[Topic 1] Coulomb's law, electrostatic field and electric dipole

Summary

Electric Charge

- Electrostatic charge is a fundamental property of matter due to which it produces and experiences electrical and magnetic effects.
- Properties of atoms, molecules and bulk matter are determined by electric and magnetic forces.
- It can be inferred from simple experiments based on frictional electricity that there are two type of charges in nature: negative and positive; and like charges repel and unlike charges attract.
- By convention, the charge on electron is considered as negative and the charge on proton is considered as positive and the charge present is equal. The S.I. unit of electric charge is coulomb. Its C.G.S unit is stat coulomb.
- The nature and amount of electric charge present in a charged body is detected by Gold-leaf electroscope.
- Total charge on a body is expressed as $q = \pm ne$.

Conductors and Insulators

- Objects that allow charges to flow through them are called Conductors (metals) and objects that do not allow charges to flow through are called Insulators (rubber, wood, and plastic).
- Objects that behave as an intermediate between conductors and insulators are called semi-conductors, for example- silicon.
- The process of sharing charges with the earth, when we bring a charged body in contact with the earth is called grounding or earthing.

Charging by Induction

- Charging by induction means charging without contact.
- If a plastic comb is rubbed with wool, it becomes negatively charged.

Three basic properties of electric charge

- **Quantization:** When the total charge of a body is an integral multiple of a basic quantum of charge, this is known as quantization of electric charge. i.e., $q = ne$ where

  $n = \pm 1, \pm 2, \pm 3, \ldots\ldots\ldots\ldots\ldots$
- **Additivity:** It means that the total charge of a system is the algebraic sum (adding taking into account negative and positive signs both) of all the charges in the system.
- **Conservation of charge:** Conservation of electric charges means that there will be no change in the total charge of the isolated system with time. There is transfer of the electric charge from one body to another, but no charge will be created or destroyed.

Coulomb's law

The force between two point charges q_1 and q_2 is directly proportional to the product of the two charges(q_1q_2) and inversely proportional to the square of the distance between them(r^2)and it acts along the straight line joining the two charges.

$$F_{12} = \text{force on } q_2 \text{ due to } q_1 = \frac{k\left(q_1q_2\right)}{r^2_{21}}\hat{r}_{21}$$

where $k = \dfrac{1}{4\pi\varepsilon_0}$

The experimental value of the constant ε_0 is

$8.854 \times 10^{-12} C^2N^{-1}m^{-2}$

Therefore, the approximate value of k is

$9 \times 10^9 Nm^2C^{-2}$

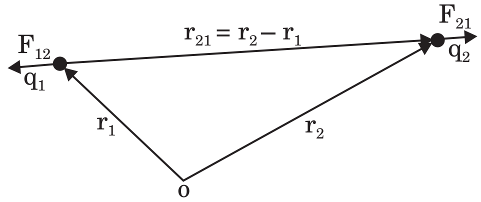


Fig. Depiction of Coulomb's law

Facts about Coulomb's law:

- Coulomb's law is not valid for charges in motion; it should only be used for point charges in vacuum at rest.
- The electrostatic force obeys Newton's third law of motion and acts along the line joining the two charges.
- Presence of other charges in the neighborhood does not affect Coulomb's force.
- The ratio of electric force and gravitational force between a proton and an electron is represented by $\frac{k e^2}{G m_e m_p} \cong 2.4 \times 10^{39}$

Superposition Principle

The presence of an (or more) additional charge does not affect the forces with which two charges attract or repel each other. Superposition principle states that the net force on any charge due to n number of charges at rest is the vector sum of all the forces on that charges, taken one at a time.

i.e. $\vec{F}_0 = \vec{F}_{01} + \vec{F}_{02} + \vec{F}_{03} + ..\vec{F}_{0n}$

- The force on a small positive test charge q placed at the point divided by the magnitude of the charge is the electric field E at a point due to charge configuration.

Electric Field

- The space around a charge up to which its force can be experienced is called electric field.
- Electric field due to a point charge q has a magnitude $E(r) = \frac{q}{4\pi\varepsilon_0 r^2}\hat{r}$
  - ➢ It is radially outwards if q is positive.
  - ➢ It is radially inwards if q is negative.
- Electric field satisfies the superposition principle.
  - ➢ The unit of electric field is N/C.
  - ➢ Electric field inside the cavity of a charged conductor is zero.

Electric Field lines

- The tangent at each point on the curve of electric field line, gives the direction of electric field at that point.
- The relative strength of electric field at different points is indicated by the relative closeness of field lines.
  - ➢ In regions of strong electric field, they crowd near each other.
  - ➢ In regions of weak electric field, they are far apart.
  - ➢ In regions of constant electric field, the field lines formed are uniformly spaced parallel straight lines.
- Field lines are continuous curves. There will be no breaks.

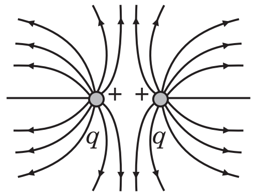


Fig. Electric field lines

- Field lines are not intersecting. They cannot cross each other.
- Electrostatic field lines begin at positive charges and terminate at negative charges.
- No closed loop can be formed by them.

Electric Dipole

- A pair of equal and opposite charges q and –q separated by small distance 2a is known as electric dipole. The magnitude of its dipole moment vector is 2qa and is in the direction of the dipole axis from –q to q.

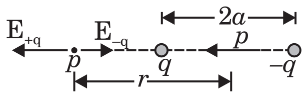


Fig. Electric dipole

- Field of an electric dipole in its equatorial plane at a distance r from the center:

$$E = \frac{-p}{4\pi\varepsilon_o}\frac{1}{\left(a^2 + r^2\right)^{3/2}}$$

$$\cong \frac{-p}{4\pi\varepsilon_o r^3} \quad \text{for } r >> a$$

- Dipole electric field on the axis at a distance r from the center:

$$E = \frac{2pr}{4\pi\varepsilon_o\left(r^2 - a^2\right)^2}$$

$$\cong \frac{2p}{4\pi\varepsilon_o r^3} \quad \text{for } r >> a$$

The $1/r^3$ dependence of dipole electric fields should be noted in contrast to the $1/r^2$ dependence of electric field due to a point charges.

- In a uniform electric field E, a dipole experiences a torque τ given by

$\tau = p \times E$

But no net force will be experienced by it.

Topic 2: Electric Flux

Summary

- Electric flux is proportional to number of lines leaving a surface, outgoing lines with positive sign, incoming lines with negative sign.

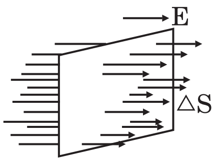


Fig. Electric flux

- Through a small area element ΔS, the flux Δϕ of electric field E is given by

  $\Delta\phi = E.\Delta S$

  And the vector area element ΔS is

  $\Delta S = \Delta S\hat{n}$

Where ΔS is the magnetic of the area element and $\hat{n}$ is normal to the area element, which can be considered planar for the sufficiently small ΔS.

Gauss's Law and its application

- The flux of electric field through any closed surface S is $1/\varepsilon_0$ times the total charge enclosed by S.

$$\phi = E\int dA = \frac{q_{enclosed}}{\varepsilon_0}$$

- The law is mainly useful in determining electric field E, when the source distribution has simple symmetry:
  - ➢ Thin infinitely long straight wire of uniform linear charge density λ

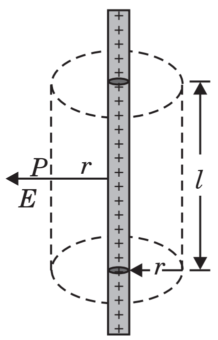


Fig. Thin infinitely long Straight wire

$$E = \frac{\lambda}{2\pi\varepsilon_o r}\hat{n}$$

Where, r is the radial (perpendicular) distance of the point from the wire and $\hat{n}$ is the radial unit vector in the plane normal to the wire passing through the point.

- Infinite plane sheet (thin) of uniform surface charge density σ

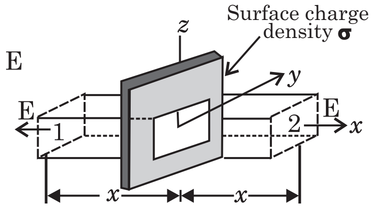


Fig. Infinite plane sheet (thin)

$$E = \frac{\sigma}{2\varepsilon_o}\hat{n}$$

Where $\hat{n}$ is a unit vector normal to the plane and going away from it.

- Thin spherical shell of uniform surface charge density σ

$$E = \frac{q}{4\pi\varepsilon_o r^2}\hat{r} \qquad (r \geq R)$$

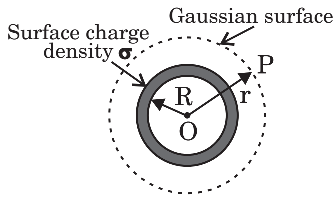


Fig.: Thin uniformly surface charged spherical shell (r > R)

(For r > R)

E = 0 (r < R)

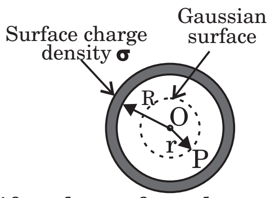


Fig.: Thin uniformly surface charged spherical shell (r < R)

(For r < R)

Where r is the distance of the point from the center of the shell whose radius is R with the total charge q. The electric field outside the shell is the same as the total charge is concentrated at the center. A solid sphere of uniform volume charge density shows the same result. Inside the shell at all the points, the field is zero.

Topic 1: Electrostatic Potential and Electrostatic Potential Energy

Summary

Electrostatic potential:

- The amount of work done by an external force in moving a unit positive charge from one point to another in electrostatic field is called electrical potential.
- Such that $V = \frac{1}{4\pi\varepsilon}\frac{q}{r}$
- Where, q = charge causing the field, ε = permittivity, r = separation between centre of charge point.
- Electrostatic force is a conservative force.
- Work done by an external force (equal and opposite to the electrostatic force) in bringing a charge q from a point R to a point P is $V_P - V_R$, which is the difference in potential energy of charge q between the final and initial points.

Potential difference:

When the work is done upon a charge to change its potential energy then the difference between the final and the initial location is called electric potential difference.

Electric Potential due to a dipole:

- The electrostatic potential at a point with distance r due dipole at a point making an angle θ with dipole moment p placed at the origin is given by $V(r) = \frac{1}{4\pi\varepsilon_o}\cdot\frac{p\cdot\hat{r}}{r^2}$.

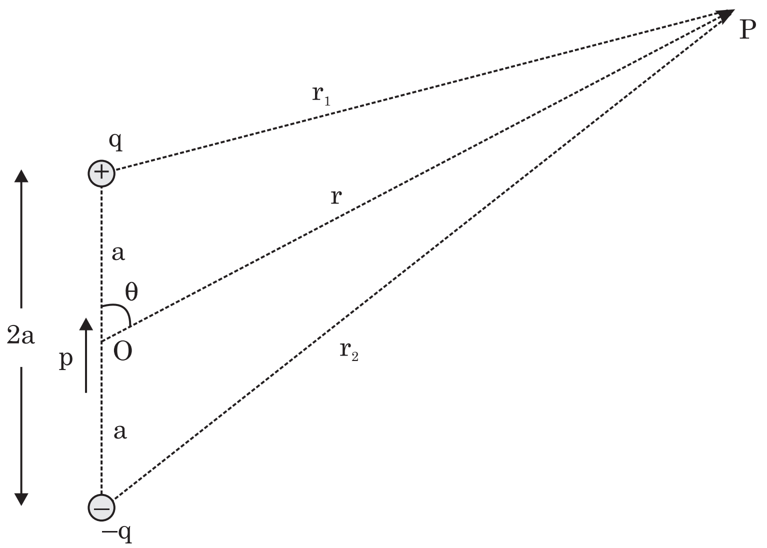


Fig. Electrical potential due to dipole

- It is a scalar quantity.
- Let A and B be the initial and final location for a single charge q then the potential difference between A and B is given by:

$$\Delta V = V_B - V_A = -\int_A^B E \times ds = -\int_A^B Eds\cos\theta = -\int_A^B E \times ds$$

Where, E is the field due to a point charge, ds = dr, so that

$$V_B - V_A = \int_{r_A}^{r_B} \frac{q}{4\pi\varepsilon_0}\frac{dr}{r^2} = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r}\right]_{r_A}^{r_B} = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r_B} - \frac{1}{r_A}\right]$$

- The result is true also for a dipole (with charges –q and q separated by 2a for r >> a.

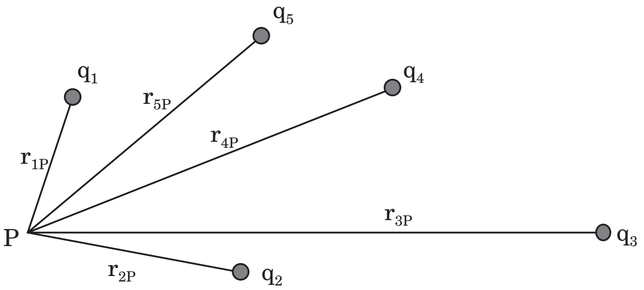
Dipole and System of charges

- For a charge configuration $q_1, q_2, ..., q_n$ with position vectors $r_1, r_2, r_3, ..., r_n$, then the potential V_1 at point P due to charge q_1 will be,

$$V_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_1}$$

And the sum of potentials due to individual charges is given by the superposition principle,

$$V = \frac{1}{4\pi\varepsilon_o}\left(\frac{q_1}{r_{1P}} + \frac{q_2}{r_{2P}} + ... + \frac{q_n}{r_{nP}}\right)$$



- In a uniformly charged spherical shell, the electric field outside the shell with outside potential is given by,

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

Equipotential surfaces

- A surface over which potential has a constant value is known as an equipotential surface.
- The amount of work done in moving a charge over an equipotential surface is zero.
- Concentric spheres centered at a location of the charge act as equipotential surfaces for a point charge.
- The electric field E, at a point and equipotential surface are mutually perpendicular to each other through the point. The direction of the steepest decrease of potential is in E.
- Regions of strong and weak fields are located because of the spacing among equipotential surfaces.

Potential Energy of a System of Charges:

Potential energy stored in a system of charges is the work done by an external agency in assembling the charges at their locations. Total work done in assembling the charges is given by $U = \frac{1}{4\pi\varepsilon_o}\cdot\left(\frac{q_1q_2}{r_{12}} + \frac{q_1q_3}{r_{13}} + \frac{q_2q_3}{r_{23}}\right)$ where r_{12} is distance between q_1 and q_2, r_{13} is distance between q_1 & q_3 and r_{23} is distance between q_2 & relabel q_3.

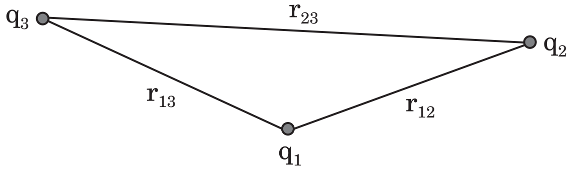


Fig. Potential energy due to System of charges

Electric potential energy of system of two point charges

- Here the work done doesn't depend on path.
- In this system the two charges q_1 and q_2 when separated by distance r, will either repel or attract each other.
- Electrical potential of charges q_1 and q_2 is given by:

$$U = \frac{1}{2}\sum_{i=1}^{2} q_i V_i$$

Potential Energy in an External Field:

- The potential energy of a charge q in an external potential V(r) is qV(r). The potential energy of a dipole moment p in a uniform electric field E is –p.E.
- Electric dipole in an electrostatic field: Electric potential due to a dipole at a point at distance r and making an angle θ with the dipole moment p is given by

$$V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2}$$

Electrostatics of conductors:

- Electrostatic field is zero inside a conductor.
- Electrostatic field at the surface of a charged conductor must be normal to the surface at every point.
- In the static situation, there cannot be any excess charge in the interior of a conductor.
- Throughout the volume of the conductor, the electrostatics potential is constant and has same value on its surface.
- Electrostatics field E is zero in the interior of a conductor; just outside the surface of a charged conductor, E is normal to the surface given by $E = \frac{\sigma}{\varepsilon_o}\hat{n}$ where $\hat{n}$ is the unit vector along the outward normal to the surface and σ is the surface charge density.
- **Electrostatic shielding:** A field which is inside the cavity of a conductor is always zero and it remains shielded from the electric field, which is known as electrostatic shielding.

Dielectrics and Polarization:

- **Dielectrics:** A non-conducting substance which has a negligible number of charge carriers unlike conductors is called dielectrics.
- **Electric polarization:** The difference between induced electric field and imposed electric field in dielectric due to bound and free charges is known as electric polarization. It is written as:

$$P = \frac{D - E}{4\pi}$$

Note: Polarisation can also be written as polarization (with 'z' in place of 's')

Topic 2: Capacitance

Summary

Capacitor and Capacitance

- **Capacitor:** The system of two conductors separated by an insulator is called capacitor.

  The device which is used to store charge is known as capacitor. The applied voltage and size of capacitor decides the amount of charge that can be stored i.e., $Q = CV$

  Two similar connecting plates are placed in capacitor in the front of each other where one plate is connected to the positive terminal and other plate is connected to the negative terminal.
- **Capacitance:** The ratio of magnitude of charge stored on the plate to potential difference between the plates is called capacitance. It is written as:

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

  Size, shape, medium and other conductors in surrounding influence the capacitance of a conductor.

  Its S.I. unit is farad.

  $1F = 1CV^{-1}$ For a parallel plate capacitor (with vacuum between the plates), $C = \varepsilon_o \frac{A}{d}$ where A is the area of each plate and d in the separation between the parallel plates.

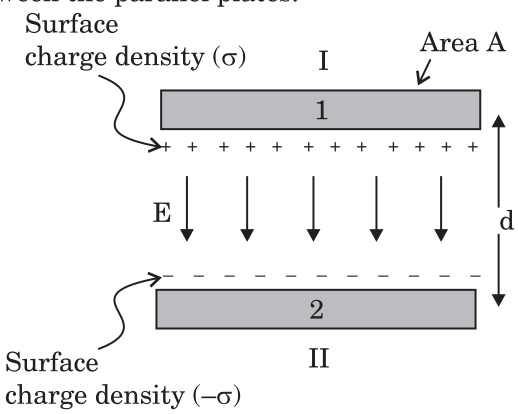


Fig. Capacitor

Effect of Dielectric on Capacitance:

- If the medium between the plates of a capacitor is filled with an insulating substance (dielectric), the electric field due to the charged plates induces a net dipole moment in the dielectric. This effect, called ***polarization***, gives rise to a field in the opposite direction.
- The dielectric is polarised by the field and also the effect is equivalent to two charged sheets with surface charge densities σ_p and $-\sigma_p$.
- The net electric field inside the dielectric and hence the potential difference between the plates is thus reduced. Consequently, the capacitance C increases from its value C_o when there is no medium (vacuum),

  $C = KC_o$ where $K = \frac{\varepsilon}{\varepsilon_0}$ is the ***dielectric constant*** of the insulating substance.

