected from the surface, the momentum delivered to the surface is $U/c - (-U/c) = 2U/c$. It follows that the electromagnetic wave incident on a surface exert a force on the surface.
 - According to Maxwell, when a charged particle is accelerated it produces electromagnetic wave. The total radiant flux at any instant is given by $P = \frac{q^2 a^2}{6\pi\epsilon_0 c^3}$ where q is the charge on the particle, and a is its instantaneous acceleration.
 - The electromagnetic wave is emitted when an electron orbiting in higher stationary orbit of atom jumps to one of the lower stationary orbit of that atom.
 - The electromagnetic waves are also produced when fast moving electrons are suddenly stopped by the metal of high atomic number.
 - The total energy flowing perpendicularly per second per unit area in to the surface in free space is called a **poyniting vector** \vec{S}
- $$\vec{S} = c^2 \epsilon_0 (\vec{E} \times \vec{B}) = \frac{\vec{E} \times \vec{B}}{\mu_0}$$
- The S.I. unit of S is **watt/m²** .
 - The rate of energy transfer for electromagnetic wave is proportional to the product of the electric and magnetic field strength, *i.e.* to the surface integral of the poyniting vector formed by the component of the field in the plane of the surface.
 - The average value of poyniting vector (\vec{S}) over a convenient time interval in the propagations of electromagnetic wave is known as radiant flux density. When energy of electromagnetic wave is incident on a surface, the flux density is called **intensity of wave** (denoted by I). Thus $I = S$.
 - The orderly distributions of electromagnetic radiations according to their wavelength or frequency is called the **electromagnetic spectrum**. The below figure and Table shows various regions of electromagnetic spectrum with source, wavelength and frequency ranges of different electromagnetic waves.

The following are some of the uses of electromagnetic waves.

- *Radio waves* : These waves are used in radio and television communication systems. AM band is from 530 kHz to 1710 kHz. Higher frequencies upto 54 MHz are used for short waves bands. Television waves range from 54 MHz to 890 MHz. FM band is from 88 MHz to 108 MHz. Cellular phones use radio waves in ultra high frequency (UHF) band.
- *Microwaves* : Due to their short wavelengths, they are used in radar communication system. Microwave ovens are an interesting domestic application of these waves.
- *Infra red waves* :
 - (i) Infrared lamps are used in physiotherapy.
 - (ii) Infrared photographs are used in weather forecasting.
 - (iii) As infrared radiations are not absorbed by air, thick fog, mist etc, they are used to take photograph of long distance objects.
 - (iv) Infra red absorption spectrum is used to study the molecular structure.

- *Visible light* the most familiar form of electromagnetic wave, is that part of the spectrum the human eye can detect. The limits of wavelength of the visible region are from 430 nm (violet) to 740 nm (red).
- *Ultra-violet radiations*
 - (i) They are used to destroy the bacteria and for sterilizing surgical instruments.
 - (ii) These radiations are used in detection of forged documents, finger prints in forensic laboratories.
 - (iii) They are used to preserve the food items.
 - (iv) They help to find the structure of atoms.
- X rays :
 - (i) X rays are used as a diagnostic tool in medicine.
 - (ii) It is used to study the crystal structure in solids.
- γ rays : Study of γ rays gives useful information about the nuclear structure and it is used for treatment of cancer.



The radiowaves can travel from the transmitting antenna to the receiving antenna by the following ways:

(i) **Ground wave propagation:**

The lower frequency [500 kHz to 1600 kHz] broadcast service use the surface wave propagation. These waves travel close to the surface of the earth. The electrical conductivity of the earth plays an important role in deciding the propagational characteristics of these waves.

(ii) **Sky wave propagation:**

The radiowaves which reach the receiving antenna as a result of reflection from the ionosphere layers are called sky waves. Frequency range from 1500 kHz to 40 MHz is used in sky wave propagation. Due to mutual reflections between the earth and the ionosphere, long distance transmission is possible by the sky waves.

(iii) **Space wave propagation :**

The electromagnetic waves which travel directly from the transmitting antenna to the receiving antenna, without being influenced by the earth are called space wave.

Sl.No.	Name	Source	Wavelength range (m)	Frequency range (Hz)
1.	γ - rays	Radioactive nuclei, nuclear reactions	$10^{-14} - 10^{-10}$	$3 \times 10^{22} - 3 \times 10^{18}$
2.	x - rays	High energy electrons suddenly stopped by a metal target	$1 \times 10^{-10} - 3 \times 10^{-8}$	$3 \times 10^{18} - 1 \times 10^{16}$
3.	Ultra-violet (UV)	Atoms and molecules in an electrical discharge	$6 \times 10^{-10} - 4 \times 10^{-7}$	$5 \times 10^{17} - 8 \times 10^{14}$
4.	Visible light	incandescent solids Fluorescent lamps	$4 \times 10^{-7} - 8 \times 10^{-7}$	$8 \times 10^{14} - 4 \times 10^{14}$
5.	Infra-red (IR)	molecules of hot bodies	$8 \times 10^{-7} - 3 \times 10^{-5}$	$4 \times 10^{14} - 1 \times 10^{13}$
6.	Microwaves	Electronic device (Vacuum tube)	$10^{-3} - 0.3$	$3 \times 10^{11} - 1 \times 10^9$
7.	Radio frequency waves	charges accelerated through conducting wires	$10 - 10^4$	$3 \times 10^7 - 3 \times 10^4$

- Microwaves *i.e.* T.V. and radar waves follow this mode of propagation.
- In the day time, the radiations from the sun reach the earth. At night, the earth's atmosphere prevents the infrared radiations of earth from passing through it and thus helps in keeping the earth's surface warm. This phenomenon is called **green house effect**.
- Electromagnetic waves of frequency less than 30 MHz form amplitude modulated range.
- The electromagnetic waves of frequencies between 80 MHz to 200 MHz form frequency modulated band.
- Height of transmitting antenna (h) related with the relation, $d = \sqrt{2hR}$, where d is the radius of the circle on the surface of earth within which the transmitted signal from the transmitting antenna can be received and R is the radius of earth.
Area covered = $\pi d^2 = \pi (2hR)$
Population covered = (area covered) \times (population density)

ELECTROMAGNETIC WAVES

MARKS WEIGHTAGE – 3 marks

Important Questions and Answers

VERY SHORT ANSWER TYPE QUESTIONS (1 MARK)

1. Name the EM waves used for studying crystal structure of solids. What is its frequency range?

[AI 2009]

Ans: X-rays, 3×10^{16} Hz to 3×10^{20} Hz

2. Name the part of electromagnetic spectrum whose wavelength lies in the range of 10 –10 m.

Give its one use. [AI 2010]

Ans: The given range corresponds to X-rays. X-rays are used for detection of fractures, formations of stones etc. in human bodies. They are also used to study crystal structure of solids.

3. A plane electromagnetic wave travels in vacuum along z direction. What can you say about the direction of electric and magnetic field vectors? [AI 2011]

Ans: The electric and magnetic field vectors \vec{E} and \vec{B} are perpendicular to each other and also perpendicular to the direction of propagation of the electromagnetic wave. If a plane electromagnetic wave is propagating along the z-direction, then the electric field is along x-axis, and magnetic field is along y-axis.

4. What are the directions of electric and magnetic field vectors relative to each other and relative to the direction of propagation of electromagnetic waves? [AI 2012]

Ans: In an electromagnetic wave \vec{E} , \vec{B} and direction of propagation are mutually perpendicular.

5. Welders wear special goggles or face masks with glass windows to protect their eyes from electromagnetic radiations. Name the radiations and write the range of their frequency. [AI 2013]

Ans: Ultraviolet radiations produced during welding are harmful to eyes. Special goggles or face masks are used to protect eyes from UV radiations. UV radiations have a range of frequency between 10^{15} Hz – 10^{17} Hz.

6. Name the part of electromagnetic spectrum which is suitable for :
(i) radar systems used in aircraft navigation (ii) treatment of cancer tumours.

Ans: (i) Microwave (ii) γ -rays.

7. Name the EM waves used for studying crystal structure of solids. What is its frequency range?

Ans: X-Rays. Frequency range : 3×10^{16} Hz – 3×10^{19} Hz.

8. Name the electromagnetic radiation which can be produced by klystron or a magnetron valve.

Ans: Electromagnetic radiation produced by a Klystron or a Magnetron valve is microwave.

9. Identify the part of the electromagnetic spectrum to which the following wavelengths belong:
(i) 10^{-1} m (ii) 10^{-12} m

Ans: (i) 10^{-1} m = 10 cm belongs to short radiowaves.

(ii) 10^{-12} m = 0.01 m belongs to gamma rays.

10. Name the part of the electromagnetic spectrum of wavelength 10^{-2} m and mention its one application.

Ans: Wavelength 10^{-2} m belongs to microwaves. It is used in RADAR.

11. In what way can the setting up of transmission tower by a mobile company in a residential colony prove to be injurious to health?

Ans: Electromagnetic radiations emitted by an antenna can cause cancer, cardiac problem and headache.

12. Name the em waves which are suitable for radar systems used in aircraft navigation. Write the range of frequency of these waves.

Ans: Microwaves Frequency range : 10^{10} Hz to 10^{12} Hz

13. If the earth did not have atmosphere, would its average surface temperature be higher or lower than what it is now? Explain.

Ans: Average surface temperature will be lower. This is because there will be no green house effect in absence of atmosphere.

14. An em wave exerts pressure on the surface on which it is incident. Justify.

Ans: An electromagnetic wave exerts pressure on the surface on which it is incident because these waves carry both energy and momentum.

15. Name the em waves which are used for the treatment of certain forms of cancer. Write their frequency range.

Ans: X rays or γ rays Range: 10^{18} Hz to 10^{22} Hz.

16. Thin ozone layer on top of stratosphere is crucial for human survival. Why?

Ans: Ozone layer absorbs the ultraviolet radiations from the sun and prevents it from reaching the earth's surface.

17. Why is the amount of the momentum transferred by the em waves incident on the surface so small?

Ans: Momentum transferred, $p = \frac{u}{c}$ where u = energy transferred and c = speed of light

Due to the large value of speed of light (c), the amount of momentum transferred by the em waves incident on the surface is small.

18. Name the em waves which are produced during radioactive decay of a nucleus. Write their frequency range.

Ans: em waves : γ -rays Range : 10^{19} Hz to 10^{23} Hz

19. Welders wear special glass goggles while working. Why? Explain.

Ans: This is because the special glass goggles protect the eyes from large amount of UV radiations produced by welding arcs.

20. Why are infrared waves often called as heat waves? Give their one application.

Ans: Infrared waves are called heat waves because water molecules present in the materials readily absorb the infra red rays get heated up.

Application: They are used in green houses to warm the plants.

21. To which part of the electromagnetic spectrum does a wave of frequency 5×10^{19} Hz belong?

Ans: X-rays or γ -rays.

22. To which part of the electromagnetic spectrum does a wave of frequency 3×10^{13} Hz belong?

Ans: Infrared radiation

23. To which part of the electromagnetic spectrum does a wave of frequency 5×10^{11} Hz belong?

Ans: Microwaves or short radiowaves.

24. Arrange the following electromagnetic waves in order of increasing frequency:

γ -rays, microwaves, infrared rays and ultraviolet rays.

Ans: Microwave < Infrared < Ultraviolet < γ -rays

SHORT ANSWER TYPE QUESTIONS (2 MARKS/3 MARKS)

25. Optical and radio telescopes are built on the ground while X-ray astronomy is possible only from the satellites orbiting the Earth. Why?

Ans: Atmosphere absorbs X-rays, so X-ray astronomy is possible only from satellites orbiting the earth. Visible and radiowaves can penetrate through the atmosphere, so optical and radio telescopes are built on the ground.

26. The small ozone layer on top of the stratosphere is crucial for human survival. Why? [AI 2009]

Ans: Ozone layer absorbs ultraviolet radiations from sun and prevents it from reaching the earth's surface and hence is crucial for human survival, as ultraviolet radiations are harmful to human beings.

27. How are infrared waves produced? Why are these referred to as heat waves? Write their one important use? [AI 2011]

Ans: Infrared waves are produced by hot bodies and molecules. This band lies adjacent to the low frequency or long wavelength end of the visible spectrum. Infrared waves are referred to as heat waves, because water molecules present in most materials readily absorb infrared waves (many other molecules, for example, CO₂, NH₃ also absorb infrared waves). After absorption, their thermal motion increases, that is they heat up and heat their surroundings. Infrared rays are used in green house effect.

28. A capacitor of capacitance 'C' is being charged by connecting it across a dc source along with an ammeter. Will the ammeter show a momentary deflection during the process of charging? If so, how would you explain this momentary deflection and the resulting continuity of current in the circuit? Write the expression for the current inside the capacitor. [AI 2012]

Ans: Yes, ammeter will show a momentary deflection. The momentary deflection is due to the flow of electrons in the circuit during the charging process. During the charging process the electric field between the capacitor plates is changing and hence a displacement current flows in the gap. Hence we can say that there is a continuity of current in the circuit.

$$\text{Expression, } I_d = \epsilon_0 \frac{d\phi}{dt}$$

29. How does oscillating charge produce electromagnetic waves?

Ans: An oscillating charge produces an oscillating electric field in space, which produces an oscillating magnetic field. The oscillating electric and magnetic fields regenerate each other, and this results in the production of em waves in space.

30. The oscillating magnetic field in a plane electromagnetic wave is given by

$$B_y = (8 \times 10^{-6}) \sin [2 \times 10^{11} t + 300 \pi x] T$$

(i) Calculate the wavelength of the electromagnetic wave.

(ii) Write down the expression for the oscillating electric field.

Ans:

Standard equation of magnetic field is

$$B_y = B_0 \sin (\omega t + kx) T$$

Comparing this equation with the given equation, we get

$$B_0 = 8 \times 10^{-6} T, \omega = 2 \times 10^{11} \text{ rad s}^{-1}, k = \frac{2\pi}{\lambda} = 300\pi$$

wavelength, $\lambda = \frac{2\pi}{300\pi} = \frac{1}{150} m$

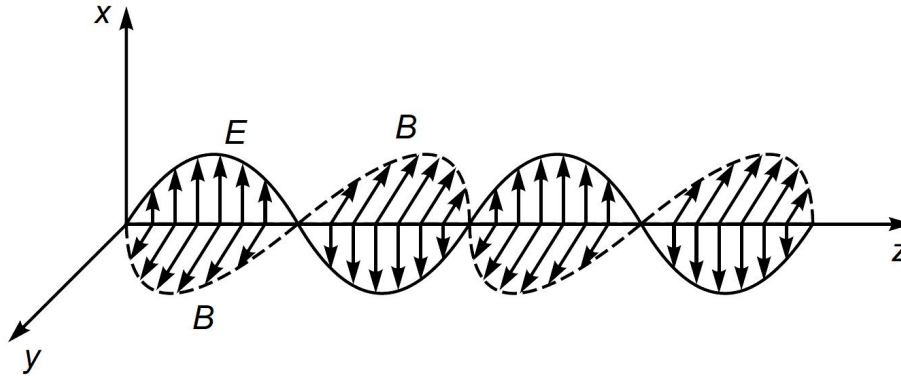
(ii) $E_0 = B_0 c = 8 \times 10^{-6} \times 3 \times 10^8 = 2.4 \times 10^3 \text{ Vm}^{-1}$.