Types of capacitor:

- Parallel plate capacitor: $C = K\varepsilon_0 \frac{A}{d}$
- Cylindrical capacitor: $C = 2\pi K\varepsilon_0 \frac{1}{\ln(b/a)}$
- Spherical capacitor: $C = 4\pi K\varepsilon_0 \left(\frac{ab}{b-a}\right)$

Combination of Capacitors

- For capacitors in the series combination, the total capacitance C is given by

  $$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots \frac{1}{C_n}$$
- In the parallel combination, the total capacitance C is $C = C_1 + C_2 + C_3 \ldots\ldots C_n$, where $C_1, C_2, C_3 \ldots\ldots$ are individual capacitances.
- Capacitors connected in series have the same charges and when connected in parallel have the same voltage.
- Potential across capacitor remains same if the battery is connected but if it is disconnected then charge remains the same which is stored in capacitor.

Electrical Energy Stored in a Capacitor:

- The energy U stored in a capacitor of capacitance C, with charge Q and voltage V is $U = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$.
- The electric energy density (energy per unit volume) in a region with electric field is $\frac{1}{2}\varepsilon_o E^2$.
- Electric density is alternatively known as ***electrostatic pressure***.

Van De Graaff Generator:

- A Van de Graaff generator consists of a large spherical conducting shell (a few meters in diameter).
- There are two pulleys, one at ground level and one at the center of the shell. Both of them are wounded around by a long and narrow endless belt of insulating material.
- The motor drives the lower pulley which keeps moving this belt continuously.
- At ground level to the top, it continuously carries the positive charge and sprayed on to it by a brush. Then the positive charge is transferred by it to another conducting brush connected to the large shell.
- After the transferring of the positive charge is done, it spreads out uniformly on the outer surface. It can build the voltage difference of as much as 6 to 8 million volts.

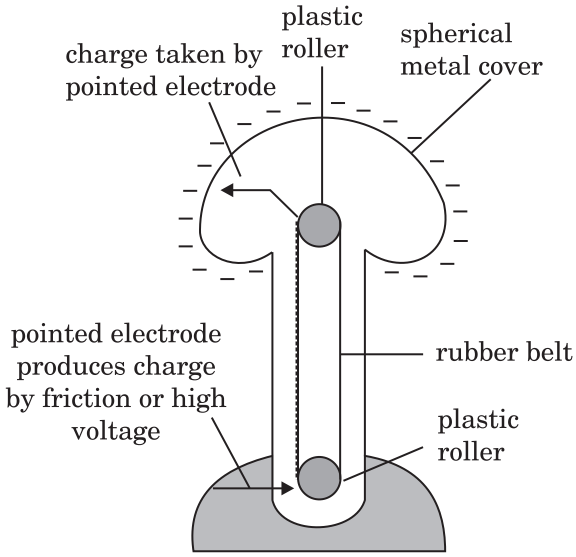


Fig. Yande Graff Generator

PREVIOUS YEARS'
EXAMINATION QUESTIONS
TOPIC 2

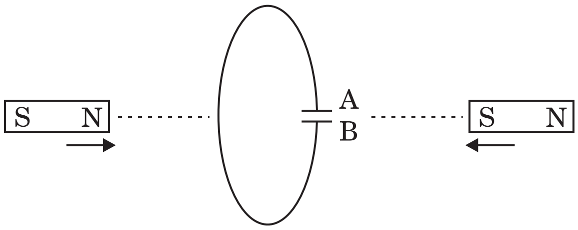
1 Mark Questions

1. Why should electrostatic field be zero inside a conductor?
[All INDIA 2012]

2. A capacitor has been charged by a dc source. What are the magnitudes of conduction and displacement current, when it is fully charged?
[All INDIA 2013]

3. Define dielectric constant of a medium. What is its S.I. unit?
[DELHI 2015]

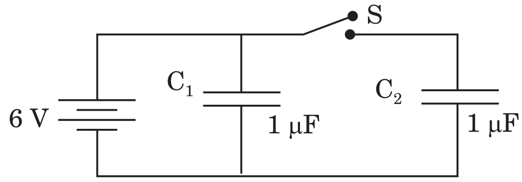
4. Predict the polarity of the capacitor in the situation described below:



[All INDIA 2017]

2 Mark Questions

5. Figure shows two identical capacitors, C_1 and C_2 each of $1\mu F$ capacitance connected to a battery of 6V. 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?



[DELHI 2011]

6. 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 $2\frac{d}{3}$, 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.
[DELHI 2011]

7. A capacitor of unknown capacitance is connected across a battery of V volts. The charge stored in it is 360 μC. When potential across the capacitor is reduced by 120 V, the charge stored in it becomes 120 μC.
Calculate:
(i) The potential V and the unknown capacitance C.
(ii) What will be the charge stored in the capacitor, if the voltage applied had increased by 120 V?
[DELHI 2011]

8. 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
[All INDIA 2014]

Topic 1: Electricity conduction, Ohm's law and resistance

Summary

Electric Current: Net charge flowing across a given area of conductor per unit time is defined as electric current.

$I = \frac{q}{t}$, S.I. unit of current is Ampere (A).

A steady current is generated in a closed circuit where electric charge moves from lower to higher potential. ***Electromotive force*** or ***emf*** is the work done by the source in taking the charge from higher to lower potential energy.

Drift velocity: The free electrons drift with some velocity towards the positive terminal when a potential difference is applied across the ends. The average velocity with which the electrons move is termed as drift velocity.

Drift velocity, $v_d = \frac{eE\tau}{m} = \frac{eV\tau}{ml}$

Where e = charge on electron

E = Electric field intensity

V = Potential difference across the ends of the conductor

τ = Relaxation time

m = Mass of electron

Relation between current and drift velocity: Current is directly proportional to the drift velocity.

$I \propto v_d$

When the number of electrons are less, current is less so the drift velocity is small.

When the number of electrons are large, high current flows so the drift velocity is large.

Ohm's law: The voltage across the ends of the conductor is directly proportional to the electric current flowing through the conductor.

$V \propto I$

Or V = IR, where R is the electrical resistance of the conductor

Resistance: The property that resists the flow of current through any conductor is called the resistance of the conductor.

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

It varies directly with the length of the conductor while depends inversely on the area of cross section of the conductor.

$R = \frac{\rho l}{A}$, ρ being the resistivity of the material of the conductor.

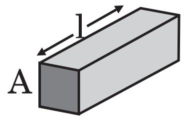


Fig.: Resistance in a conductor

Resistivity: It depends on the nature of the material and temperature. It is also termed as specific resistance.

$\rho = \frac{m}{ne^2\tau}$ gives the relation between resistivity and relaxation time.

There is an increasing order of resistivity as we go from metal to insulator.

$\rho_{metals} < \rho_{semiconductors} < \rho_{insulators}$

Conductivity and conductance: The reciprocal of resistivity is conductivity (σ).

$\sigma = \frac{1}{\rho}$ and its S.I. unit is $\Omega^{-1}m^{-1}$.

The reciprocal of resistance is the conductance of the conductor. Its S.I. unit is mho.

Current Density: The amount of charge flowing per unit area per second is called the current density.

$J = mqv_d$, where v_d is the drift velocity of the charge carriers, n is the number of charge carriers and q is the charge.

The relation between current density and conductivity is

$J = \sigma E$

Mobility: Mobility is the ratio of drift velocity to the applied electric field. Mobility is symbolized by μ .

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

Its S.I. unit is $m^2s^{-1}V^{-1}$.

Resistors: The objects which resist the flow of charge are called resistors which can be of two types, i.e. wire bound resistors and carbon resistors.

Resistors can combine in two different ways; either in series or in parallel.

- Consider n number of resistors connected in series, then the combined resistance will be as follows:

  $R_{eqv} = R_1 + R_2 + R_3 + ... + R_n$

Same amount of current will flow through each resistor connected in series while the potential difference would be different for every resistor.

- Consider n number of resistors connected in parallel, then the combined resistance will be as follows:

$$\frac{1}{R_{eqv}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... + \frac{1}{R_n}$$

The current flowing through each resistor would be different in this case while the potential difference would be same for all the resistors.

Internal resistance: It is the resistance on the current offered by the electrolyte and the electrodes. It is symbolize by r.

Let us assume a cell with 2 electrodes connected by an external resistance R. Then current is, $I = \frac{\varepsilon}{R + r}$

where ε = emf, r = Internal resistance

PREVIOUS YEARS' EXAMINATION QUESTIONS

TOPIC 1

1 Mark Questions

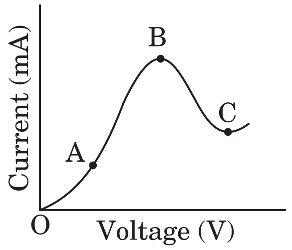
1. When electrons drift in a metal from lower to higher potential, does it mean that all the free electrons of the metal are moving in the same direction?

[ALL INDIA 2012]

2. Show on a graph, the variation of resistivity with temperature for a typical semiconductor.

[ALL INDIA 2012]

3. 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.



[ALL INDIA 2013]

4. Define the term 'Mobility' of charge carriers in a conductor. Write its S.I. unit.

[DELHI 2014]

5. Plot a graph showing variation of current versus voltage for the material Ge.

[DELHI 2014]

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

[DELHI 2014]

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

[DELHI 2014]

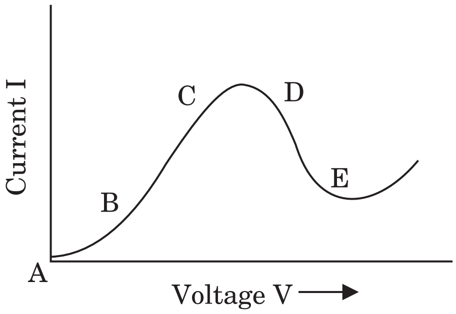
8. Show variation of resistivity of copper as a function of temperature in a graph.

[DELHI 2014]

9. Graph showing the variation of current versus voltage for a material GaAs is shown in the figure, Identify the region of:

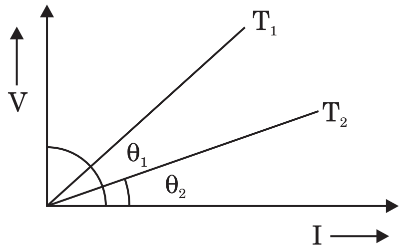
(i) Negative resistance

(ii) Where Ohm's law is obeyed



[DELHI 2015]

10. *V-I* graph for a metallic wire at two different temperature T_1 and T_2 is as shown in the figure. Which of the two temperatures is higher and why ?



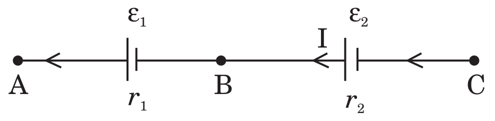
[ALL INDIA 2015]

Topic 2: Kirchhoff's Laws, cells and their combinations

Summary

Cells in series and in parallel

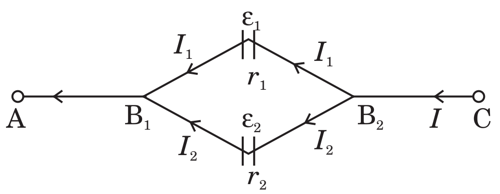
- The equivalent emf of a series combination of n cells is just the sum of their individual emfs
- The equivalent internal resistance of a series combination of n cells is the sum of their internal resistances.



$\varepsilon = \varepsilon_1 + \varepsilon_2$

- In a parallel connection,

$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \ldots\ldots + \frac{1}{r_n} \text{ and } \frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \ldots\ldots + \frac{\varepsilon_n}{r_n}$$



Kirchhoff's law:

- **Junction Rule:** The sum of currents entering a junction would be equal to the sum of currents leaving the junction.
- **Loop Rule:** The sum of changes in potential around any loop that is closed should be zero.

  Wheatstone bridge: It is an arrangement of four resistors in a way so that a galvanometer is placed between the two opposite arms.

  There is a null-point condition in the wheat stone bridge where current is zero which can be represented as follows:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

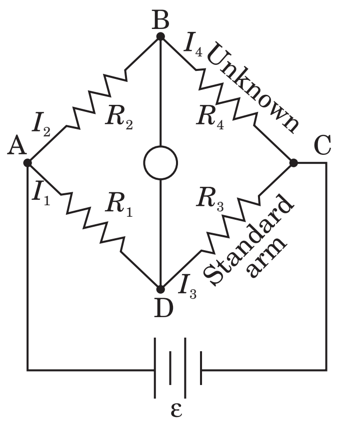


Fig.: Wheastone bridge

PREVIOUS YEARS'

EXAMINATION QUESTIONS

TOPIC 2

1 Mark Questions

1. A cell of emf E and internal distance r draws a current 'I'. Write the relation between terminal voltage 'V' in terms of E, I, r.

[DELHI 2013]

2. A heating element is marked 210 V, 630 W. What is the value of current drawn by the element when connected to a 210 V, dc source?

[DELHI 2013]

3. 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?

[ALL INDIA 2013]

2 Marks Questions

4. A cell of emf E and internal resistance r is connected to two external resistances R_1 and and R_2 a perfect ammeter. The current in the circuit is measured in four different situations:

   (i) without any external resistance in the circuit

   (ii) with resistance R_1 only

   (iii) with R_1 and R_2 in series combination

   (iv) with R_1 and R_2 in parallel combination

Topic 3: Electrical devices

Summary

Meter Bridge: Meter Bridge is the simplest form of the Wheatstone bridge which is used for accurate comparison of resistances.

In order to find out an unknown resistance R with the help of a standard known resistance S:

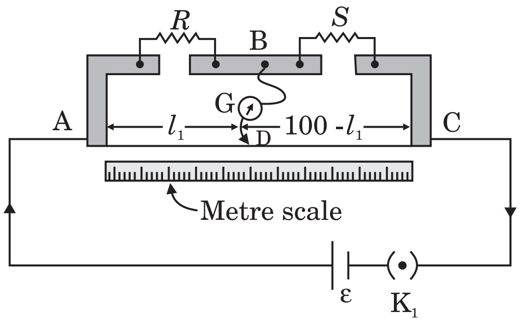


Fig.: Meter bridge

$R = S\frac{l_1}{100 - l_1}$, l_1 being the distance of the jockey from end A at the balance point.

Potentiometer: It is a device which is used to compare potential differences and emf'"s. It also measures the internal resistance of a cell.

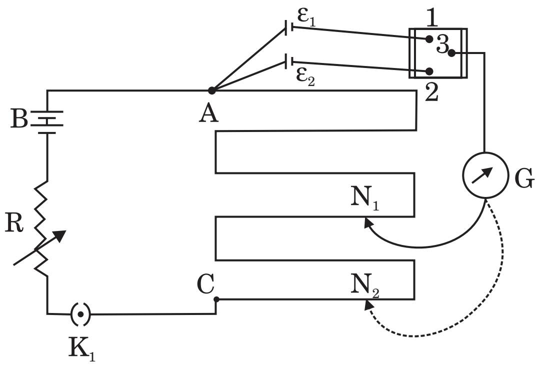


Fig.: Potentiometer

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$$

Potentiometer does not draw any current from the voltage source being measured. The internal resistance of a given cell can be measured by:

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

PREVIOUS YEARS'

EXAMINATION QUESTIONS

TOPIC 3

1 Mark Questions

1. 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*.

[ALL INDIA 2011]

2 Marks Questions

2. Use Kirchhoff's rules to obtain conditions for the balance condition in a Wheatstone bridge.

[DELHI 2015]

3. Describe briefly, with the help of a circuit diagram, how a potentiometer is used to determine the internal resistance of a cell.

[ALL INDIA 2013]

4. Two electric bulbs P and Q have their resistances in the ratio of 1:2. They are connected in series across a battery. Find the ratio of the power dissipation in these bulbs.

[DELHI 2018]

5. In a potentiometer arrangement for determining the emf of a cell, the balance point of the cell in open circuit is 350cm.When a resistance of 9Ω is used in the external circuit of the cell, the balance point shifts to 300 cm. Determine the internal resistance of the cell.

[ALL INDIA 2018]

3 Marks Questions

6. A potentiometer wire of length 1.0 m has a resistance of 15 Ω. It is connected. o a 5V battery in series with a resistance of 5 Ω. Determine the emf of the primary cell which gives a balance point at 60 cm.

[DELHI 2016]

[Topic 1] Magnetic Field Laws and their Applications

Summary

- The Oersted's law states that an electric current creates a magnetic field.
- The Biot Savart's law states that, the magnitude of magnetic field dB is proportional to the current I, the element length dl and inversely proportional to the square of the distance r. Its direction is perpendicular to the plane containing dl and r. Thus in vector notation, $dB \propto \frac{Idl \times r}{r^3}$, where $\frac{\mu_0}{4\pi}$ is the constant of proportionality and is equal to 10^{-7} Tm/A.

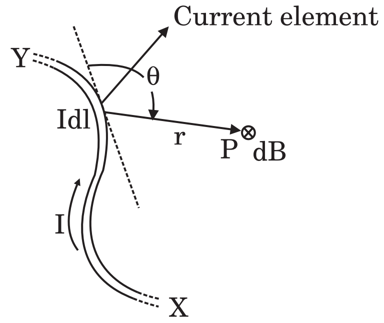


Fig.: Biot Savart's law

Applications of Biot-Savart's Law:

- Magnetic field at a point in circular loop will be $B = \frac{\mu_0 IR^2}{2\left(R^2 + x^2\right)^{\frac{3}{2}}}$

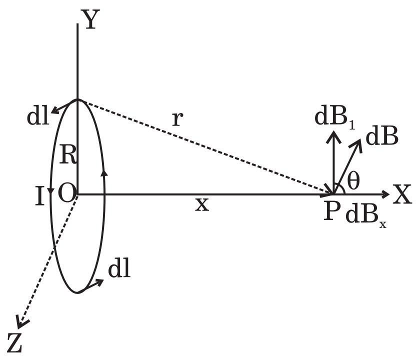


Fig.: Magnetic field at a point in circular loop

- Magnetic field at centre of the coil is $B = \frac{\mu_0 Ni}{2R} \quad (x = 0)$
- Magnetic field due to current carrying circular arc with centre O is $B = \frac{\mu_0 i}{4r}$
- If we curl the palm of our right hand around the circular wire with the fingers pointing in the direction of the current, the right hand thumb rule gives the direction of the magnetic field.
- ***Ampere's circuital law:*** The line integral of the magnetic field around some closed loop is equal to the times the algebraic sum of the currents which pass through the circular loop. For some circuital loop, C, $\oint_C B.dl = \mu_0 I$

Applications of Ampere's Law

Magnetic field due to current carrying solenoid, B = $\mu_0 nI$

At the end of a short solenoid, $B = \frac{\mu_0 nI}{2}$

- The magnetic force produced by a Solenoid as stated by Ampere's law is given as F = $\mu_0 nI$, where n is the number of turns of the wire per unit length, I is the current flowing through the wire and the direction is given using the right hand thumb rule.
- Due to a toroid a magnetic field is given as, $B = \frac{\mu_0 NI}{2\pi r}$ where 'N' is the number of turns of the toroid coil, I is the amount of current flowing and r is the radius of the toroid.
- Antiparallel currents repel and parallel currents attract.
- Magnetic moment on a rectangular current loop in a uniform magnetic field, m = NIA where m is the magnetic moment and N is the number of closely wounded turns and A is the area vector.

Topic 2: Lorentz Force and Cyclotron

Summary

- The electric field, E produced by the source of the field Q, is given as $E = \frac{Q\hat{r}}{(4\pi \epsilon_0) r^2}$, where $\hat{r}$ is the unit vector and the field E is a vector field. A charge 'q' interacts with this field and experiences a force F, expressed as

  $$F = qE = \frac{qQ\hat{r}}{(4\pi \epsilon_0) r^2}$$

- In the presence of both electric field E(r) and magnetic field B(r) there is a point charge q (moving with a velocity v and located at 'r' at a given time t). The force on an electric charge 'q' due to both of them is written as

  $F = q[E(r) + v \times B(r)] = F_{electric} + F_{magnetic}$. This force is called the Lorentz force.

- We can calculate the Lorentz force for a straight rod, if B is the external magnetic field by considering the straight rod as a collection of linear strips dl_j, where l is the length of the rod, j is the current density. Hence, the force can be calculated as $F = \sum_j I dl_j \times B$.

Cyclotron:

- It consists of two D's which are placed in a strong magnetic field. An oscillating electric field is applied from the oscillator which is parallel to the magnetic field.

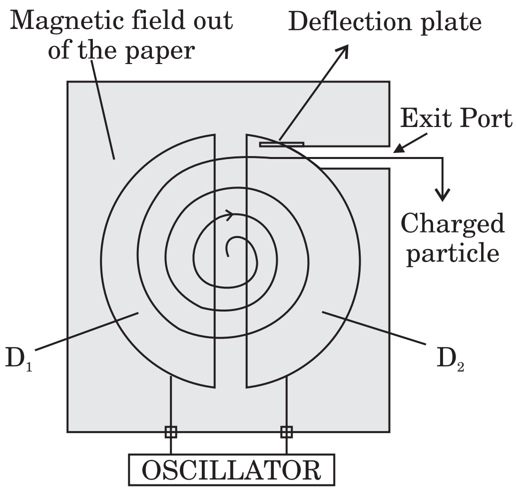


Fig.: Cyclotron

- The charged particle gets accelerated and moves in a circular path whose radius is given by $r = \frac{mv}{q_0 B}$
- The frequency of the cyclotron is given by $v = \frac{1}{T} = \frac{Bq}{2\pi m}$
- A charge of any type in uniform circular motion would have an associated magnetic moment given by $\mu_L = \frac{-e}{2m_e} l$, where l is the magnitude of angular momentum of electron. $\frac{\mu_L}{l} = \frac{e}{2m_e} = 8.8 \times 10^{10} C/kg.$, and this ratio is called Gyro magnetic ratio.

Topic 3: Magnetic Force and Torque between Two Parallel Currents

Summary

Force on a current-carrying conductor in a uniform magnetic field:

- The force on a current carrying conductor of length l in a uniform magnetic field B when θ is the angle between current and magnetic field can be calculated by F = IBℓ sin θ
- Fleming's Left-Hand Rule is used to find the direction of the magnetic force which is right angled to the plane containing conductor and magnetic field.

Force between two parallel current-carrying conductors:

Two parallel conductors carrying current experiences a force. When current flows in same direction, wire B experiences magnetic field due to wire A which is: $B_1 = \frac{\mu_0 I I_1}{2\pi d}$

Force per unit length in the given wire is

$$\frac{F_2}{l} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

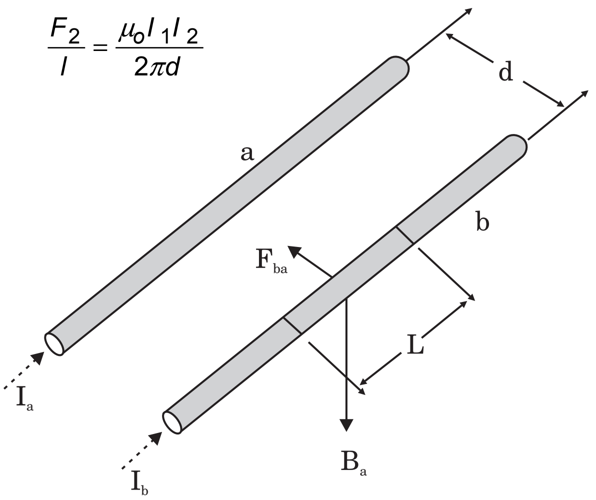


Fig.: Force between two parallel currents carrying conductores.

Torque experienced by a current loop in uniform magnetic field:

The torque experienced by a rectangular loop in uniform magnetic field B of length l, breadth b with current I lowing through it is:

τ = nBIAsinθ

Moving coil galvanometer

- Its main use is to detect and measure small electric currents.
- The current carrying coil is suspended in a uniform magnetic field, so it produces a torque which is responsible for rotating the coil.

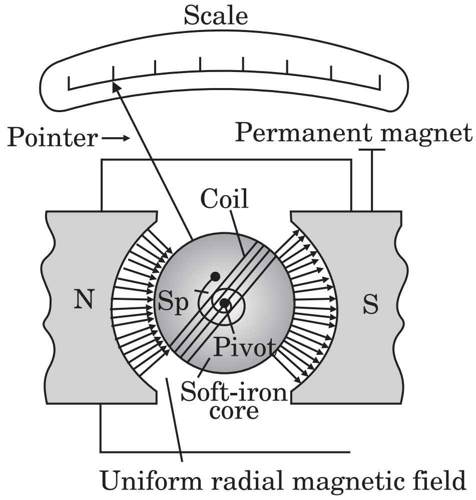


Fig.: Moving coil galvanometer

- The torque is given by τ = F × b = nBIl × b = BInA sinθ

Current sensitivity of galvanometer

- When a galvanometer produces a large deflection for a small amount of current, it is said to be sensitive.
- The voltage sensitivity of galvanometer is deflection per unit voltage and is given as $\frac{\theta}{I} = \frac{nBA}{C}$

Conversion of galvanometer into ammeter

A small resistance called a Shunt resistance is attached with the galvanometer coil in parallel so that most of the current passes through the shunt resistance.

Conversion of galvanometer into voltmeter

A high resistance is connected in series with the galvanometer coil so that the galvanometer acts as a voltmeter.

[Topic 1] Magnetic Dipole and Magnetic Field Lines

Summary

Magnetism:

- Magnetic phenomena are universal in nature. Magnetism is a physical phenomenon produced by the motion of electric charge, which results in attractive and repulsive forces between objects.
- The magnetic field of the Earth points from geographical south to the north.
- A bar magnet always points in the north-south direction when suspended freely.
- When same poles of two magnets are brought close to each other, a repulsive force is experienced. When Opposite poles of two magnets are brought close, then an attractive force is experienced.

Bar Magnet:

Iron fillings sprinkled on a glass plate kept over a short bar magnet arrange themselves in a pattern. It shows that the magnet has two poles in the same way as the positive and negative charge of an electric dipole called as the North and the South pole.

Magnetic field lines: The magnetic field lines of a bar magnet form continuous closed loops. The direction of net magnetic field at any point is determined by the tangent to the field line at that point. The magnitude of the magnetic field will be stronger for the area from which more number of field lines are passing. The magnetic field lines never intersect each other.

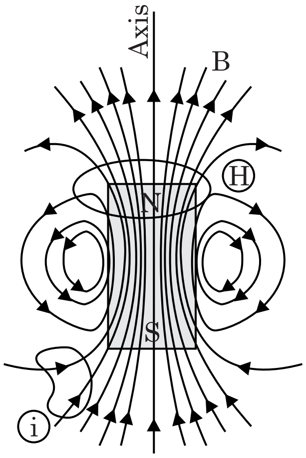


Fig: Magnetic field lines in a bar magnet

- Bar magnet as an equivalent solenoid: The magnetic field B due to bar magnet of size l and magnetic moment m which is at a distance r from the mid-point when r >> l, is given by

$$B = \frac{\mu_0 2m}{4\pi r^3} \quad \text{(Along axis)}$$

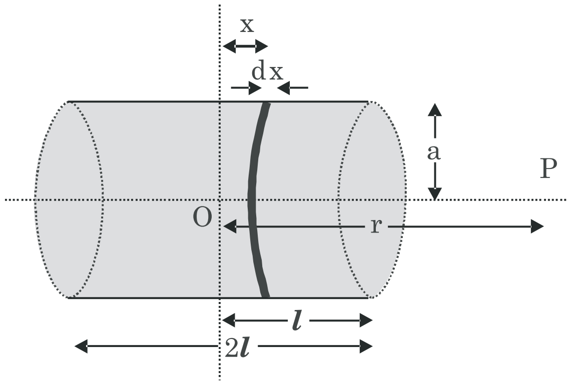


Fig: Bar magnet as an equivalent solenoid

- Dipole in a uniform magnetic field: When a bar magnet is having a dipole moment m and it is placed in uniform magnetic field B,

  The force acting on it is equal to 0.

  The torque acting on the magnet is m × B

  It has a potential energy of –m.B

Gauss's law for magnetic fields:

It states that the magnetic flux through any closed loop is equal to zero.

$$\phi_B = \sum_{all} \Delta\phi_B = \sum_{all} B.\Delta S = 0$$

[Topic 2] Earth's Magnetism and Magnetic Properties of Material

SUMMARY

Earth's Magnetism:

- The earth's magnetism is of the order of 10^{-5} T. Its strength is different at different place. The pole near to geographic north pole is called the north magnetic pole and the pole near to geographic south pole is called south magnetic pole. The magnetic of the field on the earth's surface is 4×10^{-5} T.
- There are three elements of the earth's magnetic field which are used to specify the magnetic field of earth's surface – the horizontal component, the magnetic declination and the magnetic dip.
- The magnetic field of a bar magnet tilted 11° from the spin axis of Earth is in the same direction as the Earth's magnetic field.

Magnetization and magnetic field:

- The magnetization M is equal to its magnetic moment per unit volume

$$M = \frac{m_{net}}{V}$$

- The magnetic intensity H is defined as the amount of magnetic flux in a unit area perpendicular to the direction of magnetic fow.

$$H = \frac{B_0}{\mu_0}$$

- The magnetic field B in the material is given by, $B = \mu_0(H + M)$
- The degree of magnetization of a material in response to an applied magnetic field is denoted as magnetic susceptibility. It is given by

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

So, $\mu = \mu_0\mu_r$

Where $\mu_r = 1 + \chi$

Magnetic properties of materials:

Magnetic Materials are broadly classified as paramagnetic, diamagnetic and ferromagnetic materials. For paramagnetic materials χ is positive and is small, for diamagnetic materials χ is negative and lies between 0 and -1 and for ferromagnetic materials χ is positive and large.

Property	*Ferromagnetic*	*Diamagnetic*	*Paramagnetic*
Effect of magnets	*They are strongly attracted by magnets.*	*They are feebly repelled by magnets.*	*They are feebly attracted by magnets.*
Susceptibility value χ_m	*Large and positive* $\chi_m > 1000$	*Small and negative*	*Small and positive*
Permeability value	$\mu >> \mu_0$	$\mu < \mu_0$	$\mu < \mu_0$
In a uniform magnetic field	*Freely suspended rod aligns itself parallel to the field.*	*Freely suspended rod aligns itself perpendicular to the field.*	*Freely suspended rod aligns itself parallel to the field.*
Relative permeability value	*It is greater than 1000.*	*Slightly less than 1.*	*Slightly greater than 1.*
Effect of temperature	*Susceptibility decreases with temperature.*	*Susceptibility is independent of temperature.*	*Susceptibility varies inversely with temperature.*
Physical state of the material	*Solids only.*	*Solid, liquid or gas.*	*Solid, liquid or gas.*
Hysteresis effect	*Shows hysteresis*	*Does not show hysteresis.*	*Does not show hysteresis.*
Removal of magnetic field	*Magnetization retain even on removal of magnetic field.*	*Magnetization is only for the time magnetic field is applied.*	*Magnetization is only for the time magnetic field is applied.*
Examples	*Fe, Ni, Gd, Co*	*Bi, Si, Cu, Pb*	*Al, Ca, Na*

Ferromagnetic materials show the property of hysteresis.

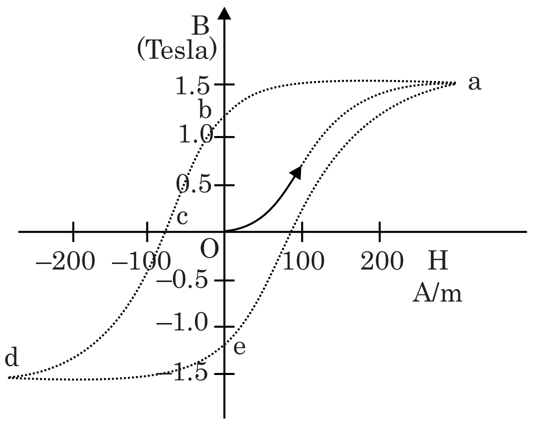


Fig: Magnetic hysteresis loop

The magnetic hysteresis loop is the B-H curve for ferromagnetic materials

Curie's law:

The intensity of magnetization I of a paramagnetic material varies directly to the strength of the external magnetic field H, called magnetizing field and is inversely proportional to absolute temperature of the material.

$\chi = \frac{C}{T}$ where C is Curie constant.

Permanent magnets:

- Permanent magnets are those substances which at room temperature retain their ferromagnetic property.
- An iron rod held in north-south direction and if it is hammered repeatedly it will become a permanent magnet.
- It can also be made by placing a ferromagnetic rod in a solenoid and passing current through it. The rod gets magnetized by the magnetic field of the solenoid.
- A material having high permeability, high coercivity, and high retentivity could be suitable for permanent magnets.

Electromagnets:

- A solenoid having a core of iron with wire wrapped around it is called an electromagnet.
- Ferromagnetic materials are used for core of electromagnets.
- Some of the applications of electromagnets are loudspeakers, electric bells, telephone diaphragms.

PREVIOUS YEARS'

EXAMINATION QUESTIONS

TOPIC 2

1 Mark Questions

1. The permeability of a magnetic material is 0.9983. Name the type of magnetic materials it represents.

[DELHI 2011]

2. The horizontal component of earth's magnetic field at a place is *B* and the angle of dip is 60°. What is the value of vertical component of the earth's magnetic field at equator?

[DELHI 2012]

3. What are permanent magnets? Give one example.

[DELHI 2013]

4. Which of the following substances are diamagnetic?
Bi, Al, Na, Cu, Ca and *Ni*

[DELHI 2013]

5. Which of the following substances are paramagnetic?
Bi, Al, Cu, Ca, Pb, Ni

[DELHI 2013]

2 Mark Questions

6. A magnetic needle free to rotate in a vertical plane parallel to the magnetic meridian has its north tip down in 60° with the horizontal. The horizontal component of the earth's magnetic field at the place is known to be 0.4 *G*. Determine the magnitude of the earth's magnetic field at the place.

[DELHI 2011]

7. The susceptibility of a magnetic material is -2.6×10^{-5}. Identify the type of magnetic material and state its two properties.

[DELHI 2013]

8. Show diagrammatically the behaviour of magnetic field lines in the presence of (i) paramagnetic and (ii) diamagnetic substances. How does one explain this distinguishing feature? **[DELHI 2014]**

[Topic 1] Electromagnetic Induction Laws

Summary

- Electromagnetic Induction is the one in which by which electric current is generated with the help of a magnetic field.
- ***The Experiments of Faraday and Henry***

  The observations from the experiments of Faraday and Henry concluded that it is the relative motion between the magnet and the coil that is responsible for generation or induction of the electric current in the coil.
- ***Magnetic Flux***

  It is the amount of field lines cutting through a surface area A defined by unit area vector. The magnetic flux that passes through a plane of area A and has a uniform magnetic field B, is given by, $\phi_B = B.A = BA\cos\theta$ where θ is the angle between magnetic field B and Area A. Magnetic flux is a scalar quantity and its SI unit is weber.

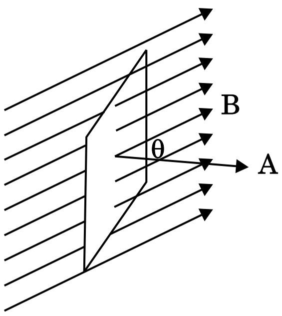


Fig. Field lines in a magnetic field

Faraday's Law of Induction

- Faraday's First Law: Whenever a conductor is placed in a varying magnetic field, there is an induced emf and if the conductor circuit is closed, there is an induced current.
- Faraday's Second Law: This law of electromagnetic induction states that the magnitude of the induced emf in a circuit is equal to the time rate of change of magnetic flux through the circuit. Mathematically, the induced emf is given by $\varepsilon = \frac{-d\phi_B}{dt}$, the negative sign indicates direction of the induced emf and hence the direction in a closed loop.

Lenz's law and Conservation of Energy

The Lenz's law states that the polarity of induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produced it.