According to right hand system of $\vec{E}, \vec{B}, \vec{K}$, the electric field oscillates along negative Z-axis, so equation is

$$E_z = -2.4 \times 10^3 \sin(2 \times 10^{11} t + 300\pi x) \text{ Vm}^{-1}$$

31. Sketch a schematic diagram depicting oscillating electric and magnetic fields of an em wave propagating along + z-direction.

Ans: Electric field is along x-axis and magnetic field is along y-axis.



32. The oscillating electric field of an electromagnetic wave is given by:

$$E_y = 30 \sin [2 \times 10^{11} t + 300 \pi x] \text{ Vm}^{-1}$$

(a) Obtain the value of the wavelength of the electromagnetic wave.

(b) Write down the expression for the oscillating magnetic field.

Ans: (a) Given equation is $E_y = 30 \sin(2 \times 10^{11} t + 300 \pi x) \text{ Vm}^{-1}$

Comparing with standard equation

$$E_y = E_0 \sin(\omega t + kx) \text{ Vm}^{-1}, \text{ we get}$$

$$E_0 = 30 \text{ Vm}^{-1}, \omega = 2 \times 10^{11} \text{ rad s}^{-1}, k = \frac{2\pi}{\lambda} = 300\pi m^{-1}$$

$$\therefore \text{Wavelength, } \lambda = \frac{2\pi}{300\pi} = \frac{1}{150} m = 6.67 \times 10^{-3} m$$

(b) The wave is propagating along X-axis, electric field is oscillating along Y-axis, so according to right hand system of $(\vec{E}, \vec{B}, \vec{K})$ the magnetic field must oscillate along Z-axis.

$$\therefore B_0 = \frac{E_0}{C} = \frac{30}{3 \times 10^8} = 10^{-7} T$$

\therefore Equation of oscillating magnetic field is

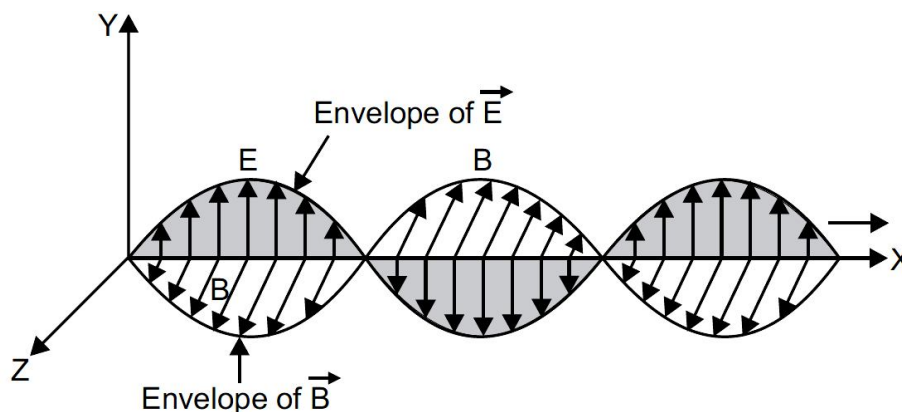
$$B_z = B_0 \sin(\omega t + kx) T$$

$$\Rightarrow B_z = 10^{-7} \sin(2 \times 10^{11} t + 300 \pi x) T$$

33. What is meant by the transverse nature of electromagnetic waves ? Draw a diagram showing the propagation of an electromagnetic wave along the x-direction, indicating clearly the directions of the oscillating electric and magnetic fields associated with it.

Ans: Transverse Nature of Electromagnetic Waves:

In an electromagnetic wave, the electric and magnetic field vectors oscillate, perpendicular to the direction of propagation of wave. This is called transverse nature of electromagnetic wave. In an electromagnetic wave, the three vectors \vec{E}, \vec{B} and \vec{K} form a right handed system. Accordingly if a wave is propagating along X-axis, the electric field vector oscillates along Y-axis and magnetic field vector oscillates along Z-axis. Diagram is shown in fig.



34. How does a charge q oscillating at certain frequency produce electromagnetic waves?

Ans: An oscillating electric charge produces oscillating electric field, which produces oscillating magnetic field; which in turn produces oscillating electric field and so on; thereby producing an electromagnetic wave propagating in free space.

35. Arrange the following electromagnetic radiations in ascending order of their frequencies:

- (i) Microwave
- (ii) Radio wave
- (iii) X-rays
- (iv) Gamma rays

Write two uses of any one of these.

Ans: In ascending order of frequencies: radiowaves, microwaves, ultraviolet rays, X-rays and gamma rays.

Uses of Electromagnetic Spectrum

(i) **γ -rays** are highly penetrating, they can penetrate thick iron blocks. Due to high energy, they are used to produce nuclear reactions. γ -rays are produced in nuclear reactions. In medicine, they are used to destroy cancer cells.

(ii) **X-rays** are used in medical diagnostics to detect fractures in bones, tuberculosis of lungs, presence of stone in gallbladder and kidney. They are used in engineering to check flaws in bridges. In physics X-rays are used to study crystal structure.

(iii) **Radiowaves** are used for broadcasting programmes to distant places. According to frequency range, they are divided into following groups

- (1) Medium frequency band or medium waves 0.3 to 3 MHz
- (2) Short waves or short frequency band 3 MHz — 30 MHz
- (3) Very high frequency (VHF) band 30 MHz to 300 MHz
- (4) Ultrahigh frequency (UHF) band 300 MHz to 3000 MHz

(iv) **Microwaves** are produced by special vacuum tubes, namely; klystrons, magnetrons and gunn diodes. Their frequency range is 3 GHz to 300 GHz. They are used in radar systems used in air craft navigation and microwave users in houses.

IMP Q/A FROM OTHER UNITS

Important Questions and Answers from other units

1. Deduce the expression for the magnetic dipole moment of an electron orbiting around the central nucleus.

Ans:

A revolving electron in an orbit of radius r moving with velocity v behaves as a current loop of effective current

$I = ve$ (v is frequency of revolution)

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

Hence it acts like a magnetic dipole moment

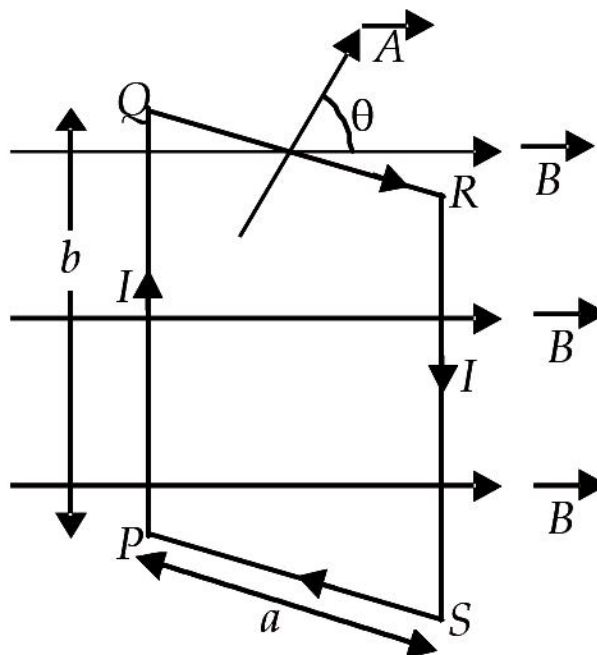
$$M = IA = \frac{ve}{2\pi r} \times \pi r^2 = \frac{evr}{2}$$

2. (a) With the help of a diagram, explain the principle and working of a moving coil galvanometer.
(b) What is the importance of a radial magnetic field and how is it produced?
(c) Why is it that while using a moving coil galvanometer as a voltmeter a high resistance in series is required whereas in an ammeter a shunt is used?

Ans:

Principle : Galvanometer works on the principle that when an electric current is passed through a coil placed in a magnetic field, it experiences a torque, whose magnitude is proportional to the strength of electric current passed through it.

Working :



When a rectangular loop $PQRS$ (suspended through a torsion head) of sides ' a ' and ' b ' carrying current I is placed in uniform magnetic field \vec{B} such that area vector \vec{A} makes an angle θ with direction of magnetic field, then forces on the arms QR and SP of loop are equal, opposite and collinear, thereby perfectly cancel each other, whereas forces on the arms PQ and RS of loop are equal and opposite but not collinear, so they give rise to torque on the loop.

or $\tau = IAB\sin\theta$ [where $A = ab$]

and if loop has N turns, then $\tau = NIAB\sin\theta$

Due to this torque, the coil is deflected by an angle α , where it is balanced by restoring torque $C\alpha$, developed in suspension strip. C is restoring torque per unit deflection or torsional constant of the strip.

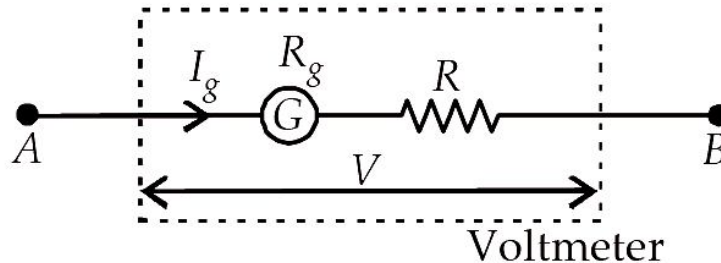
So, by measuring α , we can measure current I in the coil.

$$NIAB = C\alpha$$

$$I = \frac{C}{NAB}\alpha$$

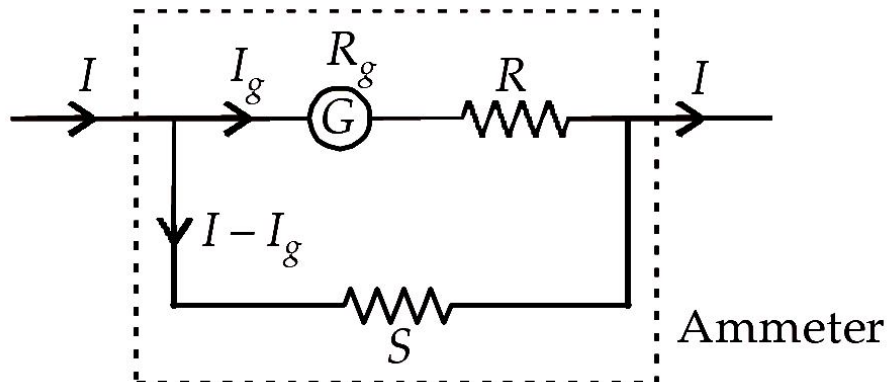
(b) In order to make torque on the coil independent of angle θ , the plane of coil should always remain parallel to the field. For this purpose a radial magnetic field is applied.

(c) A galvanometer can be converted into a voltmeter by connecting high resistance in series with it, so that most of the voltage applied drops across it, enabling the galvanometer to measure much larger voltages.



$$\text{or } R = \frac{V}{I_g} - R_g$$

A galvanometer can be converted into an ammeter by connecting a low shunt resistance in parallel to it, so that most of the current by passes through the shunt resistance, enabling the galvanometer to measure much larger currents.



$$V_s = V_g \quad \text{or} \quad (I - I_g)S = I_g R_g$$

$$\text{or } S = \frac{I_g R_g}{I - I_g}$$

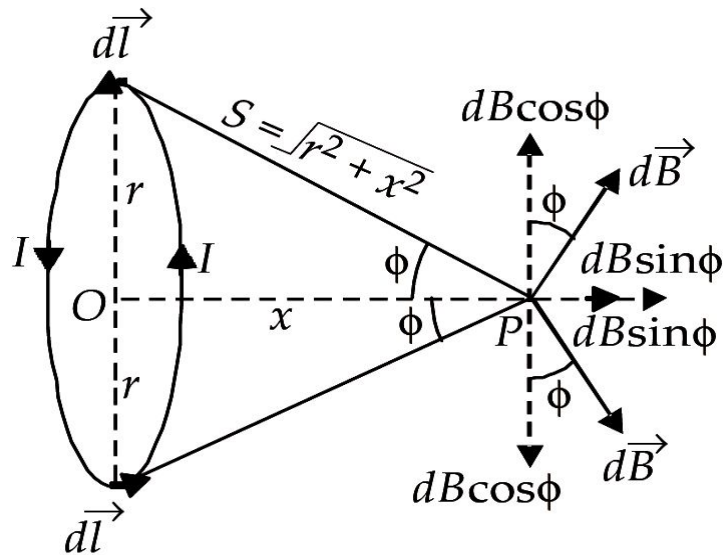
3. **State BiotSavart law, giving the mathematical expression for it. Use this law to derive the expression for the magnetic field due to a circular coil carrying current at a point along its axis. How does a circular loop carrying current behaves as a magnet**

Ans:

A current carrying wire produces a magnetic field around it. BiotSavart law states that magnitude of intensity of small magnetic field due to current I carrying element \vec{dl} at any point P at distance r from it is given by:

$$|d\vec{B}| = \frac{\mu_0}{4\pi} \frac{I dl \sin \theta}{r^2}$$

Magnetic field on the axis of circular coil



Small magnetic field due to current element $Id\vec{l}$ of circular coil of radius r at point P at distance x from its centre is

$$dB = \frac{\mu_0}{4\pi} \frac{Idl \sin 90^\circ}{r^2} = \frac{\mu_0}{4\pi} \frac{Idl}{(r^2 + x^2)}$$

Component $dB \cos \phi$ due to current element at point P is cancelled by equal and opposite component $dB \cos \phi$ of another diagonally opposite current element, whereas the sine components $dB \sin \phi$ add up to give net magnetic field along the axis. So net magnetic field at point P due to entire loop is

$$B = \oint dB \sin \phi = \int_0^{2\pi} \frac{\mu_0}{4\pi} \frac{Idl}{(r^2 + x^2)} \cdot \frac{r}{(r^2 + x^2)^{1/2}}$$

$$\Rightarrow B = \frac{\mu_0 Ir}{4\pi(r^2 + x^2)^{3/2}} \int_0^{2\pi} dl$$

$$\Rightarrow B = \frac{\mu_0 Ir}{4\pi(r^2 + x^2)^{3/2}} \cdot 2\pi r$$

$$\Rightarrow B = \frac{\mu_0 Ir^2}{2(r^2 + x^2)^{3/2}} \text{ directed along the axis,}$$

- (a) towards the coil if current in it is in clockwise direction.
 (b) away from the coil if current in it is in anticlockwise direction.

4. Draw a schematic sketch of a cyclotron. Explain briefly how it works and how it is used to accelerate the charged particles.

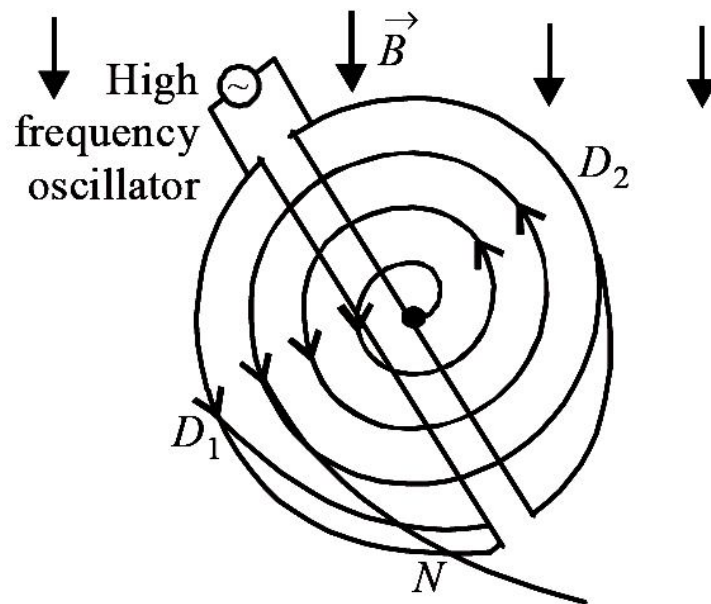
(i) Show that time period of ions in a cyclotron is independent of both the speed and radius of circular path.