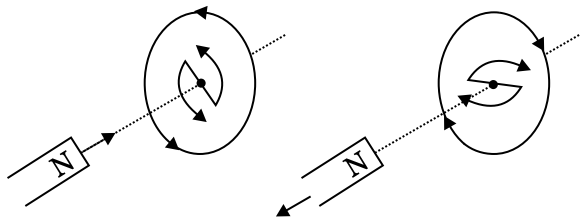


Fig. Lenz's law

Motional Electromotive Force

The relationship between induced emf and a wire moving at a constant speed v is given by $\varepsilon = Blv$

Energy Consideration: A Quantitative Study

- 'r' is the resistance of the movable arm PQ of the rectangular conductor. Assume that remaining arms QR, RS, SP have negligible resistance compared to r. In the presence of magnetic field there will be a force on the arm AB. This force I(l × B) is outwards directed in a direction opposite to the velocity of rod.
- Magnitude of force is $F = IlB = \frac{B^2l^2v}{r}$.
- Magnitude to push arm PQ $= Fv = \frac{B^2l^2v^2}{r}$

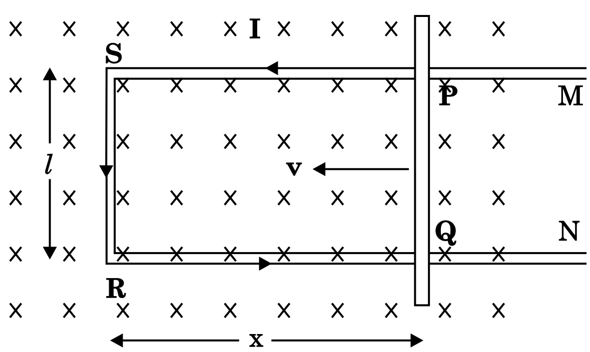


Fig. Energy Consideration in a Magnetic field

[Topic 2] Eddy currents, self and mutual inductance

Summary

Eddy Currents

- When bulk pieces of conductors are subjected to changing magnetic flux then induced currents are produced in them which are called as eddy currents.
- Eddy currents create a significant drag known as magnetic damping.
- The applications of eddy currents are in magnetic braking in trains, electromagnetic damping, electric power meters and induction furnace.

Inductance

- Flux change produced by another coil in the close proximity of a coil or flux exchange produced by the same coil induces electric current.
- The inductance in series is given by $L_s = L_1 + L_2 + L_3 + ...$
- The inductance in parallel is given by $\frac{1}{L_p} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + ...$

Mutual- Inductance

- When the emf is induced into the adjacent coil situated within the same magnetic field, the emf is said to be induced magnetically or by mutual induction.
- Mutual inductance of a pair of coils, solenoids etc. depends on their relative orientation as well as their separation.

  $$\varepsilon_1 = -M \frac{dI_2}{dt}$$

- Mutual Inductance of two coils is given by $M = \frac{\mu_0 \mu_r N_p N_s A_s}{l_p}$ where A_p, A_s are the cross sectional areas of primary and secondary coil in m^2, I is the coil current and N_s, N_p are the number of turns of secondary and primary coils respectively.

Self – Inductance

- The production of induced emf in a circuit when the current changes in the same circuit is called self-induction.
- The induced emf is given by $\varepsilon = -L \frac{dI}{dt}$, where is the coefficient of self-induction.
- The direction of induced emf is given by Lenz's Law.

AC Generator

- The electromagnetic induction has its applications in an AC generator, where mechanical energy is converted to electrical energy.

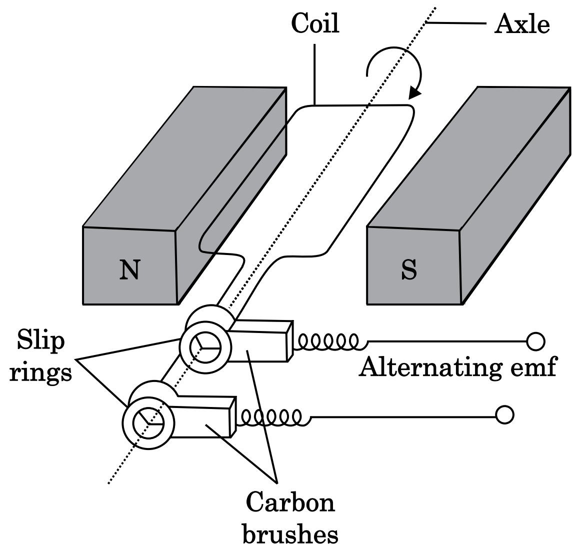


Fig. A.C. Generator

- The motional emf is of a coil with N turns and area A, rotated at v revolutions per second in a uniform magnetic field B is given as, $\varepsilon = -NBA \frac{d}{dt}(\cos \omega t)$

[Topic 1] Introduction to Alternating Current

Summary

Alternating Current

The electric main supply that varies like a sine function with time is called alternating voltage and the current drawn by it in the circuit is called Alternating current. Alternating current is the current which varies on two factors i.e. magnitude and the direction periodically and alternatively.

Mathematically alternating current can be expressed as:

$$I = I_0 \sin\omega t$$

Where I_0, is the peak value of alternating current.

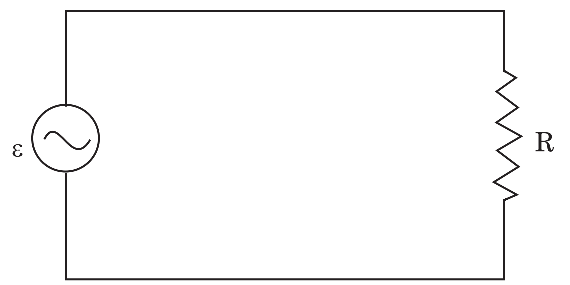


Fig.: Alternating Current in an electrical circuit.

RMS value of Alternating Current

The value of alternating current over a complete cycle which would generate same amount of heat in a given resistors that is generated by steady current in the same resistor and in the same time during a complete cycle.

$$I_{rms} = \frac{I_o}{\sqrt{2}} = 0.707 I_o$$

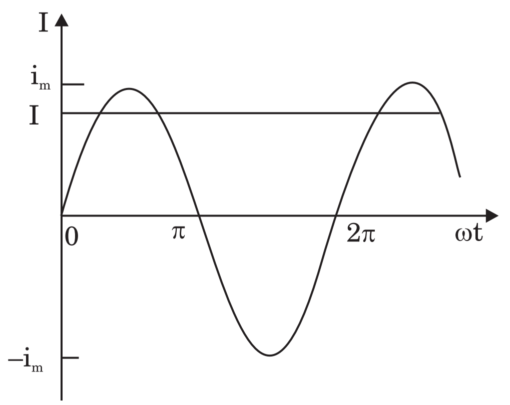


Fig.: Variation of Current with respect to wt.

Mean value of Alternating Current

The value of alternating current that would give same amount of charge in to a circuit at half cycle that is sent for steady current in the same duration.

$$I_{avg} = \frac{2I_o}{\pi} = 0.637 I_o$$

Alternating Voltage

Alternating voltage is the voltage which varies on two factors i.e. magnitude and the directions periodically and alternatively.

Alternating Voltage is expressed mathematically as,

$$V = V_o \sin\omega t$$

$$V_{rms} = \frac{V_o}{\sqrt{2}} = 0.707 V_o \text{ or } V_{rms} = 70.7\% \text{ of } V_o$$

$$V_{avg} = \frac{2V_o}{\pi} = 0.637 V_o \text{ or } V_{avg} = 63.7\% \text{ of } V_o$$

The alternating current and alternating voltage is illustrated in the following diagram:

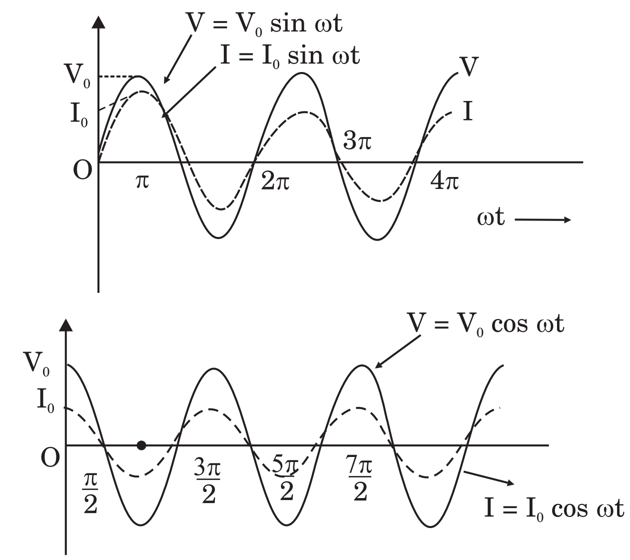


Fig.: Variation of V_0, I_0 w.r.t wt.

[Topic 2] AC Devices

Summary

Inductive Reactance (X_L)

When the current flows in the circuit, the inductor opposes its motion, this opposing nature of the inductor is termed as Inductive Reactance.

Mathematically it can be expressed as:

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

Where L is self-inductance.

Instantaneous power supplied to an inductor

$$p_l = -\frac{i_m v_m}{2} sin(2\omega t)$$

Average power supplied to an inductor over one complete cycle is zero.

In case of inductor, the current lags the voltage by $\frac{\pi}{2}$

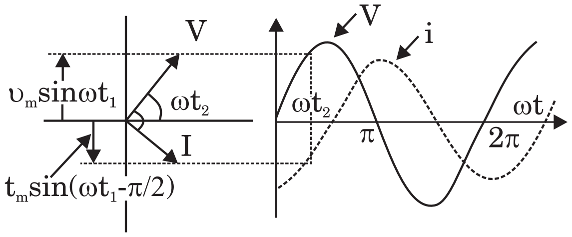


Fig.: Phasor Diagram of inductor

Inductive reactance can be graphically expressed as follows:

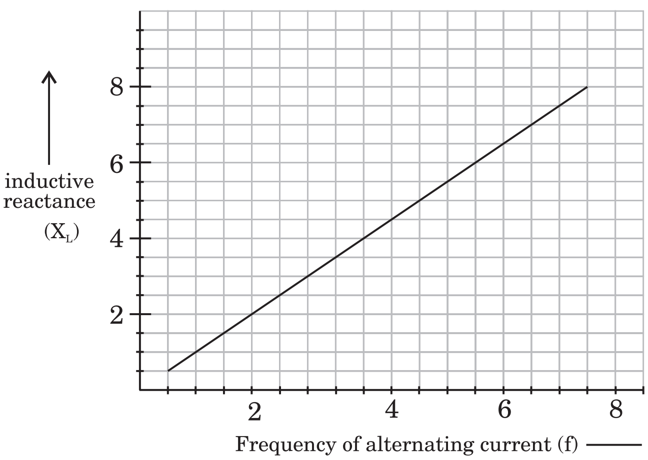


Fig.: Inductive Reactance Vs f

Capacitive Reactance (X_C)

When the current flows in the circuit, the capacitor opposes its motion, this opposing nature of the capacitor is termed as capacitive Reactance.

Mathematically it can be expressed as:

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

Where C is capacitance.

Instantaneous power supplied to the capacitor is

$$p_c = \frac{i_m v_m}{2} sin(2\omega t)$$

In case of capacitor, the current leads the voltage by $\frac{\pi}{2}$

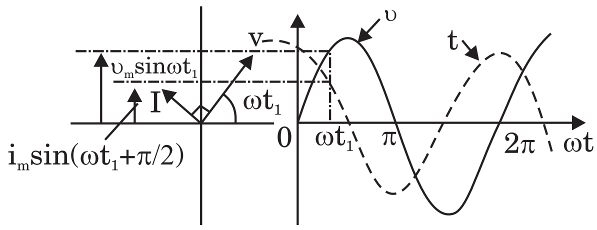


Fig.: Phasor Diagram of Capacitor

Capacitive reactance can be graphically expressed as follows:

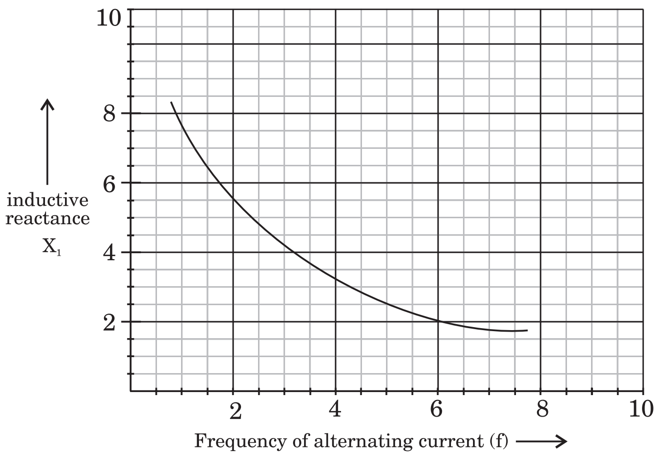


Fig.: Capacitive Reactance Vs f

- For a **series** LCR circuit driven by voltage $v = v_m \sin(\omega t)$, the current is given by

  $i = i_m \sin(\omega t + \phi)$.

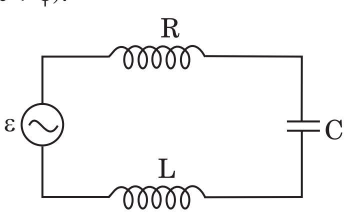


Fig.: LCR Circuit

Where $i_m = \dfrac{v_m}{\sqrt{R^2 + (X_c - X_L)^2}}$

And $\phi = tan^{-1}\dfrac{X_C - X_L}{R}$

$Z = \sqrt{R^2 + (X_C - X_L)^2}$ is called the impedance of the circuit.

Power

In an alternating circuit, the voltage and the current both keep on changing with respect to time. Hence the rate at which the electric energy is transferred in a circuit is called as it's power. The SI unit is Watt.

- Electric Power: The product of direct current flowing through a circuit and the voltage across the circuit.
  P = IV
- Instantaneous Power: The product of current and voltage as a function of time.
  $P_{inst} = E_{inst} \times I_{inst}$
- Average Power: Average of instantaneous power can be called as average power.
  Mathematically it is expressed as,
  $P_{avg} = V_{rms}I_{rms}\cos\Phi$
  where $\cos\Phi$ is power factor.
- Power factor: It is the ratio of true power to the apparent power.
- The phenomenon of ***resonance*** is an interesting characteristic of a series LCR circuit. The amplitude of the current is maximum at the resonant frequency and the circuit thus exhibits resonance, $\omega_0 = \dfrac{1}{\sqrt{LC}}$.
  The quality factor Q is defined by $Q = \dfrac{\omega_0 L}{R} = \dfrac{1}{\omega_0 CR}$ and it tells about the sharpness of the resonance.
- ***LC Oscillations:*** When an inductor is connected to an initially charged capacitor, the charge on the capacitor and the current in the circuit exhibit the phenomenon of electrical oscillations. When the circuit has no ac source and no resistor then the charge q of the capacitor is given by $\dfrac{d^2q}{dt^2} + \dfrac{1}{LC}q = 0$
  Where $\dfrac{1}{\sqrt{LC}} = \omega_0$ is the frequency of free oscillation.

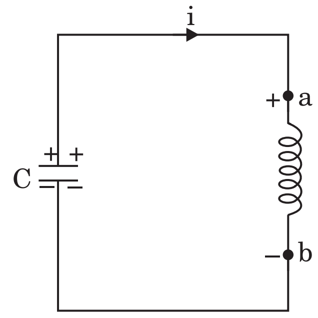


Fig.: LC Oscillalions

- ***Idle Current:*** If the average power consumed in an alternating current circuit is zero because of the current flowing through it, this current is called as Idle Current.
- Pure Inductor circuit and pure capacitor circuit are the two circuits whose average power consumed is zero as the phase difference is 90°.
- In generators and motors, the roles of input and output are reversed. In a motor, electric energy is the input and mechanical energy is the output. In a generator, mechanical energy is the input and electric energy is the output. Both devices simply transform energy from one form to another.

Transformer

- They convert an alternating voltage from one to another of greater or smaller value by using the principle of mutual induction.

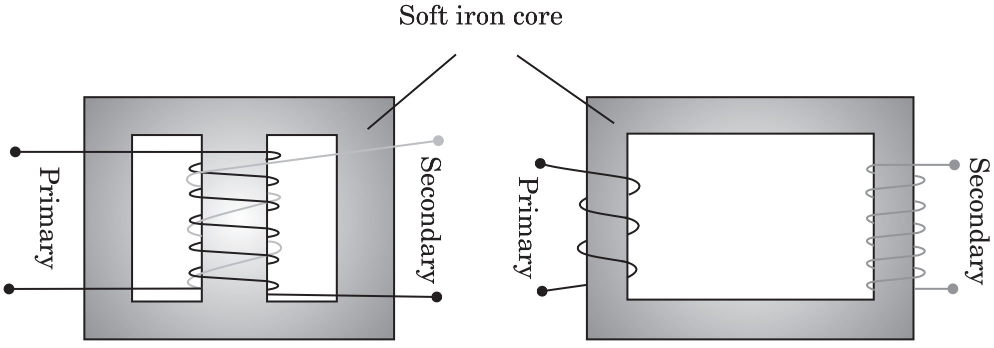


Fig.: Transformer Showing Primary & Secondary coils.

- A step-up transformer changes a low voltage in to high voltage.
- A step-down transformer changes high voltage to low voltage.
- The primary and secondary voltage and currents are given by

$$V_S = \left(\frac{N_S}{N_p}\right)V_p \quad \text{and} \quad I_s = \left(\frac{N_p}{N_s}\right)I_p$$

- Efficiency of the transformer is the ratio of the output power to the input power. It is usually   for a real one.

$$\eta = \frac{E_s I_s}{E_p I_p}$$

- ***Energy losses*** in transformers may be due to Flux leakage, resistance of windings, Eddy currents and Hysteresis.
- The choice of whether the description of an oscillatory motion is by means of sine or cosine or by their linear combinations is unimportant, since changing the zero-time position transforms one to the other.

PREVIOUS YEARS'
EXAMINATION QUESTIONS
TOPIC 2
5 Mark Questions

1. (i) With the help of a labelled diagram, describe briefly the underlying principle and working of a step up transformer.

(ii) Write any two sources of energy loss in a transformer.

(iii) A step up transformer converts a low input voltage into a high output voltage.

Does it violate law of conservation of energy? Explain.

2. (i) Write the function of a transformer. State its principle of working with the help of a diagram. Mention various energy losses in this device.

(ii) The primary coil of an ideal step up transformer has 100 turns and transformation ratio is also 100. The input voltage and power are respectively 220V and 1100 W Calculate:

(a) Number of turns in secondary.
(b) Current in primary.
(c) Voltage across secondary.
(d) Current in secondary.
(e) Power in secondary.

[CBSE 2016]

Solutions

1. (i) Principle underlying the working of transformer: The principle is of Mutual Inductance. When a changing source of voltage is introduced across a coil (which is physically coupled to another coil), the changing current through it induces an EMF across the second coil.

A transformer consists of two sets of coils, insulated from each other. They are wound on a soft-iron core, either one on top of the other, or on separate limbs of the core.

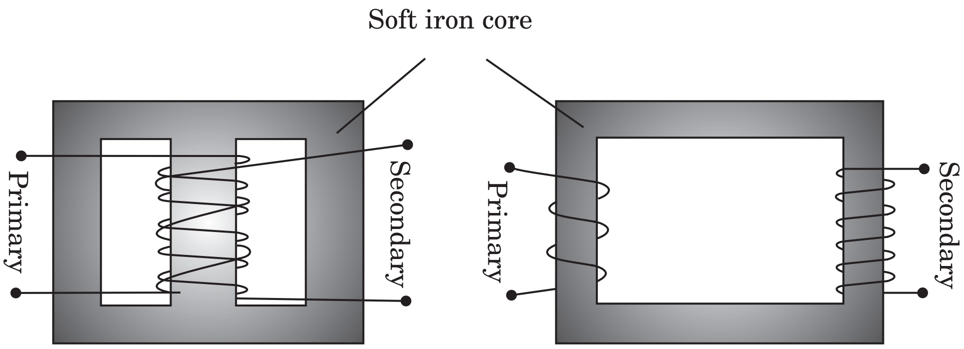


Fig.: Principle & Working of Transformer

[Topic 1] Electromagnetic Waves, its Types & Properties

Summary

Displacement Current

- It is defined as the rate of change of electric displacement.
- It is given by $I_d = \varepsilon_0 \frac{d\phi_\varepsilon}{dt}$ where ε_0 is the permittivity of the free space and ϕ_s is the amount of electric flux.

Properties of EM Waves

- The electric and magnetic fields E_x and B_y are always perpendicular to each other, and also to the direction z of propagation. E_x and B_y are given by:

$$E_x = E_0 \sin(kz\text{-}\omega t)$$

$$B_y = B_0 \sin(kz\text{-}\omega t)$$

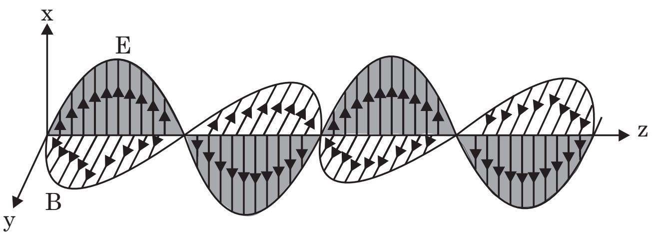


Fig. Electromagnetic Waves

Where,

"k" is the magnitude of the wave vector (or propagation vector) and can be calculated as;

$$k = \frac{2\pi}{\lambda}$$

- ω is the angular frequency,
- "k" is direction describes the direction of propagation of the wave. The speed of propagation of the wave is $\frac{\omega}{k}$.
- The frequency of EM waves can be from 0 to ∞.

  Ampere Circuital Law is given by: $\oint B \cdot dl = \mu_0 i(t)$

The four Maxwell's equations are given as:

- Gauss's law of electricity: $\oint E.dA = \frac{Q}{\varepsilon_0}$
- Gauss's law of magnetism: $\oint B.dA = 0$
- Faraday's law: $\oint E.dl = \frac{-d\phi_B}{dt}$
- Ampere-Maxwell law: $\oint B.dl = \mu_0 I_c + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$

An electric charge oscillating harmonically with a frequency, produces electromagnetic waves of the same frequency . The frequency of the electromagnetic wave naturally equals the frequency ofoscillation of the charge.

An electric dipole is a basic source of electromagnetic waves.

From Maxwell's equations it can be seen that the magnitude of the electric and the magnetic fields in an electromagnetic wave are related as $B_0 = \frac{E_0}{c}$

Properties of EM Waves

- Oscillations of electric and magnetic fields sustain in free space, or vacuum. So, the electromagnetic waves can travel in vacuum.
- An electromagnetic wave carries momentum and energy. Since an electromagnetic wave carries momentum, it also exerts pressure, called radiation pressure.
- Let the total energy transferred to a surface in time t is U, so the magnitude of the total momentum of an electromagnetic wave delivered to the surface (for complete absorption) is, $P = \frac{U}{c}$
- The energy of electromagnetic waves is shared equally by the electric and magnetic fields.

Types of EM Waves

- Radio waves are produced by the accelerated motion of charges in conducting wires. They are used in radio and television communication systems.The radio waves generally lie in the frequency range from 500 kHz to about 1000 MHz
- Microwaves have frequency in the range of gigahertz and are used in aircraft navigation.
- Infrared waves are also referred to as heat waves as they are produced by hot bodies and molecules.

- Visible rays can be detected by the human eye. They lie between frequency range of about 4×10^{14} Hz to about 7×10^{14} Hz or a wavelength range of about 700 –400 nm.
- Ultraviolet radiation or the UV radiation is produced by special lamps and very hot bodies.
- X-rays lie beyond the UV region and are used as a diagnostic tool in medicine and for treating various kinds of cancer.
- Gamma rays are emitted by radioactive nuclei and also are produced in nuclear reactions and are used in destroying the cancer cells.

The properties of different types of EM Waves are:

Type	***Wavelength range***	***Production***	***Detection***
Radio	*> 0.1 m*	*Rapid acceleration and decelerations of electrons in aerials*	*Receiver's aerials*
Microwave	*0.1 m to 1 mm*	*Klystron valve or magnetron valve*	*Point contact diodes*
Infra-red	*1 mm to 700 nm*	*Vibration of atoms and molecules*	*Thermopiles, Bolometer, Infrared photographic film*
Light	*700 nm to 400 nm*	*Electrons in atoms emit light when they move from one energy level to a lower energy level*	*The eye, Photocells, Photographic film*
Ultraviolet	*400 nm to 1 nm*	*Inner shell electrons in atoms moving from one energy level to a lower level*	*Photocells, Photographic film*
X-rays	*1 nm to 10^{-3} nm*	*X-ray tubes or inner shell electrons*	*Photographic film, Geiger tubes Ionisation chamber*
Gamma rays	*<10^{-3} nm*	*Radioactive decay of the nucleus*	*Photographic film, Geiger tubes Ionisation chamber*

PREVIOUS YEARS' EXAMINATION QUESTIONS

TOPIC 1

1 Mark Questions

1. A plane electromagnetic wave travels in vacuum along z-direction. What can you say about the direction of electric and magnetic field vectors?
[ALL INDIA 2011]
2. Name of physical quantity which remains same for microwaves of wavelength 1 mm and *UV* radiations of 1600 *A*° in vacuum.
[ALL INDIA 2012]
3. State De-Broglie hypothesis.
[ALL INDIA 2012]
4. Which of the following waves can be polarized (i) Heat waves (ii) Sound waves? Give reason to support your answer.
[ALL INDIA 2013]
5. Write the expression for the de Broglie wavelength associated with a charged particle having charge 'q' and mass 'm', when it is accelerated by a potential V.
[ALL INDIA 2013]
6. 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.
[ALL INDIA 2013]
7. Why are microwaves considered suitable for radar systems, used in aircraft navigation?
[DELHI 2016]
8. Write the following radiations in ascending order with respect to their frequencies: X-rays. Microwaves. *UV* rays and radio waves.
[DELHI 2017]
9. Do electromagnetic waves carry energy and momentum?
[DELHI 2017]

[Topic 1] Reflection, refraction and dispersion of light

Summary

The speed of light in vacuum is given by $c = 3 \times 10^8 ms^{-1}$, which is the highest speed that can be attained in nature.

A light wave travels along a straight line from one point to another. This path is called a ray of light, and bundle of such rays together form a beam of light.

Laws of reflection states that

- The angle of reflection (i.e., the angle between reflected ray and the normal to the reflecting surface or the mirror) equals the angle of incidence (angle between incident ray and the normal), i.e. $\angle i = \angle r$
- The incident ray, the normal to the mirror at the point of incidence and the reflected ray, they all lie in the same plane.

Snell's law for refraction is given by $\frac{\sin i}{\sin r} = n$, where the angle of incidence, angle of refraction and refractive index of the medium is given by i, r and n respectively.

The angle of incidence at which a ray travelling from a denser to rarer medium makes an angle of refraction of 90° is a ***critical angle*** and is denoted by i_c.

Cartesian sign convention:

- Positive sign is used for distances measured in the same direction as the incident light, whereas negative sign is used for those measured in the direction opposite to the direction of incident light.
- All distances are measured from the pole of the mirror or the optical centre of the lens. The heights measured upwards with respect to x-axis and normal to the principal axis of the mirror/lens is taken as positive.
- The heights measured downwards with respect to x-axis are taken as negative.

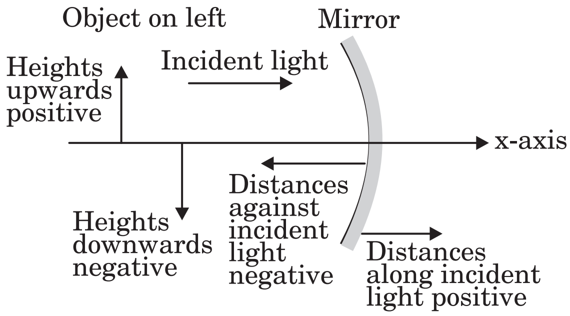


Fig.: Cartesian sign convention

If the distance of the object and the image is given by u and v, respectively and f is the focal length of the mirror. Then the ***mirror formula*** is given by,

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

Focal length f for a concave mirroris negative and is positive for a convex mirror.

The magnification produced by a mirror is given by $m = \frac{h'}{h} = -\frac{v}{u}$ where h′ is the height of the image and h is the height of the object.

Total Internal Reflection:

- When light travels from an optically denser medium to a rarer medium at the interface, it is partly reflected back into the same medium and partly refracted to the second medium. This reflection is called internal reflection when all light is reflected back, it is called total internal reflection.

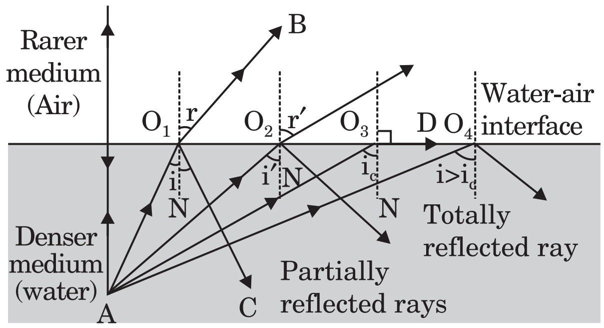


Fig.: Total Internal Reflection

- The applications of total internal reflection include mirage, diamond, prism and optical fibers.

Refraction through glass slab:

The emergent ray through a glass slab is parallel to the incident ray but it is laterally displaced.

Also, ∠Angle of incidence = ∠Angle of emergence

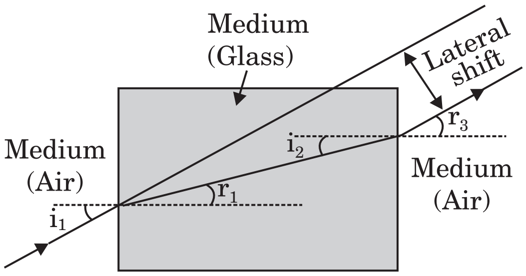


Fig.: Reflection through glass slab

Refraction at spherical surfaces

If the rays are incident from a medium of refractive index n_1 to another of refractive index n_2, then

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

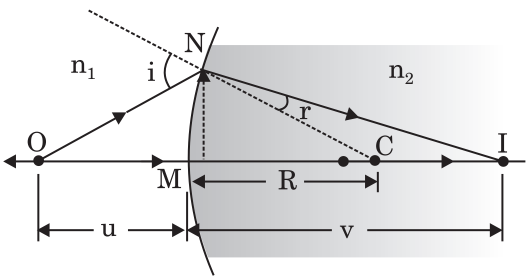


Fig.: Refraction at spherical surface

For a prism of the angle A, of refractive index n_2 placed in a medium of refractive index n_1 and D_m being the angle of minimum deviation.

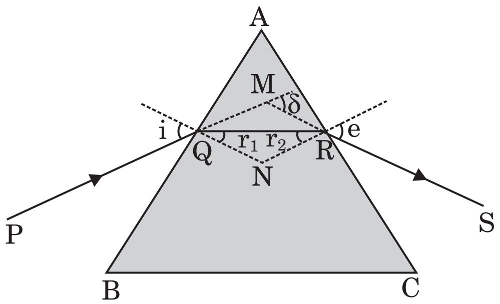


Fig.: Prism

$$n_{21} = \frac{n_2}{n_1} = \frac{\sin\left[(A + D_m)/2\right]}{\sin(A/2)}$$

- If the distance of the object and the image is given by u and v, respectively and f is the focal length of the lens. So, the ***lens formula*** is,

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

  Focal length f is positive for a converging lens and is negative for a diverging lens.
- The magnification produced by a mirror is given by $m = \frac{h'}{h} = \frac{v}{u}$ where h′ is the height of the image and h is the height of the object.
- The ***power*** (P) of a lens is given by, $P = \frac{1}{f}$.

  Where f is the focal length of the lens and the SI unit of power is dioptre (D): 1 D = 1 m^{-1}
- The effective focal length of a combination of thin lenses of focal length f_1, f_2, f_3 ..... is given by

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

  And the effective power of the same combination is given by

  $P = P_1 + P_2 + P_3$ ......

Dispersion:

- Splitting of light into its constituent colors is known as ***dispersion*** of light.
- When a white light is incident on a prism, the white light is split into seven components, violet, indigo, blue, green, yellow, orange and red (given by the acronym VIBGYOR)

Some natural phenomenon due to sunlight are rainbow and scattering of light.

The Eye: It has a convex lens of focal length about 2.5 cm. This focal length can be varied somewhat by the help of ciliary muscle so that the image is always formed on the retina. This ability of the eye of adjusting the muscle to form a clear image is called ***accommodation***.

In a defective eye, if the image is focused before the retina, it is called myopia. For correction of myopia, a diverging corrective lens is needed.

In a defective eye, if the image is focused beyond the retina, it is called hypermetropia. For correction of hypermetropia, a converging corrective lens is needed.

Astigmatism: A refractive error in which the vision is blurred at all distances, is corrected by using cylindrical lenses.

[Topic 2] Optical Instrument

Summary

Simple microscope

- A simple magnifier or microscope is a converging lens of small focal length.

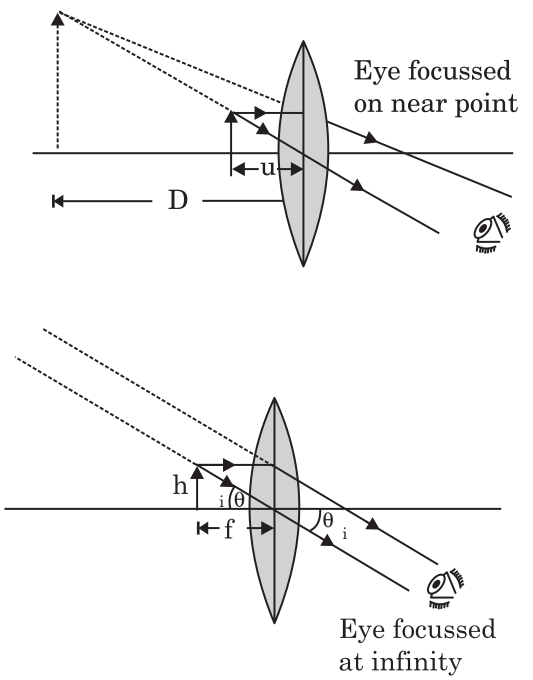


Fig.: Magnifier

- The magnifying power (m) is given by $m = 1 + \left(\frac{D}{f}\right)$, where D = 25 cm is the least distance of distinct vision and f is the focal length of the convex lens. If the image is at infinity, magnifying power (m) is given by, $m = \frac{D}{f}$.

- For a ***compound microscope***, the magnifying power m is given by m = $m_e \times m_0$ where, $m_e = 1 + \left(\frac{D}{f}\right)$ is the magnification due to the eyepiece and m_o is the magnification produced by the objective. Also, $m = \frac{L}{f_o} \times \frac{D}{f_e}$, where f_0 and f_e are the focal length of the objective and the eyepiece, respectively, and L is the distance between their focal points.

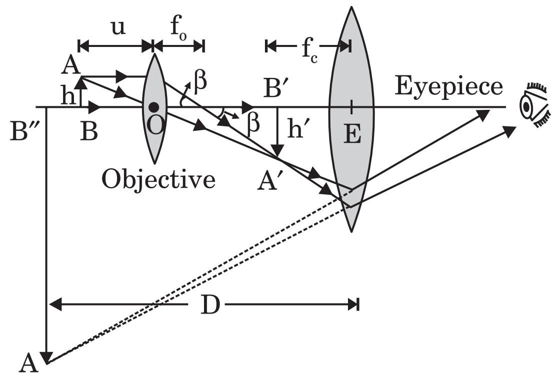


Fig.: Compound microscope

Telescope

- The telescope is used to provide angular magnification of distant objects. It also has an objective and an eyepiece
- Magnifying power (m) of a telescope is the ratio of the angle β subtended at the eye by the image to the angle α subtended at the eye by the object.

  $m = \frac{\beta}{\alpha} = \frac{f_o}{f_e}$, f_0 and f_e are the focal length of the objective and the eyepiece, respectively.

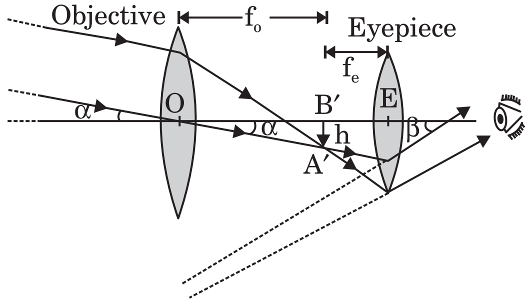


Fig.: Telescope

[Topic 1] Huygens Principle

Summary

- The effects which depend on wave nature of light are included under wave optics. Interference and diffraction of light shows that light behaves as wave and not as a stream of particles.
- ***Huygens principle:*** It states that each point of the wavefront is the source of a secondary disturbance. Also, the wavelets emanating from these points spread out in all directions with the speed of the wave which are referred to as secondary wavelets and if we draw a common tangent to all these spheres, a new position of the wavefront is obtained at a later time.
- When a wave gets refracted into a denser medium the wavelength and the speed of propagation decrease but the frequency remains the same.