(ii) What is resonance condition? How is it used to accelerate the charged particles?

(iii) Show that cyclotron frequency is independent of energy of the particle. Is there an upper limit on the energy acquired by the particle? Give reason.

Ans: Cyclotron is used to accelerate the charged particles to large velocities or large kinetic energies. In cyclotron, both electric field \vec{E} and magnetic field \vec{B} are applied normally to velocity \vec{v} of the charged particle, such that electric field accelerates the charged particle and magnetic field makes the charged particle move in circular paths repeatedly, so that charged particle is accelerated to large velocities and hence large kinetic energies, under the combined effect of electric and magnetic fields.

A charged particle produced at point P by a source is accelerated towards Dee D_1 due to applied electric field, but moves along semicircular path of radius $r = \frac{mv}{qB}$ in D_1 due to force of magnetic field on it.



When it reaches the gap between the two dees, polarities of the dees is changed by oscillator and now the charged particle is accelerated towards D_2 , where it follows semicircular path of increased radius with increased velocity. This process repeats itself again and again and charged particle spends the same time inside a dee irrespective of its velocity or the radius of circular path, as

$$t = \frac{\pi r}{v} = \frac{\pi}{v} \cdot \frac{mv}{qB} = \frac{\pi m}{qB}$$

So, time period of its motion is $T = 2t = \frac{2\pi m}{qB}$

Thus time period is independent of both the speed and radius of circular path.

(ii) Frequency of motion of charged particle is $\nu = \frac{1}{T} = \frac{qB}{2\pi m}$

When this frequency ν becomes equal to the frequency ν_a of the applied alternating voltage source or oscillator, then it is called resonance condition.

This ensure that the ions always get accelerated across the gap. Inside the dees the particles travel in a region free of the electric field. The increase in their kinetic energy is qV each time they cross from one dee to another. This is known as '**cyclotron frequency**', which is independent of radius r of semicircular path followed by charged particle or its velocity v . So if we set the oscillator at this frequency, it automatically changes the polarities of the two dees.

When charged particle reaches near the periphery of dee, it is moving in a circular path of maximum radius equal to radius R of dee and posses maximum kinetic energy

$$K.E_{\max} = \frac{1}{2}mv_{\max}^2 = \frac{1}{2}m \frac{q^2 B^2 R^2}{m^2} = \frac{q^2 B^2 R^2}{2m} \text{ when it is extracted from dees at point } N.$$

5. (i) State Faraday's law of electromagnetic induction. (ii) A jet plane is travelling towards west at a speed of 1800 km/h. What is the voltage difference developed between the ends of the wing having a span of 25 m, if the Earth's magnetic field at the location has a magnitude of 5×10^{-4} T and the dip angle is 30° ?

Ans: Faraday's law of electromagnetic induction states that whenever there is change in magnetic flux linked with the circuit, an emf is induced in it, whose magnitude is directly proportional to the rate of change of magnetic flux linked with the circuit. i.e. $\varepsilon = \frac{d\phi}{dt}$

(ii) EMF induced across the ends of the wings of plane is

$$\varepsilon = vB_v l = vB \sin \delta \cdot l$$

$$\Rightarrow \varepsilon = (1800 \times \frac{5}{18} \text{ m/s}) \times (5 \times 10^{-4} \text{ T}) \times \sin 30^\circ \times 25$$

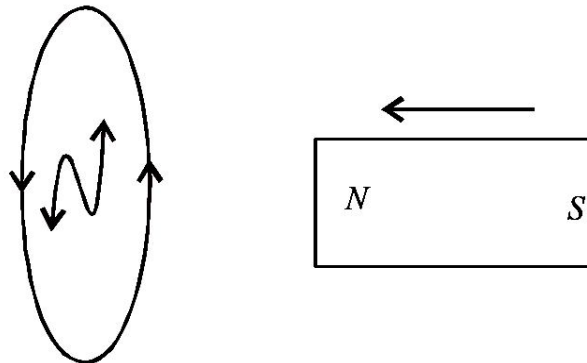
$$\Rightarrow \varepsilon = 500 \times 5 \times 10^{-4} \times \frac{1}{2} \times 25 = 3.125 \text{ V}$$

6. (a) State Lenz's law. Give one example to illustrate this law. "The Lenz's law is a consequence of the principle of conservation of energy". Justify this statement.

(b) Deduce an expression for the mutual inductance of two long coaxial solenoids but having different radii and different number of turns.

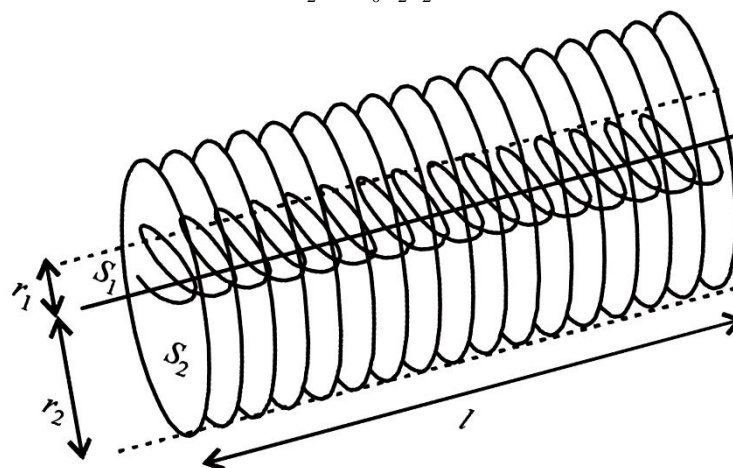
Ans:

(a) Lenz's law states that the "induced current in a circuit always flows in such a direction that it opposes the change in magnetic flux linked with the circuit or the very cause that has produced it".



When the *N* pole of a magnet is moved towards a coil, the induced current in the coil flows in anticlockwise direction on the side of magnet, so as to acquire north polarity and oppose the motion of the magnet towards the coil, by applying repulsive force on it. Lenz's law is in accordance with law of conservation of energy. Whenever magnetic flux linked with a circuit changes, it induces an EMF in it. The induced current set up in the circuit flows in such a direction that it opposes the change in magnetic flux linked with the circuit. In order to continue the change in magnetic flux linked with the circuit, some work is to be done or some energy is to be spent against the opposition offered by induced EMF. This energy spent by the external source ultimately appears in the circuit in the form of electrical energy.

(b) Magnetic field due to current I_2 in S_2 is $B_2 = \mu_0 n_2 I_2$



The magnetic flux linked with solenoid S_1 is $\phi_{12} = N_1 B_2 A \cos 0^\circ$

$$\Rightarrow \phi_{12} = (n_1 l) \cdot (\mu_0 n_2 I_2) \cdot (\pi r_1^2) \cdot 1$$

$$\Rightarrow \frac{\phi_{12}}{I_2} = \mu_0 n_1 n_2 \pi r_1^2 l$$

This gives the mutual inductance of two long coaxial solenoids.

7. (i) Draw a labelled diagram of a step-up transformer. Explain its working principle. Deduce the expression for the secondary to primary voltage in terms of the number of turns in the two coils. In an ideal transformer, how is this ratio related to the currents in the two coils? How is the transformer used in large scale transmission and distribution of electrical energy over long distances?

(ii) Write any two sources of energy loss in a transformer.

Ans:

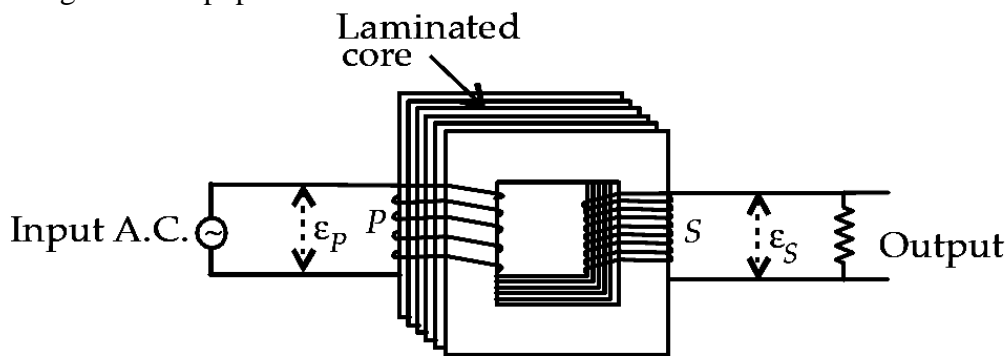
Transformer: Transformer is a device by which an alternating voltage may be decreased or increased. This is based on the principle of mutual-induction.

Construction: It consists of laminated core of soft iron, on which two coils of insulated copper wire are separately wound. These coils are kept insulated from each other and from the iron-core, but are coupled through mutual induction. The number of turns in these coils are different. Out of these coils one coil is

called *primary coil* and other is called the *secondary coil*. The terminals of primary coils are connected to AC mains and the terminals of the secondary coil are connected to external circuit in which alternating current of desired voltage is required.

Step up Transformer: It transforms the alternating low voltage to alternating high voltage and in this the number of turns in secondary coil is more than that in primary coil. (i. e. , $N_S > N_P$).

A schematic diagram of stepup transformer is shown below.



Working Principle

It works on the principle of mutual induction. It consists of two coils primary P and secondary S wound on a laminated soft iron core. The input voltage is applied across the primary coil and output voltage is obtained across the secondary coil.

Magnetic flux ϕ_S and ϕ_P linked with secondary and primary coils at any instant are proportional to the number of turns N_S and N_P in secondary and primary coils i.e.,

$$\frac{\phi_S}{\phi_P} = \frac{N_S}{N_P} \text{ or } -\frac{d\phi_S}{dt} = \frac{N_S}{N_P} \left(-\frac{d\phi_P}{dt} \right)$$

$$\text{or } \varepsilon_S = \frac{N_S}{N_P} \varepsilon_P \text{ or } \frac{\varepsilon_S}{\varepsilon_P} = \frac{N_S}{N_P}$$

where $\frac{N_S}{N_P}$ is called transformation ratio of transformer.

In step up transformer, $\varepsilon_S > \varepsilon_P$ and $N_S > N_P$ and transformation ratio > 1

In an ideal transformer, there is no loss of energy or it is 100% efficient. Then

Power input = Power output

$$\text{or } \varepsilon_P I_P = \varepsilon_S I_S \text{ or } \frac{\varepsilon_S}{\varepsilon_P} = \frac{I_P}{I_S}$$

where I_S and I_P are currents in secondary and primary coils of transformer.

Transformer is mainly used in long distance transmission of electrical energy. At the electric power producing station, a stepup transformer is used which increases the alternating voltage upto several kilo volts, thereby decreasing the electric current flowing through transmission wires, As Joule's heating is proportional to square of current, so this decreases the loss of electrical energy across

transmission wires. Further a stepdown transformer is used to decrease the alternating voltage at substation before distributing electrical energy for domestic use.

(ii) The two sources of energy loss in a transformer :

(1) Copper loss is the energy loss in the form of heat in copper coils of a transformer. This is due to joule heating of conducting wires. These are minimized using thick wires.

(2) Iron loss is the energy loss in the form of heat in the iron core of the transformer. This is due to formation of eddy currents in iron core. It is minimized by taking laminated cores.

8. (a) State the working principle of an AC generator with the help of a labelled diagram. Derive an expression for the instantaneous value of the emf induced in coil. Why is the emf maximum when the plane of the armature is parallel to the magnetic field?

(b) A 100turn coil of area 0.1 m^2 rotates at half a revolution per second. It is placed in a magnetic field 0.01 T perpendicular to the axis of rotation of the coil. Calculate the maximum voltage generated in the coil.

Ans:(a) AC generator: A dynamo or generator is a device which converts mechanical energy into electrical energy. It is based on the principle of electromagnetic induction.

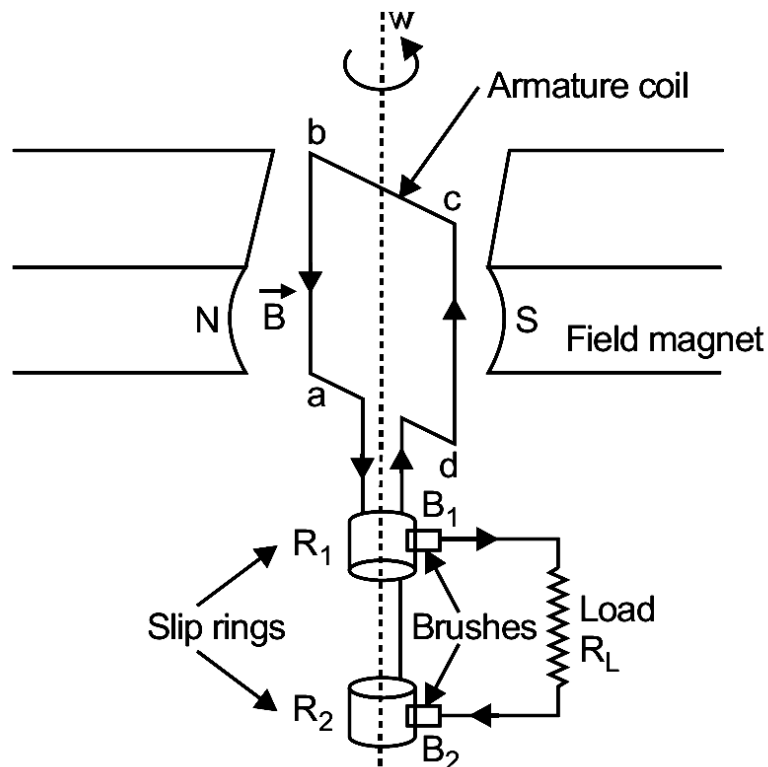
Construction: It consists of the four main parts:

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

(ii) **Armature:** It consists of a large number of turns of insulated wire in the soft iron drum or ring. It can revolve round an axle between the two poles of the field magnet. The drum or ring serves the two purposes : (i) It serves as a support to coils and (ii) It increases the magnetic field due to air core being replaced by an iron core.

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

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



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

right hand rule. Considering the armature to be in vertical position and as it rotates in anticlockwise direction, the wire ab moves upward and cd downward, so that the direction of induced current is shown in fig. In the external circuit, the current flows along $B_1R_L B_2$. The direction of current remains unchanged during the first half turn of armature. During the second half revolution, the wire ab moves downward and cd upward, so the direction of current is reversed and in external circuit it flows along $B_2R_L B_1$. Thus the direction of induced emf and current changes in the external circuit after each half revolution. If N is the number of turns in coil, f the frequency of rotation, A area of coil and B the magnetic induction, then induced emf

$$e = -\frac{d\phi}{dt} = \frac{d}{dt}\{NBA(\cos 2\pi ft)\} = 2\pi NBAf \sin 2\pi ft$$

Obviously, the emf produced is alternating and hence the current is also alternating. Current produced by an ac generator cannot be measured by moving coil ammeter; because the average value of ac over full cycle is zero.