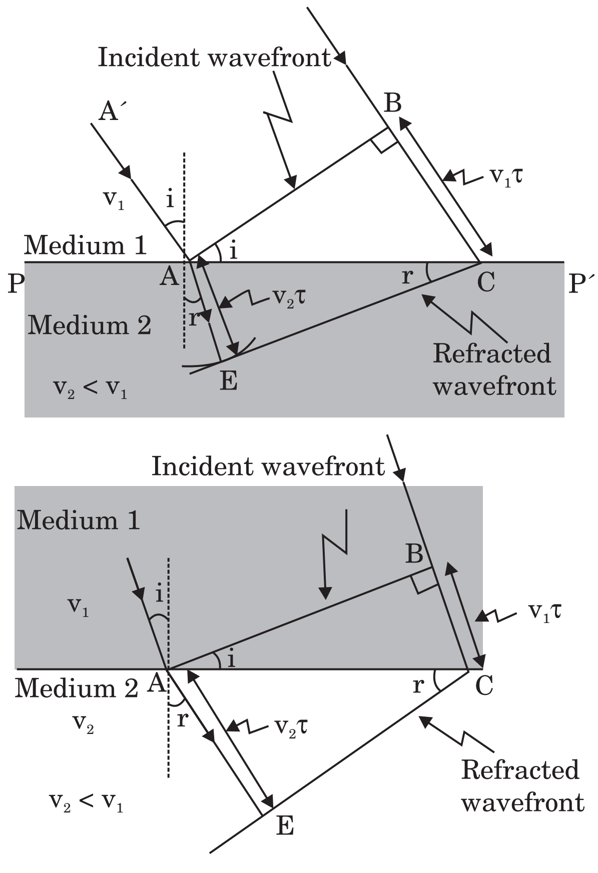


Fig.: Huggen's Principle

$n_1 \sin i = n_2 \sin r$ is the ***Snell's law*** of refraction.

- Doppler Effect is defined as the change in wavelength or frequency of a wave in relation to observer who is moving relative to the wave source. The Doppler shift is expressed as:

$$\frac{\Delta \nu}{\nu} = -\frac{\upsilon_{radial}}{c}$$

PREVIOUS YEARS' EXAMINATION QUESTIONS

TOPIC 1

1 Mark Questions

1. In a transistor, doping level in base is increased slightly. How will it affect
(1) Collector current and
(2) Base current? **[ALL INDIA 2011]**

2. What type of wave front will emerge from a (i) point source, and (ii) distant light source? **[DELHI 2017]**

2 Mark Questions

3. Define a wavefront. Using 'Huygens' principle, draw the shape of a refracted wavefront, when a plane wavefront is incident on a convex lens. **[ALL INDIA 2015]**

3 Mark Questions

4. Use Huygen's principle to verify the laws of refraction. **[ALL INDIA 2011]**

4 Mark Questions

5. Use huygen's principle to explain the formation of diffraction pattern due to a single slit illuminated by a monochromatic source of light. When the width of the slit is made double the original width, how would this affect the size and intensity of the central diffraction band? **[ALL INDIA 2012]**

5 Mark Questions

6. (a) Define wave front. Use Huygens' principle to verify the laws of refraction.
(b) How is linearly polarised light obtained by the process of scattering of light? Find the Brewster angle for air – glass interface, when the refractive index of glass = 1.5 **[ALL INDIA 2017]**

[Topic 2] Interference of Light

Summary

- ***Superposition principle*** states that at a particular point in the medium, the resultant displacement produced by a number of waves is the vector sum of the displacements produced by each of the waves.
- The resultant displacement at a point from two coherent sources will be equal to the sum of the individual displacement at that point.

  $y = 2a \cos \omega t$

  Resultant intensity is four times the intensity produced by each source.

  $I = 4I_0$ and $I_0 \propto a^2$
- ***Constructive interference:*** It is observed in cases when two coherent sources are vibrating in phase having path difference for a point P as $S_1P - S_2P = n\lambda\ (n = 0, 1, 2, ...)$ and resultant intensity is $4I_0$
- ***Destructive interference:*** It is observed in cases when two coherent sources are vibrating in phase having path difference for a point P as

  $$S_1P - S_2P = \left(n + \frac{1}{2}\right)\lambda \quad (n = 0, 1, 2, ...)$$ and

  resultant intensity is zero.
- ***Young's double slit*** of length d gives equally spaced fringes which are at angular separation $\frac{\lambda}{d}$. The midway-point of the slits, the central bright fringe and the source, all lie in a straight line. But this fringe gets destroyed by an extended source, if the angle subtended is more than $\frac{\lambda}{d}$ at the slits.

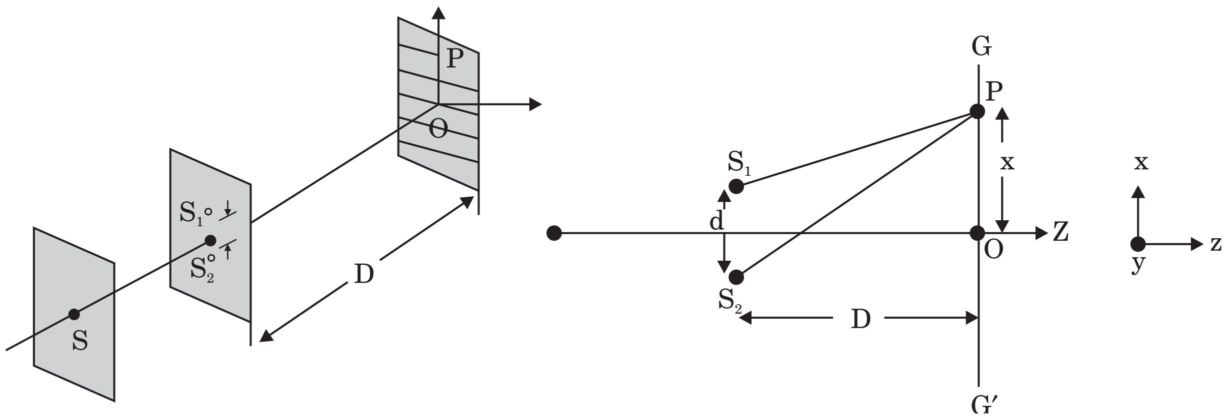


Fig.: Young's Double Slit Experiment

- Path difference, $y = \frac{n\lambda D}{d}$
- Fringe width: Distance between two consecutive bright and dark fringes represented by $\frac{\lambda D}{d}$

[Topic 3] Diffraction and Polarisation of Light

Summary

- ***Diffraction:*** Bending of light around corners of an obstacle into the region where shadow of obstacle is expected.

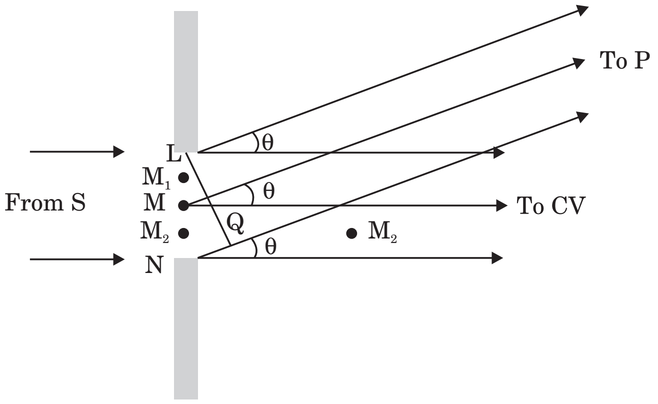


Fig.: Diffraction Phenomenon

- Light energy is redistributed in interference and diffraction. When it reduces in one region, emitting a dark fringe, it increases in another region, emitting a bright fringe. In this process the energy remains constant i.e. neither energy is gained nor lost, with the principle of conservation of light.
- The ***resolving power of the microscope*** is given by the reciprocal of the minimum separation of two points seen as distant. The resolving power can be increased by choosing a medium of higher refractive index.

$$d_{min} = \frac{1.22\lambda}{2 \sin \beta}$$

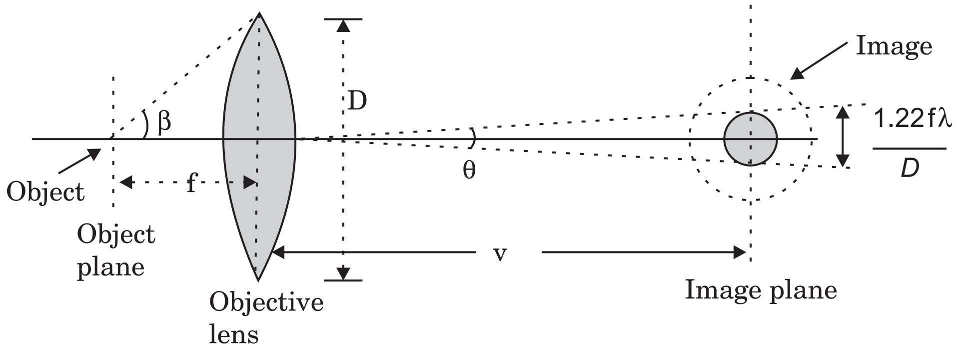


Fig.: Resolving power of the microscope

- ***Resolving power of telescope:*** For two stars to be just resolved,

$$f\,\Delta\theta \approx \frac{0.61\lambda f}{a}$$

So, $\Delta\theta \approx \frac{0.61\lambda}{a}$

Telescope will have better resolving power if a is large.

- A diffraction pattern with a central maximum is given by a single slit of width a. At angles of $\pm\frac{\lambda}{a}, \pm\frac{2\lambda}{a}$, etc., along with successively weaker secondary maxima in between, the intensity reduces to zero. The angular resolution of a telescope is limited to $\frac{\lambda}{D}$, due to diffraction where D is the diameter. Strongly overlapping images are formed when two stars are closer than this angle. Similarly, in a medium of refractive index n, a microscope objective subtending angle 2β at the focus, will just separate two objects spaced at a distance $\frac{\lambda}{(2n \sin\beta)}$, which is the resolution limit of a microscope.
- The ***Fresnel distance*** is given by the formula $Z_P = \frac{a^2}{\lambda}$, where a is the size of the aperture and λ is the wavelength.

- ***Polarized wave:*** A long string is held horizontally, the other end of which is assumed to be fixed. If the end of the string is moved up and down in a periodic manner, a wave propagating in the +x direction will be generated. Each point on the string moves on a straight line, the wave is also referred to as linearly polarised wave. The linearly polarized waves are transverse waves; i.e., the displacement of each point of the string is always at right angles to the direction of propagation of the wave.
- ***Unpolarized wave:*** When the plane of vibration of the string is changed randomly in very short intervals of time, then we have what is known as an unpolarised wave. Thus, for an unpolarised wave the displacement will be randomly changing with time though it will always be perpendicular to the direction of propagation.
- A ***Polaroid*** consists of long chain molecules aligned in a particular direction. The electric vectors along the direction of the aligned molecules get absorbed. Thus if an unpolarised light wave is incident on such a Polaroid then the light wave will get linearly polarized with the electric vector oscillating along a direction perpendicular to the aligned molecules; this direction is known as the pass-axis of the Polaroid.
- If I is the intensity of polarized light after passing through the first polariser P_1 then the intensity of the light after passing through the second polarizer P_2 will be I = Icosθ. This is called ***Malus' Law***.
- Natural light from the sun is unpolarised which means that the electric vector takes all possible random directions in the transverse plane. A polaroid transmits only one component of these vectors, which is parallel to a special axis. Therefore the light wave is called plane polarised. When this kind of light is viewed through another polaroid which is rotated through an angle 2π, we can see two maxima and minima of same intensity.
- Plane polarised light can also be producedby reflection at a special angle known as the Brewster angle and by scattering through $\frac{\pi}{2}$ in the earth's atmosphere.

PREVIOUS YEARS'
EXAMINATION QUESTIONS
TOPIC 3

1 Mark Questions

1. If the angle between the pass axis of polarizer and the analyser is 45°, write the ratio of the intensities of original light and the transmitted light after passing through the analyzer. **[DELHI 2017]**

2 Mark Questions

2. (a) When a wave is propagating from a rarer to a denser medium, which characteristic of the wave does not change and why ?
(b) What is the ratio of the velocity of the wave in the two media of refractive indices μ_1 and μ_2? **[ALL INDIA 2015]**

3. Unpolarised light is passed through a Polaroid P_1. When this polarized beam passes through another Polaroid P_2 which makes an angle θ with the pass axis of P_1, then write the expression for the polarized beam passing through P_2. Draw a plot showing the variation of intensity when θ varies from 0 to 2π. **[ALL INDIA 2017]**

3 Mark Questions

4. (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 a transparent medium, under what condition does the reflected light get polarized?

[ALL INDIA 2011]

4 Mark Questions

5. (a) What is linearly polarized light? Describe briefly using a diagram how sunlight is polarized.
(b) Unpolarized light is incident on a Polaroid. How would the intensity of would transmitted light change when the Polaroid is rotated? **[ALL INDIA 2013]**

6. What is an unpolarized light? Explain with the help of suitable ray diagram how an unpolarized light can be polarized by reflection from a transparent medium. Write the expression for Brewster angle in terms of the refractive index of the denser medium. **[DELHI 2018]**

[Topic 1] Photoelectric Effect

Summary

- ***Work Function:*** The minimum energy which is necessary for an electron to get away from the surface of metal is called the work function of the metal which is denoted by ϕ_0. The unit for measuring work function is electron volt (eV). This minimum energy can be provided by thermionic emission, field emission or photo-electric emission.

  Thermionic emission: When a metal is heated, thermal energy is imparted to free the electrons from the surface of the metal.

  Field emission: Electrons can be pulled out of metal by applying a very strong electric field (of the order of 108 Vm^{-1}) to it, as in a tesla coil.

  Photo-electric emission: Electrons are emitted when a light of suitable frequency hits a metal surface. This can be seen in a photodiode.
- 1eV is the energy attained by an electron when it has been accelerated by a potential difference of 1, so that 1eV = 1.602×10^{-19}J.
- ***Photoelectric Effect:*** When metals are irradiated by light of suitable frequency, electrons start emitting from the metal surface. This phenomenon is known as photoelectric effect.

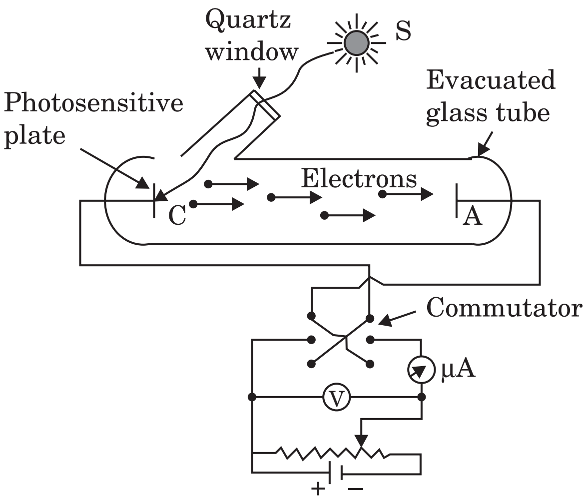


Fig.: Depiction of Photoelectric effect

- Some metals are sensible to ultraviolet light and some to visible light also. Photocurrent depends upon the intensity of light, frequency of incident light, potential difference between both the plates and the material of the plate.
- ***Stopping Potential:*** Stopping potential or cut-off potential is the minimum retarding (negative) potential for which the photoelectric current stops at a particular frequency of incident light. It is denoted by V_0.
- ***Saturation Current:*** At a certain potential difference, the photoelectric current stops increasing further. This maximum value of photocurrent is known as the saturation current.
- ***Maximum Kinetic Energy:*** The maximum kinetic energy of the photoelectric electrons is denoted by K_{max} and it depends directly on the frequency of the incident light. It is independent of the intensity of the light.

  The maximum kinetic energy $K_{max} = eV_0$
- ***Threshold Frequency:*** The minimum cut-off frequency which is required for the emission of electrons is called the threshold frequency which is denoted by ν_0. No emission is possible for the frequency lower than the cut-off frequency.
- In the photoelectric effect, the light energy is converted into the electrical energy. The photoelectric emission is a quick process having very less time lag.
- ***Effect of intensity of light on photocurrent:*** Number of photoelectrons emitted per second varies directly with the intensity of incident radiation.
- ***Effect of potential on photoelectric current:*** The stopping potential is independent of its intensity for a given frequency of the incident radiation.
- ***Effect of frequency of incident radiation on stopping potential:***

  The stopping potential V_0 varies linearly with the frequency of incident radiation for a given photosensitive material.

  There exists a certain minimum cut-off frequency v_0 for which the stopping potential is zero.
- ***Einstein's Photoelectric Equation:*** Einstein proposed that light is comprised of small discrete

energy packets known as photons or quanta and energy carried by each photon is hν, where ν is the frequency of light and Planck's constant. The momentum carried by each photon is $\frac{h}{\lambda}$. In photoelectric effect, emission is possible because of the absorption of a photon by an electron. The maximum kinetic energy of the emitted electron is:

$K_{max} = h\nu - \phi_0$, where ϕ_0 is the work function.

$= h(\nu - \nu_0)$

The photoelectric emission is possible only when $h\nu > \phi_0$ as K_{max} must be non-negative.

$\Rightarrow \nu > \nu_0$ where $\nu_0 = \frac{\phi_0}{h}$

- From the photoelectric equation,

  $eV_0 = h\nu - \phi_0$, for $\nu \geq \nu_0$ (as $K_{max} = eV_0$)

  or $V_0 = \left(\frac{h}{e}\right)\nu - \frac{\phi_0}{e}$

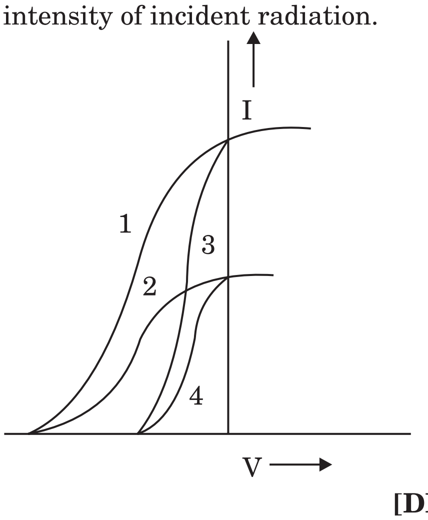
  According to this result, the graph of V_0 versus ν is a straight line having the slope equal to $\left(\frac{h}{e}\right)$.

PREVIOUS YEARS' EXAMINATION QUESTIONS

TOPIC 1

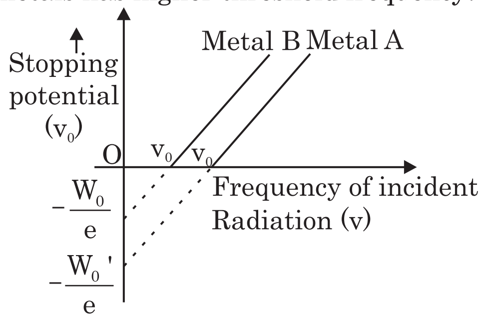
1 Mark Questions

1. The given graph shows the variation of photo-electric current (I) versus applied voltage (V) for two different photosensitive materials and for two different intensities of the incident radiations. Identify the pairs of curves that correspond to different materials but same intensity of incident radiation.



[DELHI 2013]

2. The graph shows variation of stopping potential versus frequency of incident radiation υ for two photosensitive metals A and B. Which of the two metals has higher threshold frequency?

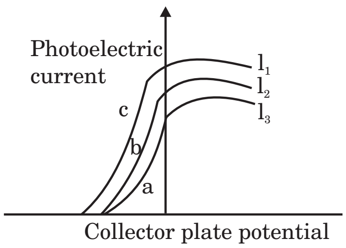


[ALL INDIA 2014]

3. Draw graphs showing variation of photoelectric current with applied voltage for two incident radiations of equal frequency and different intensities. Mark the graph for the radiation of higher intensity.

[DELHI 2014]

4. The figure shows a plot of three curves a, b, c, showing the variation of photocurrent vs collector plate potential for three different intensities I_1, I_2 and I_3 having frequencies υ_1, υ_2 and υ_3 respectively incident of a photosensitive surface. Point out the two curves for which the incident radiations have same frequency but different intensities.



[DELHI 2017]

2 Mark Questions

5. Using Bohr's postulates, obtain the expressions for (i) kinetic energy and (ii) potential energy of the electron in stationary state of hydrogen atom.

   Draw the energy level diagram showing how the transitions between energy levels result in the appearance of Lyman series.

[DELHI 2013]

6. (i) Monochromatic light of frequency 6.0×10^{14} Hz is produced by a laser. The power emitted is 2.0×10^{-3} W. Estimate the number of photons emitted per second on an average by the source.

[Topic 2] Matter Wave

Summary

Dual Nature of matter

- ***Particle Nature of matter:***

  Radiation behaves as if it is made up of particles in interaction of radiation with matter, called photons.

  Each photon has energy E = hv and momentum $p = \frac{h\upsilon}{c}$, and speed c that is the speed of light.

- ***Wave Nature of Matter:***

  De Broglie proposed that the moving particles are associated with the waves. If a particle is having a momentum p, then the associated wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$, where v is the speed of the moving particle and its mass. The wavelength λ is known as the ***de Broglie wavelength*** and the above relation as the ***de Broglie relation***.

  The wavelength of an electron accelerated with the potential V is:

  $\lambda = \frac{1.227}{\sqrt{V}} nm$

- ***Heisenberg's uncertainty principle:*** This principle states that, "it is not possible to measure both the position and momentum of an electron at the same time exactly. There is always some uncertainty in the position and in momentum.

  $\Delta x \, \Delta p \approx \hbar$, where $\hbar = \frac{h}{2\pi}$

- The wave nature of electron was verified and confirmed by the electron diffraction experiments performed by Davisson and Germer, and G.P. Thomson. Many other experiments later also confirmed the wave nature of electron.

PREVIOUS YEARS'

EXAMINATION QUESTIONS

TOPIC 2

1 Mark Questions

1. Show graphically, the variation of the de-Broglie wavelength (λ) with the potential (*V*) through which an electron is accelerated from rest.

[DELHI 2011]

2. State de-Broglie hypothesis.

[DELHI 2012]

2 Mark Questions

3. A proton and a deuteron are accelerated through the same accelerating potential. Which one of the two has,

(a) Greater value of de-Broglie wavelength associated with it, and

(b) Less momentum?

Give reasons to justify your Answer.

4. A proton and an α-particle have the same de Broglie wavelength. Determine the ratio of (i) their accelerating potentials (ii) their speeds.

[DELHI 2015]

5. Plot a graph showing variation of de-Broglie wavelength λ versus $\frac{1}{\sqrt{V}}$, where V is accelerating potential for two particles A and B carrying same charge but of masses m_1, m_2 ($m_1 > m_2$). Which one of the two represents a particle of smaller mass and why?

[DELHI 2016]

6. A proton and an α particle are accelerated through the same potential difference. Which one of the two has (i) greater de-Broglie wavelength, and (ii) less kinetic energy? Justify your answer.

[ALL INDIA 2016]

7. An electron is accelerated through a potential difference of 64 volts. What is the De-Broglie wavelength associated with it? To which part of the electromagnetic spectrum does this value of wavelength correspond?

[DELHI 2018]

Topic 1: Rutherford's Atomic Model, Bohr's Model & Energy Level Diagram

Summary

Introduction

- Atoms in simple terms are defined as the smallest unit of matter.
- Atoms are electrically neutral because they contain same number of electrons and protons.

Plum-Pudding Model

- In 1898, J. J. Thomson proposed the first model of atom.
- He stated, there is a uniform distribution of the positive charge of the atom throughout the volume of the atom and like seeds in a watermelon, the negatively charged electrons are embedded in it. This model was picturesquely called plum pudding model of the atom.

Alpha-Particle Scattering

- Rutherford used a "Gold foil experiment"
- Rutherford only identified one of type of radiation given off by radioactive elements like polonium, uranium and named them as alpha particles.
- The alpha particles are fast moving and positively charged Helium nuclei with two protons and two neutrons.

Rutherford observed the deflection of alpha particles after passing through metal sheet and proposed his atomic model

- After passing through the metal sheet, the alpha particles strike on fluorescent screen which was coated with zinc sulphide and produced a visible flash of light
- He concluded that an atom consists of a minute positively charged body at its center called as nucleus. The nucleus, though small, contains all the protons and neutrons.

Alpha-Particle Trajectory

- The trajectory traced by an α particle depends on the impact parameter, b of collision.
- The particle near to the nucleus suffers large scattering.
- Only a small fraction of the number of incident particles rebound back indicating that the number of α-particles undergoing head on collision is small.

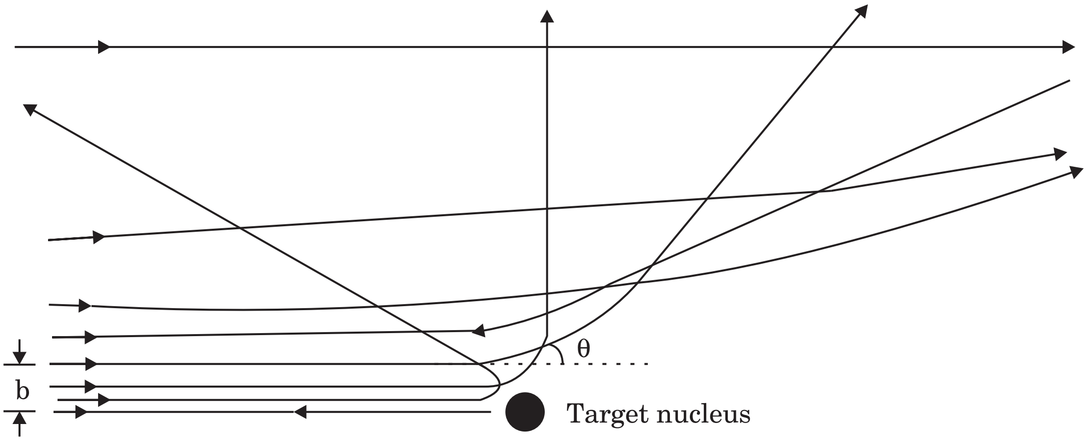


Fig.: Alpha-Particle Trajectory

Rutherford's nuclear model of Atom

- According to Rutherford's model, the entire positive charge and most of the mass of the atom is concentrated in a small volume called the nucleus with electrons revolving around the nucleus just as planets revolve around the sun.
- Rutherford scattering is a powerful way to determine an upper limit to the size of the nucleus.
- **Drawbacks of Rutherford's model:** There were two major drawbacks in Rutherford nuclear model in explaining the structure of atom:

It cannot explain the characteristic line spectra of atoms of different elements.

It contradicts the stability of matter because it speculates that atoms are unstable because the accelerated electrons revolving around the nucleus must spiral into the nucleus.

Electron Orbits

- The electrostatic force of attraction, F_e between the revolving electrons and the nucleus provides the requisite centripetal force (F_c) to keep them in their orbits. Hence, for a dynamically states orbit in a hydrogen atom $F_e = F_c$
- The total energy of the electron is negative. It is given by $E = -\dfrac{e^2}{8\pi\varepsilon_0 r}$.

Atomic Spectra

- Each element has a characteristic spectrum of radiation, which it emits.
- Study of emission line spectra of a material can therefore serve as a type of "fingerprint" for identification of the gas.
- The atomic hydrogen emits a line spectrum consisting of various series as:

Lyman series: $v = Rc\left(\dfrac{1}{1^2} - \dfrac{1}{n^2}\right) : n = 2, 3, 4, ...$

Balmer series: $v = Rc\left(\dfrac{1}{2^2} - \dfrac{1}{n^2}\right) : n = 3, 4, 5, ...$

Paschen series: $v = Rc\left(\dfrac{1}{3^2} - \dfrac{1}{n^2}\right) : n = 4, 5, 6, ...$

Brackett series: $v = Rc\left(\dfrac{1}{4^2} - \dfrac{1}{n^2}\right) : n = 5, 6, 7, ...$

Pfund series: $v = Rc\left(\dfrac{1}{5^2} - \dfrac{1}{n^2}\right) : n = 6, 7, 8, ...$

Bohr Model of the Hydrogen Atom

Bohr combined classical and early quantum concepts, explained the spectrum of hydrogen atom based on quantum ideas and gave his theory in the form of three postulates. These are:

- Bohr's first postulate was that an electron in an atom could revolve in certain stable orbits without the emission of radiant energy, contrary to the predictions of electromagnetic theory. According to this postulate, each atom has certain definite stable states in which it can exist, and each possible state has definite total energy. These are called the stationary states of the atom.
- Bohr's second postulate defines these stable orbits. This postulate states that the electron revolves around the nucleus only in those orbits for which the angular momentum is some integral multiple of $h/2\pi$ where h is the Planck's constant (= 6.6×10^{-34} Js). Thus the angular momentum (L) of the orbiting electron is quantised. That is $L = nh/2\pi$.
- Bohr's third postulate incorporated into atomic theory the early quantum concepts that had been developed by Planck and Einstein. It states that an electron might make a transition from one of its specified non-radiating orbits to another of lower energy. When it does so, a photon is emitted having energy equal to the energy difference between the initial and final states. The frequency of the emitted photon is then given by

  $hv = E_i - E_f$, where E_i and E_f are the energies of the initial and final states and $E_i > E_f$.
- Bohr radius is represented by the symbol a_0, is given by $a_0 = \dfrac{h^2\varepsilon_0}{\pi m e^2}$.
- The total energy of the electron in the stationary states of the hydrogen atom is given by

  $E_n = -\dfrac{13.6}{n^2} eV$

De Broglie's Explanation of Bohr's Second Postulate of Quantisation

- De Broglie hypothesis provided an explanation for Bohr's second postulate for the quantisation of angular momentum of the orbiting electron. The quantised electron orbits and energy states are due to the wave nature of the electron and only resonant standing waves can persist.
- De Broglie's hypothesis is that electrons have a wavelength $\lambda = \dfrac{h}{mv}$.

Limitations of Bohr's model: Bohr's model however has many limitations.

- It is applicable only to hydrogenic (single electron) atoms.
- It cannot be extended to even two electron atoms such as helium.
- While the Bohr's model correctly predicts the frequencies of the light emitted by hydrogenic atoms, the model is unable to explain the relative intensities of the frequencies in the spectrum.

Topic 1: Radioactivity and Decay Law

Summary

- **Nucleus:** Nucleus can be defined as the central part of an atom, made up of neutrons, protons, and other elementary particles. The nucleus has protons and neutrons inside it. They are called nucleons.
- **Mass Number:** The total number of protons and neutrons present inside the nucleus of an atom of an element is referred to as mass number (A) of the element.
- **Atomic Number:** The number of protons present in the nucleus of an atom of an element is known as atomic number (Z) of the element.
- **Nuclear Size:** The radius of the nucleus $R \propto A^{\frac{1}{3}}$
- $R = R_o A^{\frac{1}{3}}$ where $R_0 = 1.2 \times 10^{-15}$ m is an empirical constant.
- **Nuclear Density:** Nuclear density is independent of mass number and is therefore same for all nuclei.

  $$\rho = \frac{Mass\ of\ nucleus}{volume\ of\ nucleus}$$

  $\rho = \frac{3m}{4\pi R_0^3}$ where is the average mass of a nucleon.
- **Atomic Mass Unit:** Abbreviated as amu and is defined as one-twelfth of the mass of a carbon nucleus. It is also denoted by u.

  Therefore,

  $$1\ amu = \frac{1.992678 \times 10^{-26}}{12} kg$$

  $= 1.6 \times 10^{-27}$ kg = 931 MeV
- **Isomers:** The atoms that have the same mass number, atomic number but different radioactive properties are known isomers.
- **Isotones:** Atoms of elements that have different mass numbers, atomic numbers but same number of neutrons are known as isotones. e.g., $_1H^3$, $_2H^4$ and $_6C^{14}$, $_8O^{16}$ are isotones.
- **Isobars***:* The atoms of an element having different atomic numbers but same mass numbers are known as isobars. e.g., $_1H^3$, $_2H^3$ and $_{10}Na^{22}$, $_{10}Ne^{22}$ are isobars.
- **Isotopes***:* Atoms of an element that have different mass numbers but same atomic number are known as isotopes. e.g., $_1H^1$, $_1H^2$, $_1H^3$ is an example of isotopes.
- **Nuclear Force***:* Nuclear force can be referred to as the force that acts inside the nucleus or between nucleons. These forces are neither electrostatic nor gravitational in nature. They have a very short range and are independent of any charge. They are a hundred times that of electrostatic force and 10^{38} times that of gravitational force.
- **Radioactivity***:* Radioactivity refers to the breakdown of heavy elements into comparably lighter elements by the emission of radiations. This phenomenon was discovered by Henry Becquerel in 1896.
- **Packing Fraction (P):**

  $$P = \frac{(Exact\ nuclear\ mass) - (Mass\ number)}{Mass\ number}$$

  $$= \frac{(A - M)}{M}$$

For greater stability of the nucleus, the value of packing friction should be larger.

- ***Radioactive Decay law***

The Radioactive law states that the rate of disintegration of radioactive atoms at any instance is directly proportional to the number of radioactive atoms present in the given sample at that instant.

Rate of disintegration $\left(-\frac{dN}{dt}\right) \propto N$

$-\frac{dN}{dt} = \lambda N$, where λ is the decay constant.

The number of undecayed atoms present in the sample at any instance $N = N_0 e^{-\lambda t}$ where, N_0 is number of atoms at time t = 0 and N is number of atoms at time t.

- **Activity of a radioactive element**

The activity of a radioactive element is equal to its rate of disintegration.

Activity $R = \left(-\frac{dN}{dt}\right)$

Activity of the sample after time t, $R = R_0 e^{-\lambda t}$

Its SI unit is Becquerel (Bq). Curie and Rutherford are its other units.

1 Curie = 3.7 × 10^{10} decay/s and 1 rutherford = 10^6 decay/s

- **Half-life of a radioactive element**

Half-life (T) of a radioactive element is the time taken for the radioactivity of an isotope to fall to half its original value. The relation between disintegration constant and half-life is given by

$$T = \frac{\log_e 2}{\lambda} = \frac{0.6931}{\lambda}$$

- **Average Life or Mean Life (τ)**

Average life or mean life (τ) of a radioactive element can be defined as the ratio of total life time of all the atoms and total number of atoms present, initially in the sample.

Relation between half-life and average life τ = 1.44T

Relation between average life and decay constant $\tau = \frac{1}{\lambda}$

- **Alpha decay:** In alpha decay, a nucleus gets transformed into a different nucleus and an α particle is emitted. The general form can be expressed as:

  $^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}He$ and the Q value:

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

- **Beta decay:** When a nucleus undoes beta decay, it emits an electron or a positron. When an electron is emitted, it is said to be beta minus decay while in beta plus decay, a positron is emitted.
- **Gamma decay:** In gamma decay, the photons are emitted from the nuclei having MeV energy and thus the gamma rays are emitted. This is called as gamma decay.

PREVIOUS YEARS'
EXAMINATION QUESTIONS
TOPIC 1

1 Mark Questions

1. Define the activity of a given radioactive substance. Write its S.I. units.

[DELHI 2011]

2. Why is it found experimentally difficult to detect neutrinos in nuclear β-decay?

[ALL INDIA 2014]

3. Two nuclei have mass numbers in the ratio 1: 2. What is the ratio of their nuclear densities?

[DELHI 2017]

2 Marks Questions

4. A radioactive nucleus '*A*' undergoes a series of decays according to the following scheme:

$$A \xrightarrow{\alpha} A_1 \xrightarrow{\beta^-} A_2 \xrightarrow{\alpha} A_3 \xrightarrow{\gamma} A_4$$

The mass number and atomic number of *A* are 180 and 72 respectively.

What are these numbers for A_4?

[DELHI 2017]

3 Marks Questions

5. 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.

Depict in the plot the number of undecayed nuclei at (i) $t = 3T_{1/2}$ and (ii) $t = 5T_{1/2}$

[ALL INDIA 2011]

6. Show that the density of nucleus over a wide range of nuclei is constant independent of mass number A.

[ALL INDIA 2012]

7. Draw a plot of potential energy between a pair of nucleons as a function of their separation. Mark the regions where potential energy is (i) positive and (ii) negative

[DELHI 2013]

8. (a) In a typical nuclear reaction, e.g.

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + ^{1}_{0}n + 3.27\,MeV,$$

although number of nucleons is conserved, yet energy is released. How? Explain.

(b) Show that nuclear density in a given nucleus is independent of mass number *A*.

[DELHI 2013]

Topic 2: Mass Defect and Binding Energy

Summary

- **Mass Defect***:* Mass defect can be mentioned as the difference between the sum of masses of all nucleons (M) and the mass of the nucleus (m).