The source of energy generation is the mechanical energy of rotation of armature coil.

When plane of armature coil is parallel to magnetic field, then $\sin\omega t = 1$, so emf is maximum, the maximum value is $e_0 = NBA\omega$.

(b) $N = 100$, $A = 0.1 \text{ m}^2$, $n = \frac{1}{2} \text{ s}^{-1}$ $B = 0.01 \text{ T}$

Maximum voltage generated in the coil is

$$e_0 = NBA\omega = NBA \times 2\pi v$$

$$\text{or } e_0 = 100 \times 0.01 \times 0.1 \times 2 \times 3.14 \times \frac{1}{2}$$

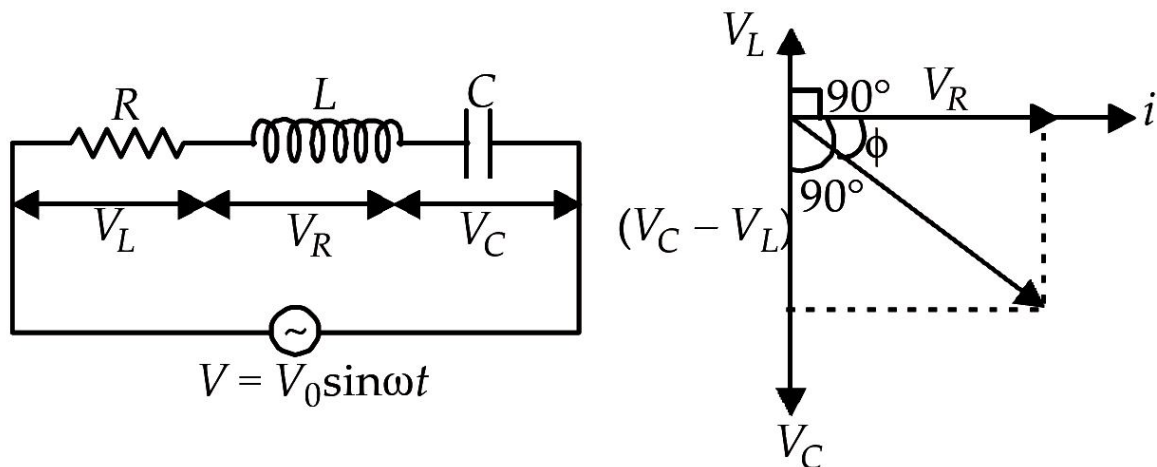
$$\text{or } e_0 = 0.314 \text{ V.}$$

9. Derive an expression for the impedance of a series LCR circuit connected to an AC supply of variable frequency. Plot a graph showing variation of current with the frequency of the applied voltage.

Explain briefly how the phenomenon of resonance in the circuit can be used in the tuning mechanism of a radio or a TV set.

Ans:

Expression for impedance in LCR series circuit : Suppose resistance R , inductance L and capacitance C are connected in series and an alternating source of voltage $V = V_0\sin\omega t$ is applied across it as shown in figure. On account of being in series, the current i flowing through all of them is the same.



Consider the voltage across resistance R is V_R , voltage across inductance L is V_L and voltage across capacitance C is V_C . The voltage V_R and current i are in the same phase, the voltage V_L will lead the current by angle 90° while the voltage V_C will lag behind the current by angle 90° (figure). Clearly V_C and V_L are in opposite directions, therefore their resultant potential difference = $V_C - V_L$ (if $V_C > V_L$).

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

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

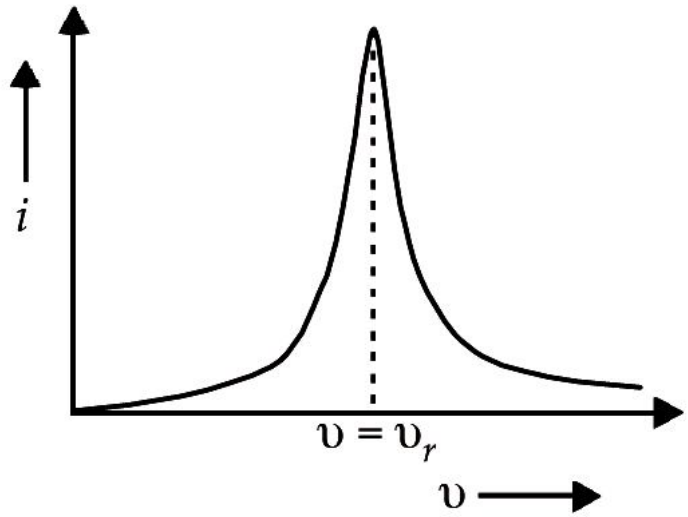
$$\Rightarrow V = \sqrt{V_R^2 + (V_C - V_L)^2} \quad \dots\dots\dots(i)$$

But $V_R = Ri$, $V_C = X_C i$
and $V_L = X_L i \quad \dots\dots\dots(ii)$

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

$X_L = \omega L$ = inductive reactance

$$\therefore \text{Impedance of circuit, } Z = \frac{V}{i} = \sqrt{R^2 + (X_C - X_L)^2} = \sqrt{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}$$



The practical application of series resonance circuit is in radio and T.V. receiver sets. The antenna of a radio/T.V. intercepts signals from many broadcasting stations. To receive one particular radio station./T.V. channel, we tune our receiver set by changing the capacitance of a capacitor in the tuning circuit of the set such that resonance frequency of the circuit becomes equal to the frequency of the desired station. Therefore, resonance occurs. The amplitude of current with the frequency of the signal from the desired station becomes maximum and it is received in our set.

10. Describe briefly how a diffraction pattern is obtained on a screen due to a single narrow slit illuminated by a monochromatic source of light. Hence obtain the conditions for the angular width of secondary maxima and secondary minima.

Ans: Diffraction of light at a single slit : When monochromatic light is made incident on a single slit, we get diffraction pattern on a screen placed behind the slit. The diffraction pattern contains bright and dark bands, the intensity of central band is maximum and goes on decreasing on both sides.

Explanation : Let AB be a slit of width ‘ a ’ and a parallel beam of monochromatic light is incident on it. According to Fresnel the diffraction pattern is the result of superposition of a large number of waves, starting from different points of illuminated slit.

Let θ be the angle of diffraction for waves reaching at point P of screen and AN the perpendicular dropped from A on wave diffracted from B .

The path difference between rays diffracted at points A and B ,

$$\Delta = BP - AP = BN$$

In ΔANB , $\angle ANB = 90^\circ \therefore$ and $\angle BAN = \theta$

As $AB =$ width of slit = a

$$\therefore \text{Path difference, } \Delta = a \sin \theta \quad \dots\dots\dots (i)$$

To find the effect of all coherent waves at P , we have to sum up their contribution, each with a different phase. This was done by Fresnel by rigorous calculations, but the main features may be explained by simple arguments given below :

At the central point C of the screen, the angle θ is zero. Hence the waves starting from all points of slit arrive in the same phase. This gives maximum intensity at the central point C .

If point P on screen is such that the path difference between rays starting from edges A and B is λ , then path difference

$$a \sin \theta = \lambda \Rightarrow \sin \theta = \frac{\lambda}{a}$$

If angle θ is small, $\sin \theta = \theta = \frac{\lambda}{a}$ (ii)

Minima : Now we divide the slit into two equal halves AO and OB , each of width $\frac{a}{2}$. Now for every point, M_1 in AO , there is a corresponding point M_2 in OB , such that $M_1M_2 = \frac{a}{2}$; Then path difference

between waves arriving at P and starting from M_1 and M_2 will be $\frac{a}{2} \sin \theta = \frac{\lambda}{2}$. This means that the contributions from the two halves of slit AO and OB are opposite in phase and so cancel each other. Thus equation (2) gives the angle of diffraction at which intensity falls to zero. Similarly it may be shown that the intensity is zero for $\sin \theta = \frac{n\lambda}{a}$, with n as integer.

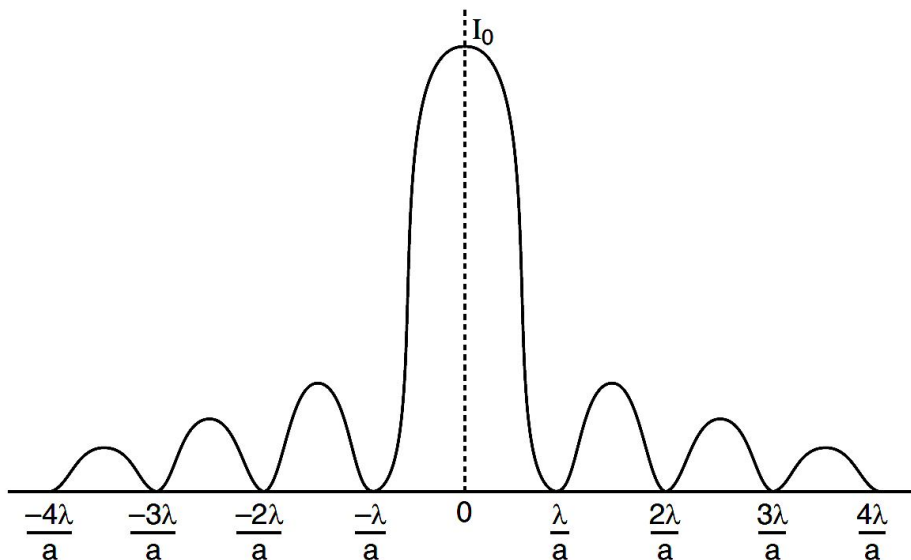
Thus the general condition of **minima** is

$$a \sin \theta = n\lambda \quad \text{.....(iii)}$$

Secondary Maxima : Let us now consider angle θ such that $\sin \theta = \theta = \frac{3\lambda}{2a}$

which is midway between two dark bands given by

$$\sin \theta = \theta = \frac{\lambda}{a} \quad \text{and} \quad \sin \theta = \theta = \frac{2\lambda}{a}$$



Let us now divide the slit into three parts. If we take the first two of parts of slit, the path difference between rays diffracted from the extreme ends of the first two parts

$$\frac{2}{3} a \sin \theta = \frac{2}{3} a \times \frac{3\lambda}{2a} = \lambda$$

Then the first two parts will have a path difference of $\frac{\lambda}{2}$ and cancel the effect of each other. The

remaining third part will contribute to the intensity at a point between two minima. Clearly there will be a maxima between first two minima, but this maxima will be of much weaker intensity than central maximum. This is called *first secondary maxima*. In a similar manner we can show that there

are secondary maxima between any two consecutive minima; and the intensity of maxima will go on decreasing with increase of order of maxima. In general the position of n th maxima will be given by

$$a \sin \theta = \left(n + \frac{1}{2} \right) \lambda, [n = 1, 2, 3, 4, \dots] \dots\dots\dots(iv)$$

The intensity of secondary maxima decrease with increase of order n because with increasing n , the contribution of slit decreases.

For $n = 2$, it is one-fifth, for $n = 3$, it is one-seventh and so on.

(b) Angular width of secondary maxima

$$a \cdot \theta = \left(n + \frac{1}{2} \right) \lambda$$

$$\Rightarrow \theta = \left(n + \frac{1}{2} \right) \frac{\lambda}{a}$$

and Linear width $\theta = \frac{y}{D}$

$$\Rightarrow y = D \cdot \theta = \left(n + \frac{1}{2} \right) \frac{\lambda D}{a}$$

If $n = 1$, and $\lambda_1 = 590$ nm,

$$y_1 = \left(1 + \frac{1}{2} \right) \frac{\lambda_1 D}{a} = \frac{3\lambda_1 D}{2a}$$

If $n = 1$ $\lambda_2 = 596$ nm

$$y_2 = \left(1 + \frac{1}{2} \right) \frac{\lambda_2 D}{a} = \frac{3\lambda_2 D}{2a}$$

$$\text{Linear separation} = y_2 - y_1 = \frac{3(\lambda_2 - \lambda_1)D}{2a}$$

$$= \frac{3(596 - 590) \times 10^{-9} \times 1.5}{2 \times 2 \times 10^{-6}} = \frac{3 \times 6 \times 10^{-3} \times 1.5}{4}$$

$$= 4.5 \times 1.5 \times 10^{-3}$$

$$= 6.75 \times 10^{-3} = 6.75 \text{ mm}$$

11. (a) Write three characteristic features to distinguish between the interference fringes in Young's double slit experiment and the diffraction pattern obtained due to a narrow single slit.
 (b) A parallel beam of light of wavelength 500 nm falls on a narrow slit and the resulting diffraction pattern is observed on a screen 1 m away. It is observed that the first minimum is a distance of 2.5 mm away from the centre. Find the width of the slit.

Ans:

Interference	Diffraction
(i) It is due to the superposition of two waves coming from two coherent sources.	(i) It is due to the superposition of secondary wavelets originating from different parts of the same wavefront.
(ii) The width of the interference bands is equal.	(ii) The width of the diffraction bands is not the same.
(iii) The intensity of all maxima (fringes) is same.	(iii) The intensity of central maximum is maximum and goes on decreasing rapidly with increase of order of maxima.

(b) The distance of n th bright fringe from central fringe is, $y_n = \frac{n\lambda D}{d}$

$$\text{Width, } d = \frac{n\lambda D}{y_n} = \frac{1 \times 500 \times 10^{-9} \times 1}{2.5 \times 10^{-3}} = 2 \times 10^{-4} \text{ m} = 0.2 \text{ mm}$$

12. (a) For a ray of light travelling from a denser medium of refractive index n_1 to a rarer medium of refractive index n_2 , prove that $\frac{n_2}{n_1} = \sin i_c$, where i_c is the critical angle of incidence for the media.

(b) Explain with the help of a diagram, how the above principle is used for transmission of video signals using optical fibres.

Ans:

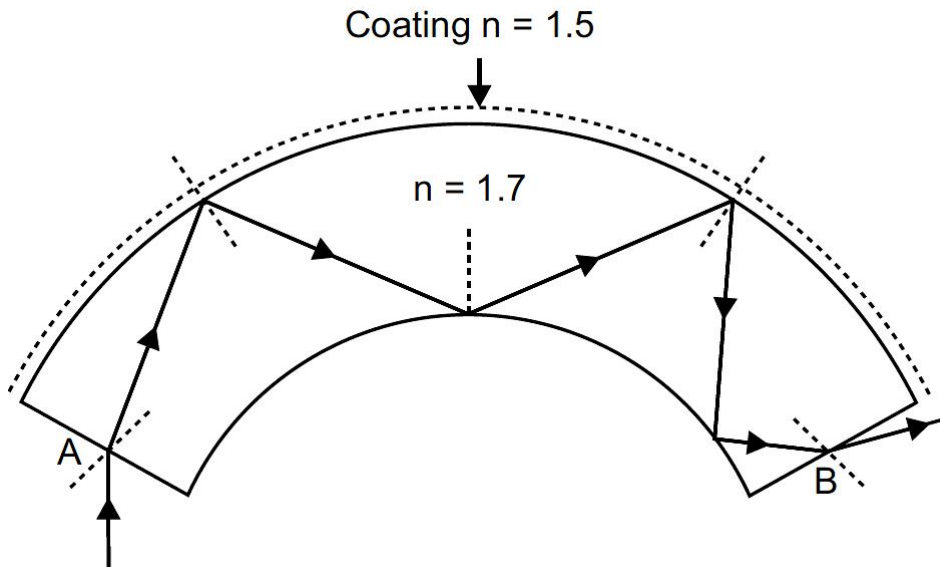
(a) Snell's laws is $\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$ (i)

Critical angle is the angle of incidence in denser medium for which angle of refraction in rarer medium is 90° i.e., $i = i_c, r = 90^\circ$

\therefore From (i) $\frac{\sin i}{\sin 90^\circ} = \frac{n_2}{n_1} \Rightarrow \frac{\sin i_c}{1} = \frac{n_2}{n_1} \Rightarrow \frac{n_2}{n_1} = \sin i_c$

(b) Transmission of video signals using optical fibre.

An optical fibre is a device based on total internal reflection by which a light signal may be transmitted from one place to another with a negligible loss of energy. It is a very long and thin pipe of quartz ($n = 1.7$) of thickness nearly $\approx 10^{-4}$ m coated all around with a material of refractive index 1.5. A large number of such fibres held together form a *light pipe* and are used for communication of light signals. When a light ray is incident on one end at a small angle of incidence, it suffers refraction from air to quartz and strikes the quartz-coating interface at an angle more than the critical angle and so suffers total internal reflection and strikes the opposite face again at an angle greater than critical angle and so again suffers total internal reflection. Thus the ray within the fibre suffers multiple total internal reflections and finally strikes the other end at an angle less than critical angle for quartz-air interface and emerges in air.

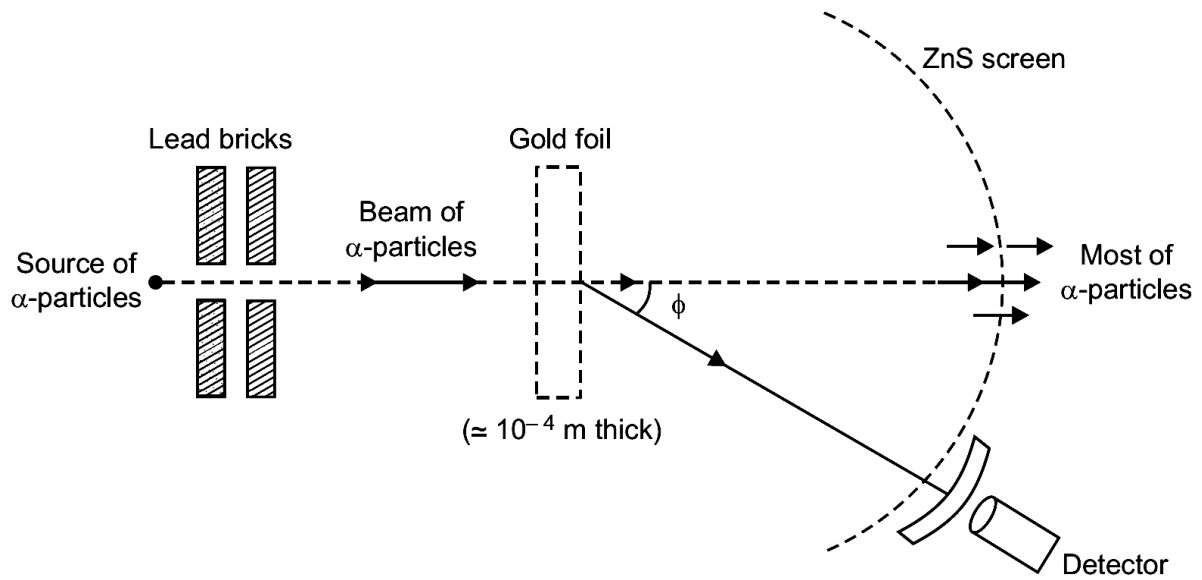


As there is no loss of energy in total internal reflection, the light signal is transmitted by this device without any appreciable loss of energy.

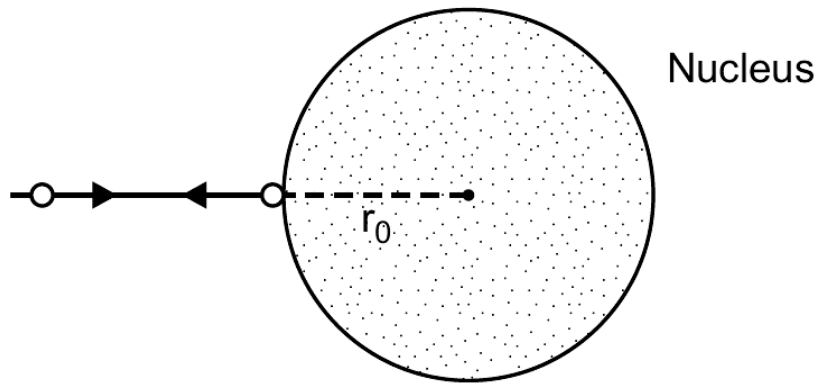
13. Draw a schematic arrangement of the Geiger-Marsden experiment. How did the scattering of α -particles of a thin foil of gold provide an important way to determine an upper limit on the size of the nucleus? Explain briefly.

Ans:

The Schematic arrangement of Geiger-Marsdon Experiment (also known as Rutherford Scattering Experiment) is shown in fig.



Observations: (i) Only a small fraction of number of α -particles rebound back. This shows that the number of α -particles undergoing head on collision is very small. The conclusion is that the entire positive charge of atom is concentrated in a small volume called the **nucleus**.



At the distance of head on approach, the entire kinetic energy of α -particle is converted into electrostatic potential energy. This distance of head on approach gives an upper limit of the size of nucleus (denoted by r_0) and is given by

$$E_k = \frac{1}{4\pi\epsilon_0} \frac{(Ze)(2e)}{r_0}$$

$$\Rightarrow r_0 = \frac{1}{4\pi\epsilon_0} \frac{2Ze^2}{E_k}$$

This is about 10^{-14} m.

- 14. Derive an expression for the de-Broglie wavelength associated with an electron accelerated through a potential V. Draw a schematic diagram of a localised-wave describing the wave nature of the moving electron.**

Ans:

Expression for de Broglie Wavelength associated with Accelerated Electrons

The de Broglie wavelength associated with electrons of momentum p is given by

$$\lambda = \frac{h}{p} = \frac{h}{mv} \quad \dots\dots\dots (i)$$

where m is mass and v is velocity of electron. If E_k is the kinetic energy of electron, then

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{p}{m}\right)^2 = \frac{p^2}{2m} \quad \left(\because p = mv \Rightarrow v = \frac{p}{m}\right)$$

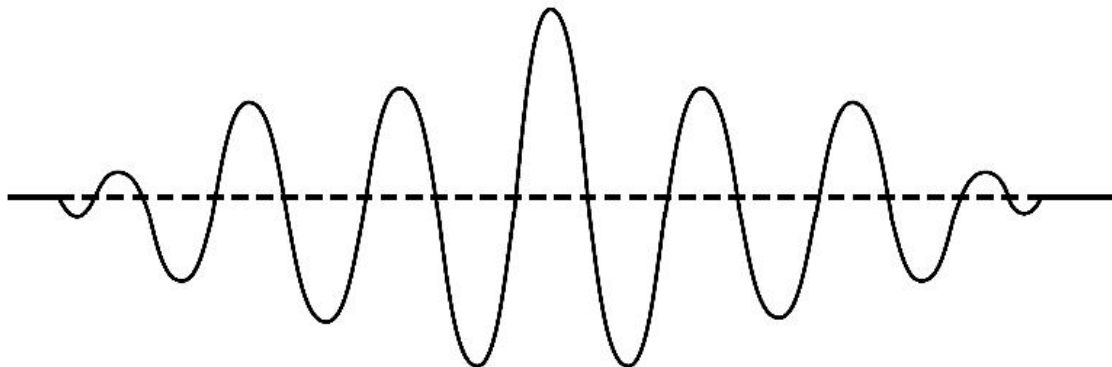
$$\Rightarrow p = \sqrt{2mE_k}$$

∴ Equation (i) gives $\lambda = \frac{h}{\sqrt{2mE_k}}$ (ii)

If V volt is accelerating potential of electron, then Kinetic energy, $E_k = eV$

∴ Equation (ii) gives $\lambda = \frac{h}{\sqrt{2meV}}$ (iii)

This is the required expression for de Broglie wavelength associated with electron accelerated to potential of V volt. The diagram of wave packet describing the motion of a moving electron is shown.



15. Draw a labelled ray diagram of a reflecting telescope. Mention its two advantages over the refracting telescope.

Ans:

Reflecting type telescope:

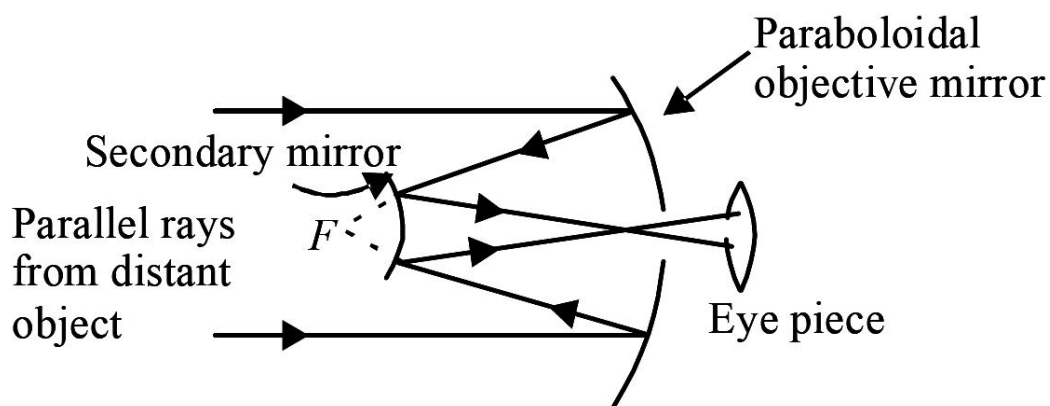
It is a telescope with concave parabolic mirror as objective. It has several advantages over refracting type telescope like having no chromatic aberration, no spherical aberration, has huge light gathering power and low cost.

The magnifying power of reflecting telescope is given by

$$M = + \frac{f_o}{f_e}$$

(i) Cassegrain Reflecting Telescope

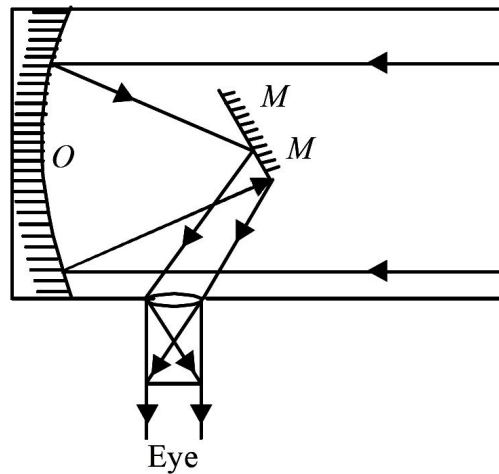
It consist of a large primary concave parabolic shape mirror having a hole at its centre. Another secondary convex mirror before the focus of primary mirror forms the image



The parallel rays from astronomical object are reflected by primary concave mirror and then are further reflected by convex mirror before getting focussed at eye piece. Eyepiece removes the defects from the image and also act as magnifier.

(ii) Newtonian Telescope

Primary concave mirror of large aperture as objective reflects the parallel rays from astronomical object.



Plane mirror M is placed at 45° with the axis of the tube. Light reflected from concave mirror falls on plane mirror M and further deviated to form a real image at eyepiece located at convenient place for observer. The eyepiece removes the defects from image and also act as magnifier.

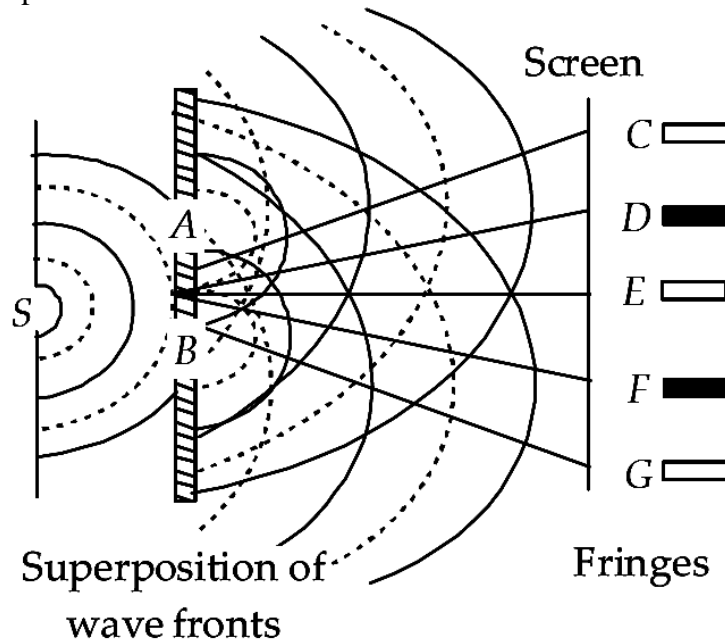
Advantage of reflecting type telescope over refracting type :

- (i) In refracting type the final image is formed after two times of partial refraction through the lens major losses in the intensity take places due to partial reflection and refractions. In reflecting type all the light intensity incident forms the final image as no loss of intensity can be ensured in reflection.
- (ii) Glass of lens offers different refractive index to different colours hence chromatic aberration due to which coloured image is formed take place in refracting type telescope. Reflecting telescope is free from chromatic aberration as no refraction.

16. Describe Young’s double slit experiment to produce interference pattern due to a monochromatic source of light. Deduce the expression for the fringe width.

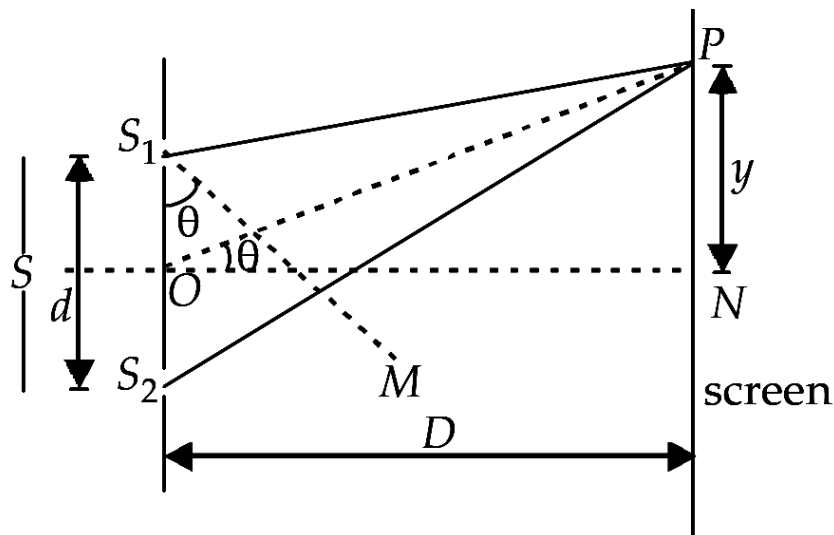
Ans:

Young’s double slit experiment :



S is a narrow slit (of width about 1 mm) illuminated by a monochromatic source of light, S . At a suitable distance (about 10 cm) from S , there are two fine slits A and B about 0.5 mm apart placed symmetrically parallel to S . When a screen is placed at a large distance (about 2 m) from the slits A and B , alternate bright and dark fringes running parallel to the lengths of slits appear on the screen. These are the interference fringes. The fringes disappear when one of the slits A or B is covered.

Expression for fringe width : In Young’s double slit experiment we obtain two sources from a single source.



Here S_1P and S_2P are nearly parallel since the distance $S_1S_2 = d$ is much less than D . The angle that these two lines make with the normal to the screen is taken as θ .

Path difference between the waves reaching the point P on screen is

$$\Delta P = S_2P - S_1P = S_2P - MP = S_2M = d \sin \theta$$

As angle is very small

$$d \sin \theta \approx d \tan \theta$$

$$\text{i.e. } \Delta P = \frac{yd}{D} \left(\because \text{in } \triangle NOP, \tan \theta = \frac{y}{D} \right) \dots\dots\dots(i)$$

We know, that for maxima

$$\Delta P = n\lambda \dots\dots\dots(ii)$$

where, $n = 1, 2, 3, \dots$

From equation (i) and (ii), we get

$$y_n = \frac{n\lambda D}{d}$$

Similarly for minima

$$y_n = \frac{(2n-1)\lambda D}{2d}$$

The fringe width is the separation between two consecutive maxima or minima,

$$\Delta y = \frac{\lambda D}{d}(n+1-n) = \frac{\lambda D}{d}$$

It is denoted by β

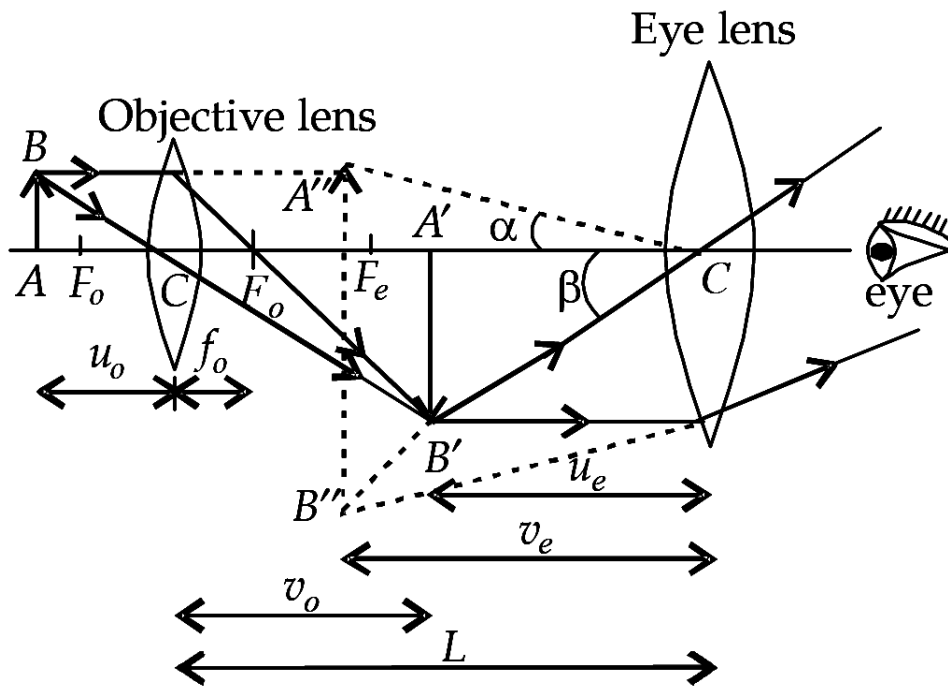
$$\beta = \frac{\lambda D}{d}$$

17. (i) Draw a neat labelled diagram of a compound microscope. Explain briefly its working.
 (ii) Why must both the objective and the eyepiece of a compound microscope have short focal lengths?

Ans:

- (i) Compound microscope is used to see extremely small objects. It consists of two lenses.
 ➤ Objective lens of short aperture and short focal length f_o
 ➤ Eye lens of large aperture and short focal length f_e

Ray diagram of a compound microscope is shown below.



Working : A real, inverted and enlarged image $A'B'$ of a tiny object AB , is formed by objective. Eye lens is so adjusted that $A'B'$ lies between its optical centre and principle focus F_e . A virtual and magnified image $A''B''$ (erect w.r.t. $A'B'$) is formed by the eye lens.

(ii) Both, the objective and the eye piece of a compound microscope should have short focal lengths to have greater magnifying power as magnifying power of a compound microscope is given by

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

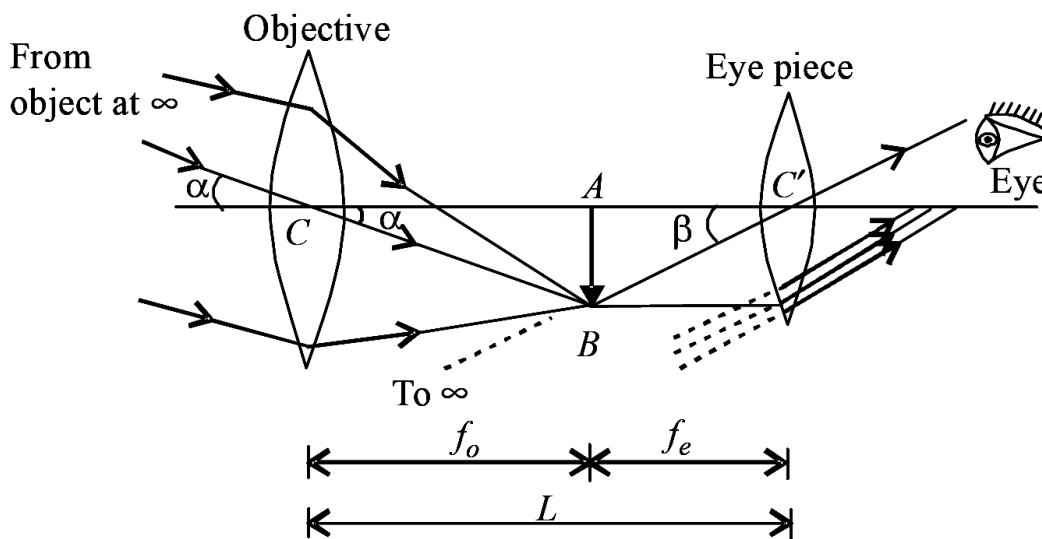
where

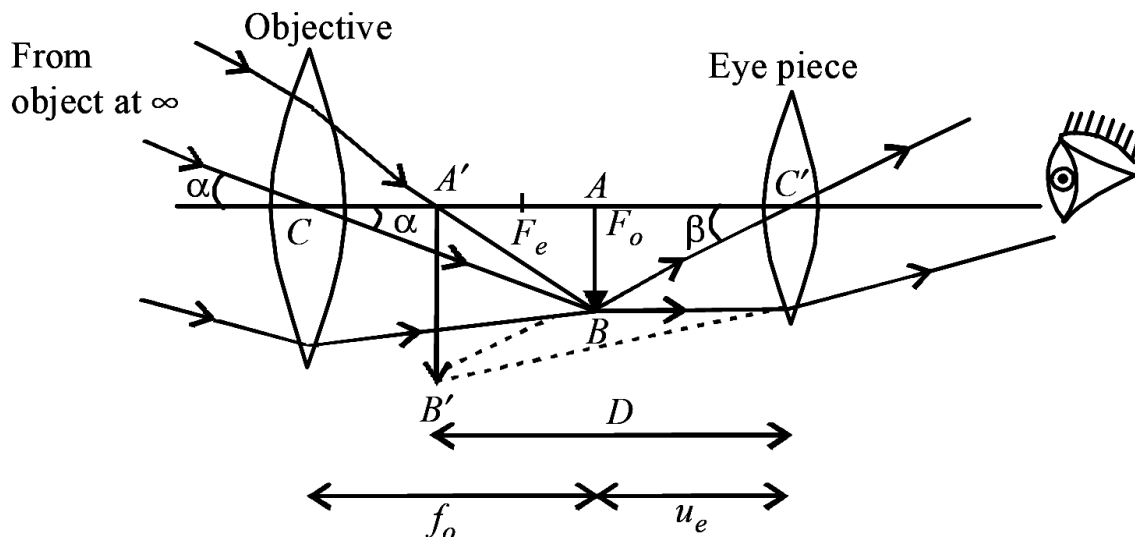
L = length of microscope tube

D = least distance of distinct vision.

18. Draw a labelled ray diagram of a refracting telescope. Define its magnifying power and write the expression for it. Write two important limitations of a refracting telescope over a reflecting type telescope.

Ans:





The magnifying power of a telescope is measured by the ratio of angle (β) subtended by the final image on the eye to the angle (α) subtended by object on eye.

$$M = -\frac{f_o}{f_e} \text{ or } M = -\frac{f_o}{f_e} \left(1 + \frac{f_o}{D}\right)$$

where f_o is focal length of the objective and f_e is the focal length of eye piece.

Any two limitations of refracting type telescope

- (i) Image formed is of lesser intensity.
- (ii) Image is not free from chromatic aberration due to refraction.
- (iii) Image is not free from spherical aberration.
- (iv) Objective of telescope should have a large aperture for resolving power.

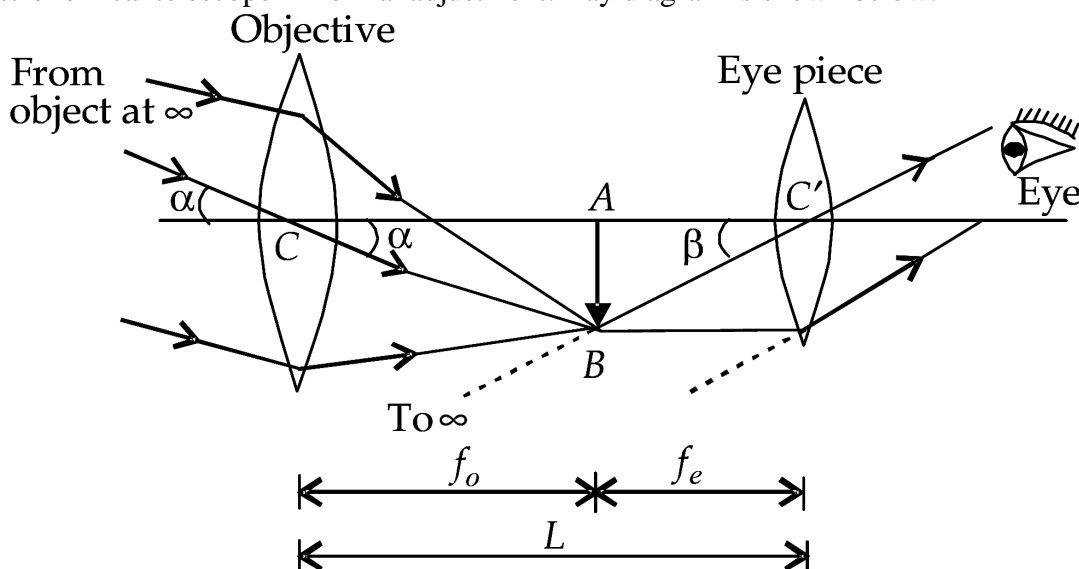
19. (i) Draw a neat labelled ray diagram of an astronomical telescope in normal adjustment.

Explain briefly its working.

(ii) An astronomical telescope uses two lenses of powers 10 D and 1 D. What is its magnifying power in normal adjustment?

Ans:

(i) An astronomical telescope in normal adjustment. Ray diagram is shown below.



It is used to see distant objects.

It consists of two lenses:

- Objective of large aperture and large focal length f_o
- Eyepiece of small aperture and short focal length f_e

Working : A parallel beam of light from an astronomical object at infinity is made to fall on objective lens. It forms a real, inverted and diminished image AB of the object. In normal

adjustment, AB lies at focus of the eye piece. So a highly magnified, erect image (w.r.t. AB) is formed at infinity.

(ii) Here, power of objective lens = 1 D

Power of eye piece = 10 D

In normal adjustment

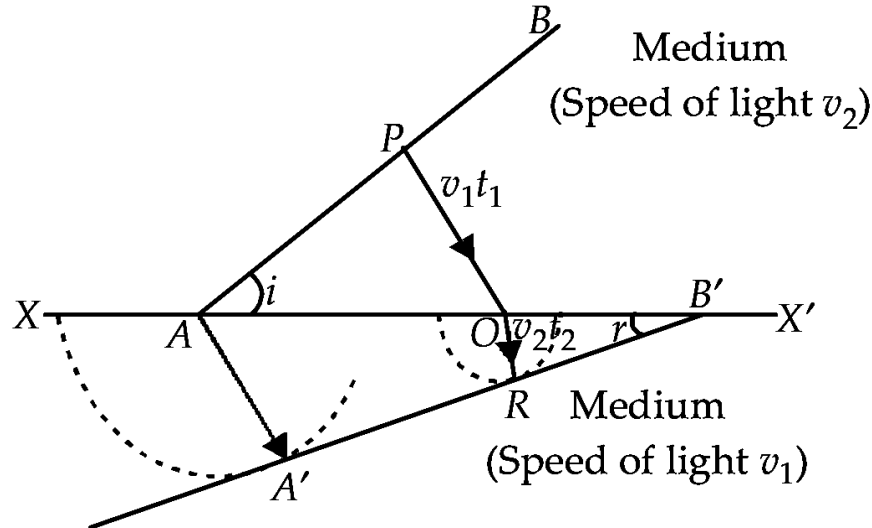
$$\text{Magnifying power, } M = -\frac{f_0}{f_e} = -\frac{P_e}{P_0}$$

$$\Rightarrow M = -10$$

20. Use Huygen's principle to verify the laws of refraction.

Ans:

Verification of Snell's law of refraction by using Huygen's principle.



We take a plane wavefront AB incident at a plane surface XX' . We use secondary wavelets starting at different times. We get refracted wavefront only when time taken by light to travel along different rays from one wavefront to another is same. We take any arbitrary ray starting from point P on incident wavefront to refracted wavefront at point R .

Let total time be t

$$t = \frac{PO}{v_1} + \frac{OR}{v_2} = \frac{AO \sin i}{v_1} + \frac{(AB' - AO) \sin r}{v_2}$$

$$\Rightarrow t = \frac{AB' \sin r}{v_2} + AO \left(\frac{\sin i}{v_1} - \frac{\sin r}{v_2} \right)$$

As time should be independent of the ray to be considered, the coefficient of AO in the above equation should be zero.

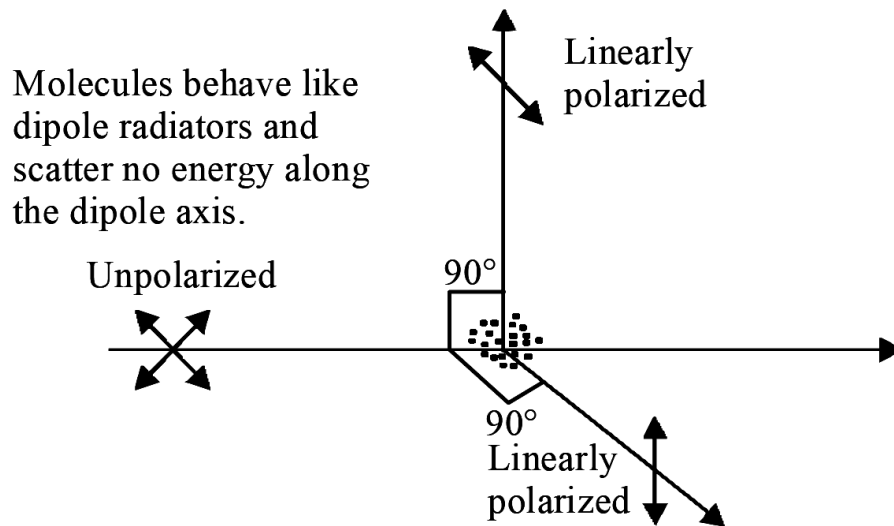
That is, $\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}^1\mu_2$, where ${}^1\mu_2$ is called refractive index of medium 2 w.r.t. medium 1. This is

Snell's law of refraction.

- 21. (a) What is linearly polarized light? Describe briefly using a diagram how sunlight is polarised.**
(b) Unpolarised light is incident on a polaroid. How would the intensity of transmitted light change when the polaroid is rotated?

Ans:

(a) If the electric field vector of a light wave vibrates just in one direction perpendicular to the direction of the propagation then it is said to be linearly polarised.



Unpolarised light incident on air molecules is scattered and gets polarized.

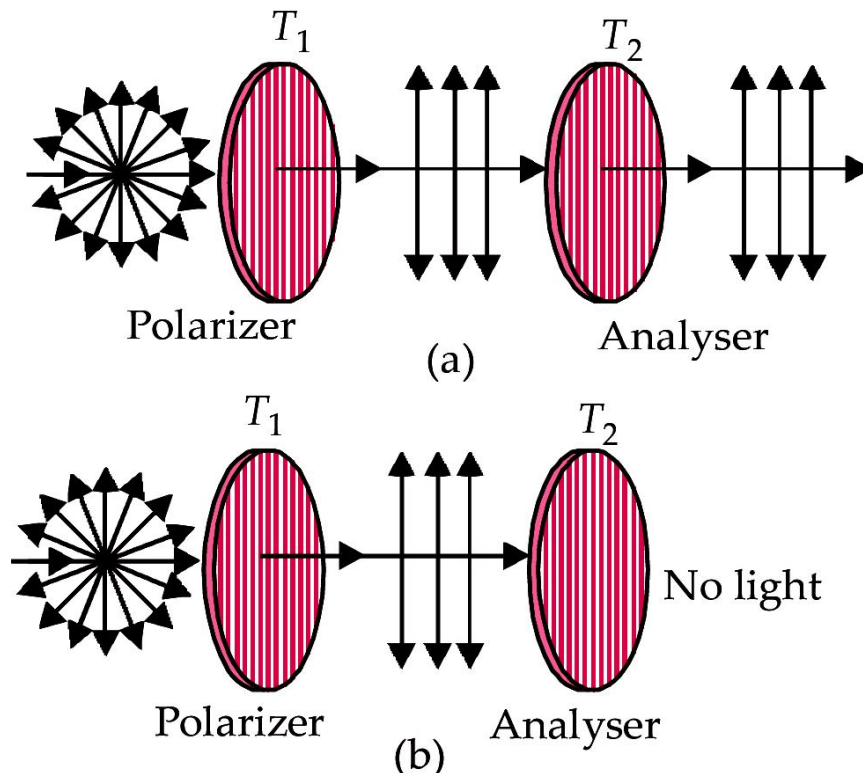
(b) Same/Unchanged/constant

22. (a) Describe briefly, with the help of suitable diagram, how the transverse nature of light can be demonstrated by the phenomenon of polarization.

(b) When unpolarized light passes from air to transparent medium, under what condition does the reflected light get polarized?

Ans:

(a) If two thin plates of tourmaline crystals T_1 and T_2 are rotated with the same angular velocity in the same direction as shown in the figure below, no change in intensity of transmitted light is observed.



The phenomenon can be explained only when we assume that light waves are transverse. Now the unpolarized light falling on T_1 has transverse vibrations of electric vector lying in all possible directions. The crystal T_1 allows only those vibrations to pass through it, which are parallel to its axis. When the crystal T_2 is introduced with its axis kept parallel to the axis of T_1 , the vibrations of electric vector transmitted by T_1 are also transmitted through T_2 . However, when axis of T_2 is perpendicular to axis of T_1 , vibrations of electric vector transmitted from T_1 are normal to the axis of T_2 . Therefore, T_2 does not allow them to pass and hence eye receives no light. Light coming out of

the crystal T_1 is said to be polarized *i.e.* it has vibrations of electric vector which are restricted only in one direction (*i.e.* parallel to the optic axis of crystal T_1).

Since the intensity of polarized light on passing through a tourmaline crystal changes, with the relative orientation of its crystallographic axes with that of polariser, therefore, light must consist of transverse waves.

(b) The reflected ray is totally plane polarised, when reflected rays and refracted rays are perpendicular to each other.

23. (a) Write Einstein's photoelectric equation and point out the characteristic properties of photons on which this equation is based. Briefly explain the observed features which can be explained by this equation.

(b) Define the terms (i) 'cutoff voltage and (ii) threshold frequency' in relation to the phenomenon of photoelectric effect.

Using Einstein's photoelectric equation show how the cutoff voltage and threshold frequency for a given photosensitive material can be determined with the help of a suitable plot/ graph.

Ans: (a) Einstein's photoelectric equation

$$K_{\max} = \frac{1}{2}mv_{\max}^2 = h\nu - \nu_0$$

Characteristics properties :

(i) In the interaction of photons with free electrons, the entire energy of photon is absorbed.

(ii) Energy of photon is directly proportional to frequency.

(iii) In photon electron collision, the total energy and momentum remain constant.

Three features :

(i) There is no time lag between the incidence of radiation and emission of electrons from the surface.

(ii) The number of electrons emitted per second, *i.e.*, photoelectric current, is directly proportional to the intensity of the incident radiations.

(iii) There is a minimum frequency of the incident radiations below which emission of electrons cannot occur.

(iv) The maximum KE of electrons increases proportionally, with increase in the frequency of incident radiations.

(b)

Cutoff Voltage : The minimum negative V_0 potential applied to the plate or anode, (A) for which the photoelectric current just becomes zero.

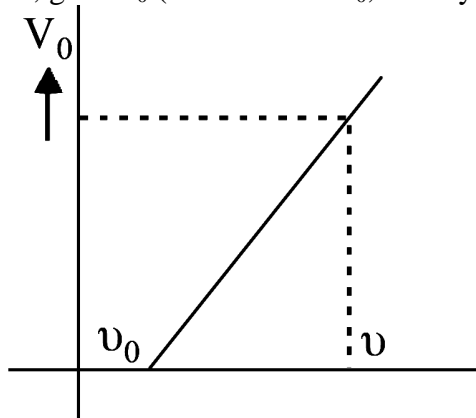
Threshold frequency : The minimum frequency of incident radiation which is required to have photo electrons emitted from a given metal surface.

As per Einstein's photoelectric equation

$$eV_0 = h\nu - h\nu_0 \text{ for } \nu > \nu_0$$

$$V_0 = \frac{h}{e}(\nu - \nu_0)$$

Hence the intercept, on the yaxis, gives ν_0 (one can read V_0 , for any ν , from the graph)



24. Using Bohr's postulates, derive the expression for the frequency of radiation emitted when electron in hydrogen atom undergoes transition from higher energy state (quantum number n_i) to the lower state, (n_f). When electron in hydrogen atom jumps from energy state $n_i = 4$ to $n_f = 3, 2, 1$, identify the spectral series to which the emission lines belong.

Ans: Since, $\frac{mv^2}{r_n} = \frac{1}{4\pi\epsilon_0} \cdot \frac{e^2}{r_n^2}$ and $mvr_n = \frac{nh}{2\pi}$

Therefore, $r_n = \frac{\epsilon_0 h^2 n^2}{\pi m e^2}$ (i)

Total energy, $E_n = \frac{1}{2} mv_n^2 - \frac{1}{4\pi\epsilon_0} \cdot \frac{e^2}{r_n} = \frac{1}{4\pi\epsilon_0} \cdot \frac{e^2}{2r_n} - \frac{1}{4\pi\epsilon_0} \cdot \frac{e^2}{r_n}$

$\Rightarrow E_n = -\frac{1}{4\pi\epsilon_0} \cdot \frac{e^2}{2r_n} = -\frac{1}{8\epsilon_0^2} \cdot \frac{me^4}{h^2 n^2}$ [using (i)]

$\Rightarrow E_n = \frac{-Rhc}{n^2}$ where Rydberg constant, $R = \frac{me^4}{8\epsilon_0^2 h^3 c}$

Energy emitted $\Delta E = E_i - E_f$

$\Delta E = Rhc \left[\frac{1}{n_f^2} - \frac{1}{n_i^2} \right]$

But $\Delta E = hu$

$\therefore \nu = Rc \left[\frac{1}{n_f^2} - \frac{1}{n_i^2} \right]$

or $\nu = \frac{me^4}{8\epsilon_0^2 h^3} \left[\frac{1}{n_f^2} - \frac{1}{n_i^2} \right]$

Paschen, Balmer, Lyman

25. (a) Using de Broglie's hypothesis, explain with the help of a suitable diagram, Bohr's second postulate of quantization of energy levels in a hydrogen atom.

(b) The ground state energy of hydrogen atom is -13.6 eV. What are the kinetic and potential energies of the electron in this state?

Ans:

(a) According to de Broglie's hypothesis,

$\lambda = \frac{h}{mv}$ (i)

According to de Broglie's condition of stationary orbits, the stationary orbits are those which contain complete de-Broglie wavelength.

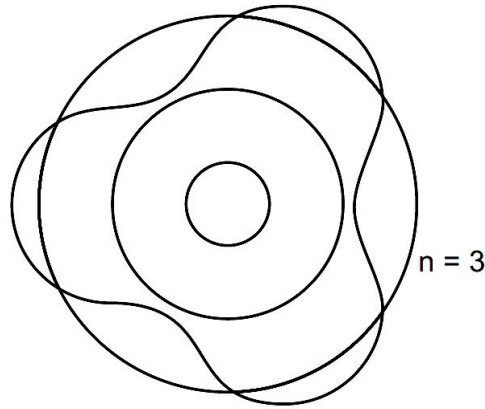
$2\pi r = n\lambda$ (ii)

Substituting value of λ from (ii) in (i), we get

$2\pi r = n \frac{h}{mv}$

$\Rightarrow mvr = n \frac{h}{2\pi}$ (iii)

This is Bohr's postulate of quantisation of energy levels.



(b) Kinetic energy, $K = \frac{1}{2}mv^2 = \frac{1}{4\pi\epsilon_0} \cdot \frac{e^2}{2r} \dots(i)$

Potential energy, $U = -\frac{1}{4\pi\epsilon_0} \cdot \frac{e^2}{r} \dots(ii)$

Total energy $E = K + U = -\frac{1}{4\pi\epsilon_0} \cdot \frac{e^2}{2r} \dots(iii)$

Comparing equations (i), (ii), (iii), we have

$$K = -E \text{ and } U = 2E$$

Given $E = -13.6 \text{ eV}$ (in ground state)

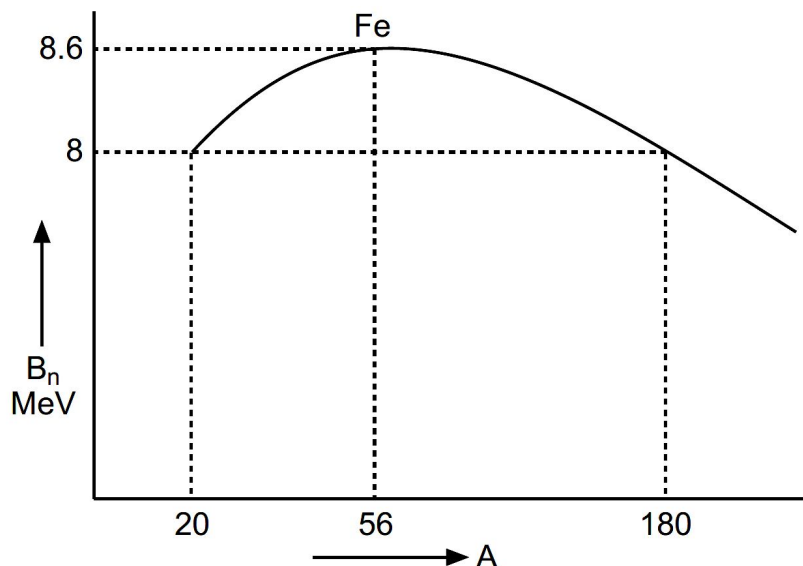
\therefore Kinetic energy, $K = 13.6 \text{ eV}$

Potential energy $U = 2 \times (-13.6 \text{ eV}) = -27.2 \text{ eV}$

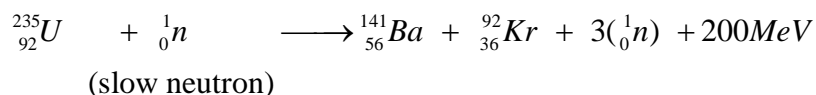
26. Draw a plot showing the variation of binding energy per nucleon versus the mass number A . Explain with the help of this plot the release of energy in the processes of nuclear fission and fusion.

Ans:

The variation of binding energy per nucleon versus mass number is shown in figure.

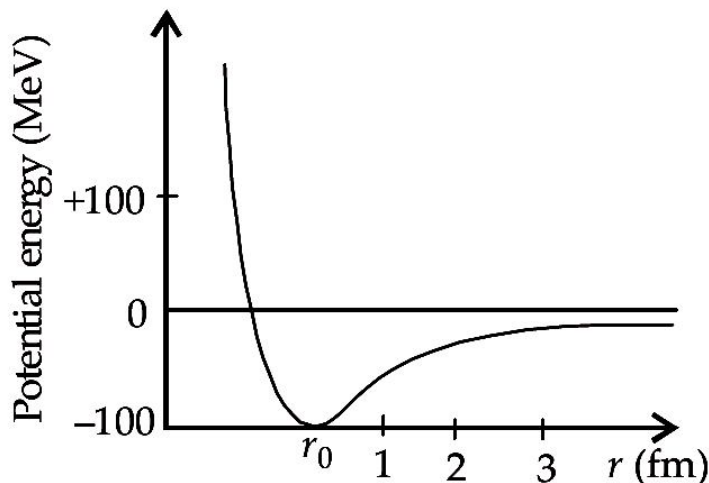


The binding energy curve indicates that binding energy for nucleon of heavy nuclei is less than that of middle nuclei. Clearly a heavy nucleus breaks into two lighter nuclei then binding energy per nucleon will increase and energy will be released in the process. This process is called nuclear fission. Nuclear fission reaction is



27. Draw a plot of potential energy of a pair of nucleons as a function of their separation. Write two important conclusions which you can draw regarding the nature of nuclear forces.

Ans:



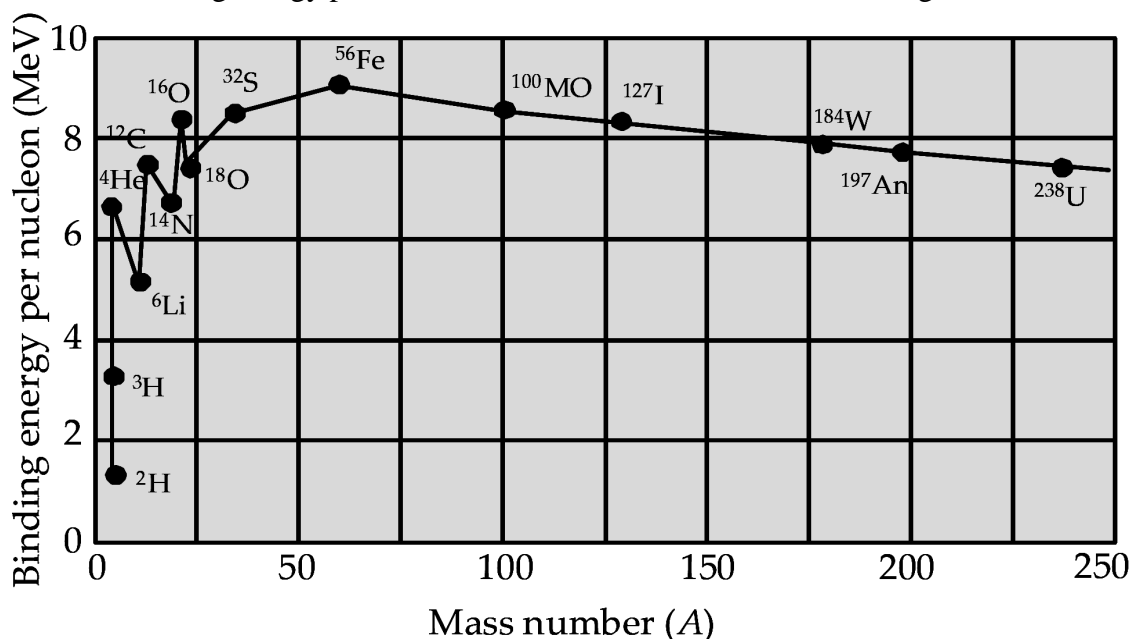
From the above plot, following conclusions can be drawn.

- (i) Nuclear forces are short range forces
- (ii) For a separation greater than r_0 , the nuclear forces are attractive and for separation less than r_0 , the nuclear forces are strongly repulsive.

28. Draw a plot of the binding energy per nucleon as a function of mass number for a large number of nuclei, $2 \leq A \leq 240$. How do you explain the constancy of binding energy per nucleon in the range $30 < A < 170$ using the property that nuclear force is short ranged?

Ans:

The variation of binding energy per nucleon versus mass number is shown in figure.



The binding energy per nucleon as a function of mass number.

Inferences from graph

1. The nuclei having mass number below 20 and above 180 have relatively small binding energy and hence they are unstable.
2. The nuclei having mass number 56 and about 56 have maximum binding energy – 5.8 MeV and so they are most stable.
3. Some nuclei have peaks, e.g., ^4_2He , $^{12}_6\text{C}$, $^{16}_8\text{O}$; this indicates that these nuclei are relatively more stable than their neighbours.

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

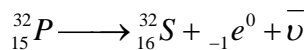
When two very light nuclei ($A \leq 10$) join to form a heavy nucleus, the binding is energy per nucleon of fused heavier nucleus more than the binding energy per nucleon of lighter nuclei, so again energy would be released in nuclear **fusion**.

29. (a) Write symbolically the β^- decay process of ${}^{32}_{15}P$.

(b) Derive an expression for the average life of a radionuclide. Give its relationship with the half life.

Ans:

(a) β^- decay process of ${}^{32}_{15}P$



(b) The average or mean life of a radioactive substance is defined as the time for which the active nuclei of the atoms of the radioactive substance exit. In mean life T_a , both number of nuclei, N and rate of disintegration, R reduce to $1/e$ of their initial values.

i.e., when $t = T_a$ then $N = \frac{N_0}{e}$

Using it in equation $N = N_0 e^{-\lambda t}$, we get $\frac{N_0}{e} = N_0 e^{-\lambda t}$

$$\Rightarrow e^{-1} = e^{-\lambda T_a}$$

$$\Rightarrow 1 = \lambda T_a \Rightarrow T_a = \frac{1}{\lambda}$$

so, finally mean life is reciprocal of decay constant λ .

Also half life $T_{1/2} = \frac{0.693}{\lambda} = 0.693 T_a$.

30. State the law of radioactive decay. Plot a graph showing the number (N) of undecayed nuclei as a function of time (t) for a given radioactive sample having half life $T_{1/2}$. Depict in the plot the number of undecayed nuclei at (i) $t = 3T_{1/2}$ and (ii) $t = 5T_{1/2}$.

Ans:

Radioactive Decay Law : Laws of radioactive decay

(i) Radioactivity is a nuclear phenomenon. It is independent of all physical and chemical conditions.

(ii) The disintegration is random and spontaneous. It is a matter of chance for any atom to disintegrate first.

(iii) The radioactive substance emit α or β particles.

These rays originate from the nuclei of disintegrating atom and form fresh radioactive products.

(iv) The rate of decay of atoms is proportional to the number of undecayed radioactive atoms present at any instant.

If N is the number of undecayed atoms in a radioactive substance at any time t , dN the number of atoms disintegrating in time dt , the rate of decay is $\frac{dN}{dt}$ so that

$$-\frac{dN}{dt} \propto N \text{ or } \frac{dN}{dt} = -\lambda N \dots\dots\dots(i)$$

where λ is a constant of proportionality called the decay (or disintegration) constant, equation (i) results

$$N = N_0 e^{-\lambda t} \dots\dots\dots(ii)$$

where N_0 = initial number of undecayed radioactive atoms.

If N_0 is the initial number of radioactive atoms present then in a half life time $T_{1/2}$, the number of undecayed radioactive atoms will be $N_0/2$ and in next half $N_0/4$ and so on.

Using, $\frac{N}{N_0} = \left(\frac{1}{2}\right)^{\frac{t}{T_{1/2}}}$

According to problem

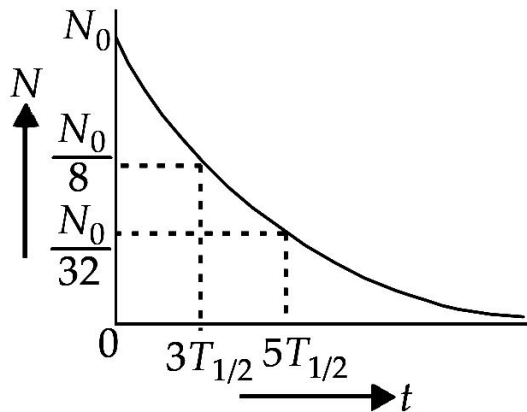
$$t = 3T_{1/2}$$

$$\therefore \frac{N}{N_0} = \left(\frac{1}{2}\right)^3 \Rightarrow N = N_0 \left(\frac{1}{2}\right)^3 = \frac{N_0}{8}$$

and at $t = 5T_{1/2}$

$$N = \frac{N_0}{32}$$

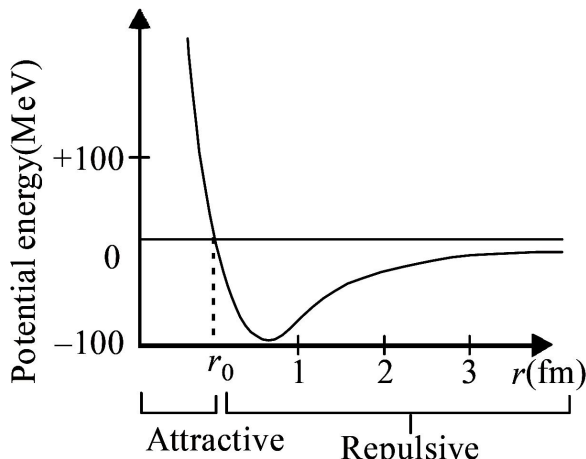
The graph shown below for the number of undecayed nuclei at $t = 3T_{1/2}$ and $t = 5T_{1/2}$.



31. Draw a plot of potential energy of a pair of nucleons as a function of their separations. Mark the regions where the nuclear force is (i) attractive and (ii) repulsive. Write the characteristic features of nuclear forces.

Ans:

The nuclear force must be of short range because its influence does not exist far beyond its nuclear 'surface'. The graph of potential energy of a pair of nucleons as function of their separation is as shown. It depicts the shortrange character of nuclear force. It is attractive for a separation greater than r_0 (< 1 fm), but becomes strongly repulsive for separations less than r_0 . This region is known as hard core. Nuclear attractive force is strongest when the separation is about 1 fm, or potential energy of two nucleons is minimum.



Properties of nuclear force are:

- Nuclear forces are short range forces and are strongly
- Nuclear forces above 4.2. Fermi are negligible, whereas below 1 Fermi, they become repulsive in nature. It is this repulsive nature below 1 Fermi, which prevents the nucleus from collapsing under strong attractive force.
- Nuclear forces are charge independent. The same magnitude of nuclear force act between a pair of protons, pair of proton and neutron and pair of neutrons. The attractive nuclear force is due to exchange of p mesons (π^0, π^+, π^-) between them.

- Nuclear force of one nucleon at a time is only with nearest neighbouring nucleon and not with all
- neighbouring nucleons. Thus nuclear forces are saturated forces.
- Nuclear forces are strongest forces in nature and are 10^2 times stronger than electrostatic force and 10^{38} times stronger than the gravitational force, in their own small range of few fermi.

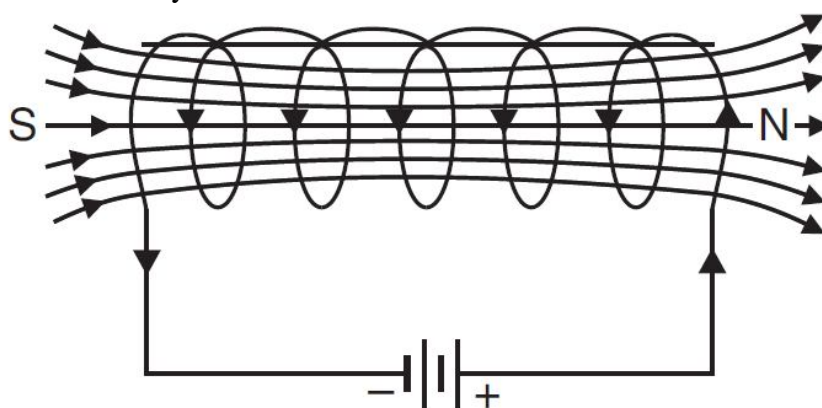
32. (a) State Ampere's circuital law. (b) Use it to derive an expression for magnetic field inside, along the axis of an air cored solenoid. (c) Sketch the magnetic field lines for a finite solenoid. How are these field lines different from the electric field lines from an electric dipole?

Ans:

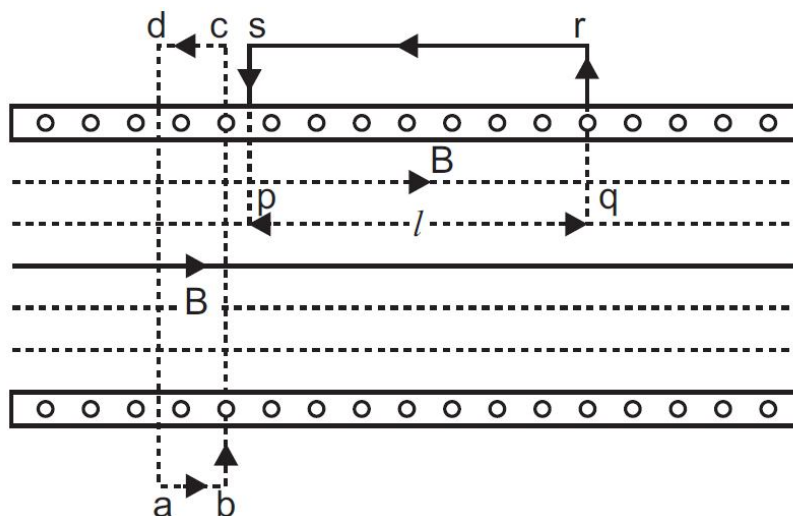
(a) It states that the line integral of magnetic field induction along a closed path is equal to μ_0 -times the current enclosed by the path i.e., $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$

(b) **Magnetic Field Due to a Current Carrying Long Solenoid:**

A solenoid is a long wire wound in the form of a close-packed helix, carrying current. To construct a solenoid a large number of closely packed turns of insulated copper wire are wound on a cylindrical tube of card-board or china clay.



When an electric current is passed through the solenoid, a magnetic field is produced within the solenoid. If the solenoid is long and the successive insulated copper turns have no gaps, then the magnetic field within the solenoid is uniform; with practically no magnetic field outside it. The reason is that the solenoid may be supposed to be formed of a large number of circular current elements. The magnetic field due to a circular loop is along its axis and the current in upper and lower straight parts of solenoid is equal and opposite. Due to this the magnetic field in a direction perpendicular to the axis of solenoid is zero and so the resultant magnetic field is along the axis of the solenoid.



If there are ' n ' number of turns per metre length of solenoid and I amperes is the current flowing, then magnetic field at axis of long solenoid is $B = \mu_0 n I$

If there are N turns in length l of wire, then $n = \frac{N}{l}$ or $B = \frac{\mu_0 NI}{l}$

Derivation: Consider a symmetrical long solenoid having number of turns per unit length equal to n . Let I be the current flowing in the solenoid, then by right hand rule, the magnetic field is parallel to the axis of the solenoid.

Field outside the solenoid: Consider a closed path $abcd$. Applying Ampere's law to this path

$$\oint \vec{B} \cdot d\vec{l} = \mu \times 0 \text{ (since net current enclosed by path is zero)}$$

As $dl \neq 0 \therefore B = 0$

This means that the magnetic field outside the solenoid is zero.

Field Inside the solenoid: Consider a closed path $pqrs$. The line integral of magnetic field \vec{B} along path $pqrs$ is

$$\oint \vec{B} \cdot d\vec{l} = \int_{pq} \vec{B} \cdot d\vec{l} + \int_{qr} \vec{B} \cdot d\vec{l} + \int_{rs} \vec{B} \cdot d\vec{l} + \int_{sp} \vec{B} \cdot d\vec{l} \quad \dots\dots(i)$$

For path pq , \vec{B} and $d\vec{l}$ are along the same direction,

$$\therefore \int_{pq} \vec{B} \cdot d\vec{l} = \int B dl = Bl \text{ (since } pq = l)$$

For paths qr and sp , \vec{B} and $d\vec{l}$ are mutually perpendicular.

$$\therefore \int_{qr} \vec{B} \cdot d\vec{l} = \int_{sp} \vec{B} \cdot d\vec{l} = \int B dl \cos 90^\circ = 0$$

For path rs , $B = 0$ (since field is zero outside a solenoid)

$$\therefore \int_{rs} \vec{B} \cdot d\vec{l} = 0$$

In view of these, equation (i) gives

$$\int_{pqrs} \vec{B} \cdot d\vec{l} = \int_{pq} \vec{B} \cdot d\vec{l} = Bl \quad \dots\dots(ii)$$

By Ampere's law $\oint \vec{B} \cdot d\vec{l} = \mu_0 \times \text{net current enclosed by path}$

$$\therefore Bl = \mu_0 (nl I) \Rightarrow B = \mu_0 nI$$

This is the well known result.

(c) The magnetic field lines of magnet (or current carrying solenoid) form continuous closed loops and are directed from N to S pole outside the magnet and S to N pole inside the magnet and forms closed loops while in the case of an electric dipole the field lines begin from positive charge and end on negative charge or escape to infinity.