  Mass Defect (Δm) = M – m

  = $[Zm_p + (A - z)m_n - m_n]$
- **Nuclear Binding Energy***:* Nuclear binding energy can be referred to as the minimum energy that is required to separate the nucleons up to an infinite distance from the nucleus.

Nuclear binding energy per nucleon = Nuclear binding energy / Total number of nucleons Binding energy, E_b = $[Zm_p + (A - Z)m_n - m_n]c^2$

- **Nuclear Fission**

The process of the splitting a heavy nucleus into two or more lighter nuclei is known as nuclear fission.

- **Nuclear Reactor**

When a slow moving neutron strikes with a uranium nucleus $\left({}_{92}U^{235}\right)$, it splits into ${}_{56}Ba^{141}$ and ${}_{36}Kr^{92}$ along with three neutrons and a lot of energy.

$$ {}_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} \rightarrow 3\,{}_0n^1 + energy $$

- **Nuclear Chain Reaction**

Nuclear chain reactions are defined as a chain of nuclear fission reactions (splitting of atomic nuclei), and each one of them is initiated by a neutron produced in the previous fission reaction. Nuclear chain reactions are of two types:

➢ Controlled chain reaction
➢ Uncontrolled chain reaction

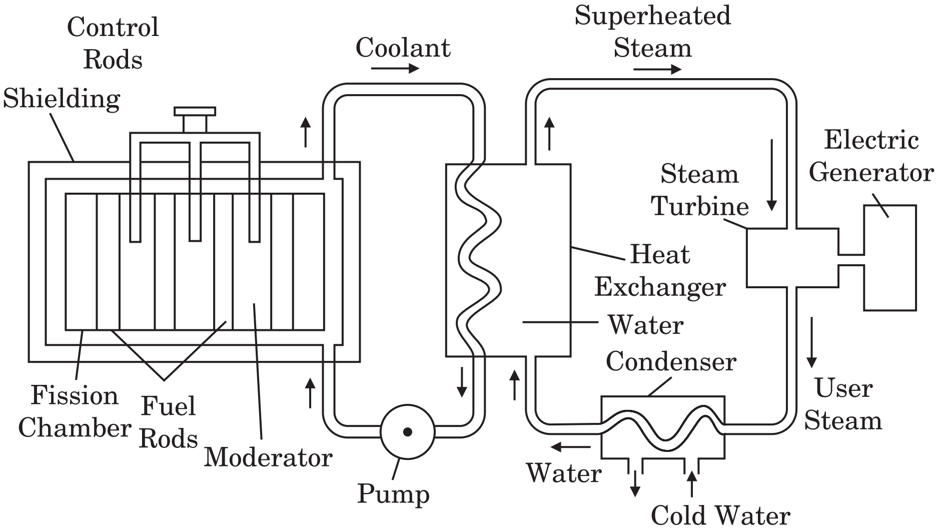


Fig.: Setup of a Nuclear Reactor

The vital parts of a nuclear reactor are the following:

➢ Fuel: Fissionable materials like ${}_{92}U^{235}$, ${}_{92}U^{238}$, ${}_{94}U^{239}$ are used as fuel.
➢ Moderator: Graphite, heavy water and beryllium oxide are used to slower down fast moving neutrons.
➢ Coolant: Liquid oxygen, cold water, etc. are used to remove heat generated in the fission process.
➢ Control rods: Cadmium or boron rods are considered as good absorber of neutrons and are therefore used to control the fission reaction.

- **Nuclear Fusion:** The process of combining two light nuclei in order to form a single large nucleus is called nuclear fusion. A large amount of energy is released in this process. The example of nuclear fusion is:

${}_1^1H + {}_1^1H \rightarrow {}_1^2H + e^+ + \nu + 0.42$ MeV, where a deuteron and a positron are formed by the combination of two protons and 0.42 MeV energy is released.

The source of energy of sun and all the stars is a nuclear fusion reaction in which hydrogen nuclei combine to form helium nuclei.

$$ 4\,{}_1^1H + 2e^- \rightarrow {}_2^4He + 2\nu + 6\gamma + 26.7 \text{ MeV} $$

- **Advantages of Nuclear fusion:**
  ➢ Nuclear fusion does not cause any waste as the only by product is helium.
  ➢ Nuclear fusion is very simple to control as there is no change of chain reaction.
  ➢ There is unlimited supply of fuel for nuclear fusion.

[Topic 1] Semiconductor, diode and its applications

Summary

- The materials which are present in solid state and their conductivity lies between insulator and conductor are called as semiconductors. Semiconductors are either pure substance like silicon, germanium or they can also be formed by addition of impurities which form a compound like gallium arsenide, cadmium selenide, etc.
- Semiconductors have resistivity in the range of metals and insulators. Insulators have resistivity in the range of $10^{11} - 10^{19}$ Ωm and metals have resistivity in the range of 10^{-2} to 10^{-8} Ωm while semiconductors have resistivity in the range of $10^{-5} - 10^{6}$ Ωm
- Semiconductors can be elemental (without doping) as well as compound (by doping).
- ***Intrinsic semiconductors:*** These are pure semiconductors where the conductivity is due to electrons moving from valence band to conduction band. Their conductivity is called intrinsic conductivity. In intrinsic conductors, $n_e = n_h$
- ***Extrinsic semiconductors:*** When Impurity is added to pure semiconductor to increase its conductivity, is called as extrinsic semiconductor.

  It can be divided into two types, i.e. p-type semiconductors and n-type semiconductors.

  In p-type semiconductors, number of holes are greater than number of electrons.

  $n_h >> n_e$

  In n-type semiconductors, number of electrons are greater than number of holes.

  $n_e >> n_h$

  Trivalent atoms (B, Al, etc.) called acceptor atoms are used for doping p-type semiconductors while pentavalent atoms (As, Sb, etc.) called donor atoms are used for doping n-type semiconductors.
- ***Energy bands:*** Valence electrons of an atom are shared by different number of atoms in the crystal which causes splitting of energy levels. These energy levels are called energy bands. The energy band which contains valence electrons is called as valence band. It always has some electrons and can never be empty.
  - The energy band which contains conduction electrons is called as conduction band. It can be empty or have some electrons which take part in flow of current.
  - The band which lies between conduction band and valence band is called as forbidden band. The minimum amount of energy required to transfer electrons from valence band to conduction band is called as band gap.
  - Metals do not have any band gap and $E_g \approx 0$

  while band gap in insulators is greater than 3 eV and the band gap for semiconductors lies between 0.2 eV and 3 eV.

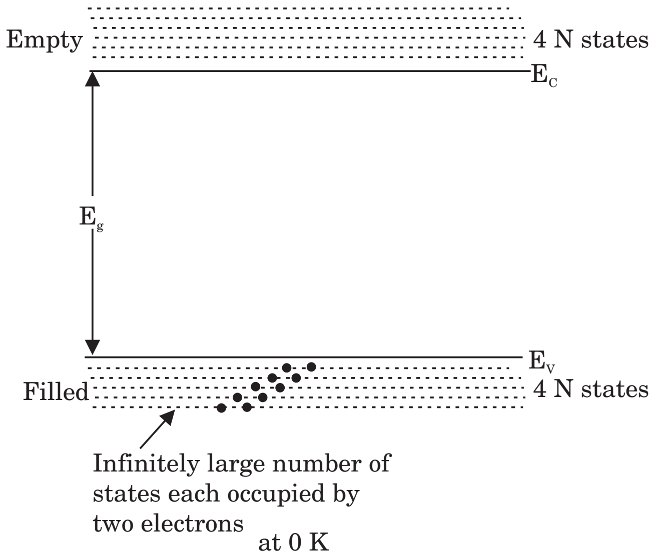


Fig.: The energy band positions in a semiconductor at 0 K. The upper band is conduction band and the lower band is called valence bond.

- ***p-n junction:*** p-type semiconductor when brought in contact with n-type semiconductor forms a p-n junction.

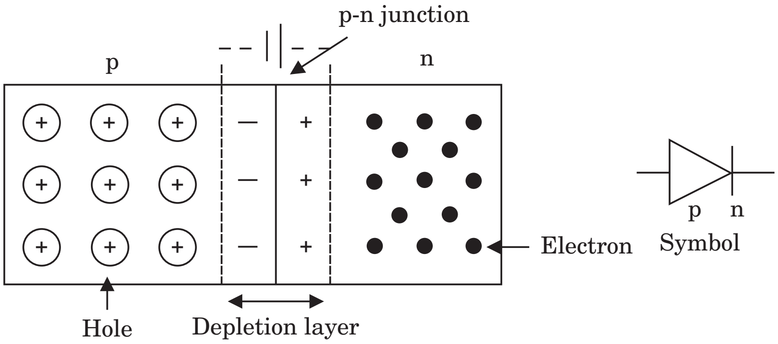


Fig.: p–n junction depicting Depletion layer

When there are no charge carriers, a region is created at the p-n junction called as depletion layer.

- Forward Biasing: When the p-side is connected to the positive terminal and n-side is connected to the negative terminal of a battery, it is called forward biasing. Majority charge carriers cause forward current flow in this biasing and the width of the depletion layer decreases.
- Reverse Biasing: When the n-side is connected to the positive terminal and p-side is connected to the negative terminal of the battery then it is called reverse biasing. Minority charge carriers cause reverse current flow in this biasing and width of the depletion layer increases.

- ***Junction diode as rectifier:*** By applying alternating voltage across a diode the current flows in only that part if the diode is forward biased and by using this property diode could be used to design a circuit which can be used as a rectifier.

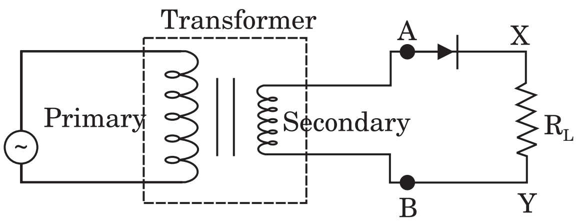


Fig.: Half-wave rectifier circuit using diode

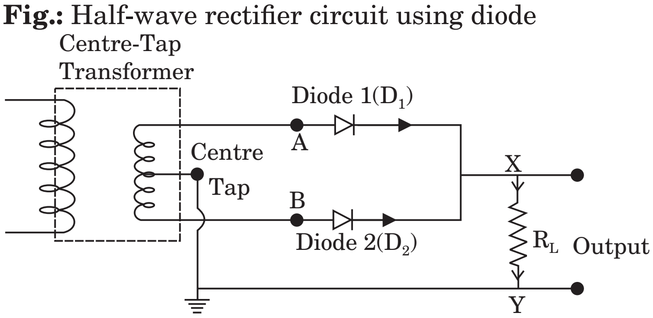


Fig.: Full-wave rectifier circuit using diode

- ***Diodes:*** Ac voltage can be restricted to one direction using diodes. Some examples of p-n junction diodes are zener diode, light-emitting diode, photo-diode, etc.

- In ***zener diodes***, when it is reversed biased the current increases after a certain voltage and the voltage is called breakdown voltage. This property of zener diodes is used in regulating voltage.

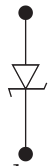


Fig.: Zener diode

- In ***photodiodes***, photons are excited which result in change of reverse saturation current to measure light intensity.

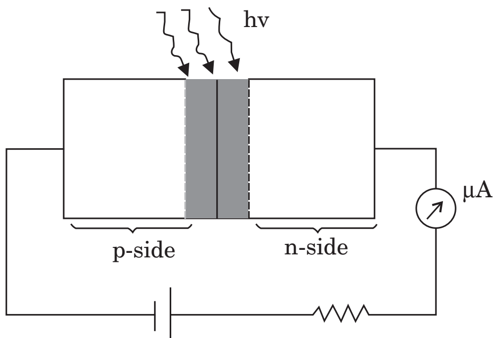


Fig.: An illuminated photodiode

- In ***light emitting diodes,*** electrons are excited by a biasd voltage resulting in generation of light.
- In ***solar cells,*** emf is generated when solar radiation falls on the p-n junction. It works on the principle of photovoltaic effect.

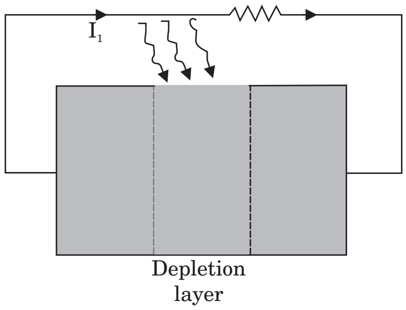


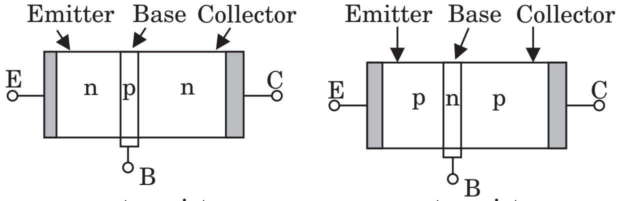
Fig.: Typical p-n junction solar cell

[Topic 2] Transistors, its application and logic gates

Summary

- A thin layer of one type of semiconductor is added between two thick layers of other semiconductor of same type and this forms a transistor.

  It can be done in two ways, i.e. adding a p-type semiconductor between two n-type semiconductors forming n-p-n transistor or by adding an n-type semiconductor between two p-type semiconductors forming p-n-p transistor.

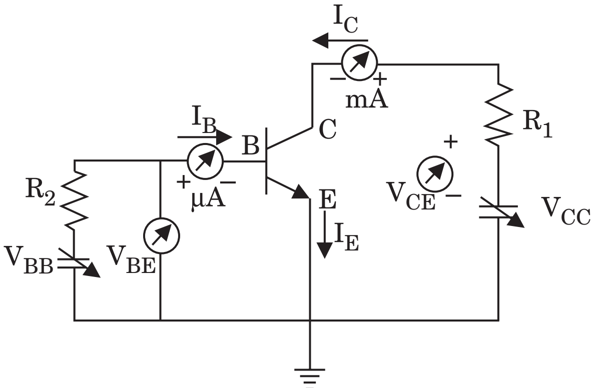


n-p-n transistor p-n-p transistor

➢ Any transistor has 3 parts: Base (central block), Emitter and Collector (two electrodes). Therefore the three parts of the transistor can be connected in three ways: Common Emitter (CE), Common Collector (CC) and Common Base (CB).

➢ For fixed I_B, the plot between I_C gives output characteristics and for fixed V_{CE}, the plot between I_B and V_{BE} gives input characteristics.

- ***Common emitter transistor:*** The input is between the base and the emitter and output is between the collector and the emitter.



n-p-n transistor in CE configuration

➢ ***Input resistance*** is the ratio of change in base emitter voltage to the resulting change in base current at constant collector emitter voltage and is given by

$$r_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE}}$$

➢ Output resistance is the ratio of change in collector emitter voltage to the change in collector current at a constant base current and is given by

$$r_o = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B}$$

- ***Current gain:*** There are two low current gains defined as follows:

➢ ***Common base current amplification factor (α) :*** Ratio of the small change in collector current to the small change in emitter current at constant collector-base voltage.

$$\alpha = \left[\frac{\delta I_C}{\delta I_E}\right]_{V_{CB}=\text{constant}}$$

➢ ***Common emitter current amplification factor (β)***: Ratio of the small change in collector current to the small change in base current at constant collector-emitter voltage.

$$\beta = \left[\frac{\delta I_C}{\delta I_B}\right]_{V_{CE}=\text{constant}}$$

Terms α and β are related as: $\alpha = \dfrac{\beta}{1+\beta}$ and

$$\beta = \frac{\alpha}{1-\alpha}$$

- A transistor can be used as an amplifier to increase voltage, current or power. Voltage gain of an amplifier can be defined as the ratio of small change in output voltage to small change in input voltage. Ratio of the small change in collector current to the small change in base current at constant collector-emitter voltage is called current gain.

  Voltage gain of amplifier is given by,

$$A_v = -\left(\frac{\beta_{ac} R_L}{r}\right)$$

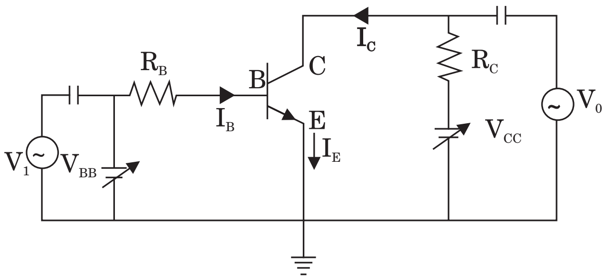


Fig.: C-E transistor amplifier

- A transistor can be used as a switch by analyzing the behavior of the base-biased transistor in CE configuration. When transistor works as a switch a low input to the transistor gives high output and a high input gives a low output. In this case the transistor does not remain in active state.

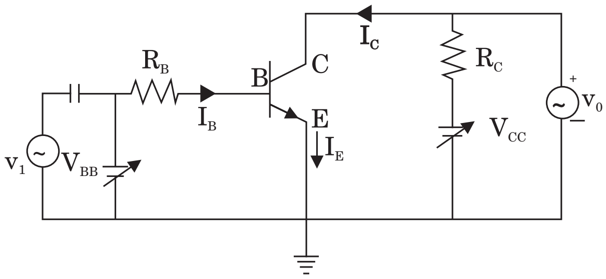


Fig.: Base-biased transistor in CE configuration to work as a switch

- ***Transistor oscillator:*** When we get ac output without any external input signal then the transistor works as an oscillator.

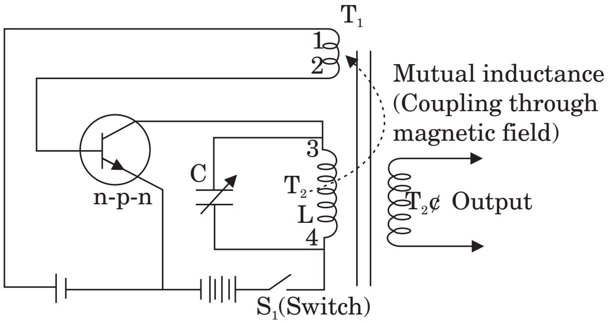
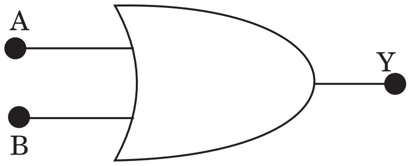


Fig.: Tuned collector oscillator

Frequency at which the oscillator will work is given by, $v = \dfrac{1}{2\pi\sqrt{LC}}$

- Logic gates are digital circuits which perform special; logic operations. These logic gates can be described as OR, AND, NOT, NAND, and NOR. Different logic gates are integrated in a single chip called Integrated circuits (IC).

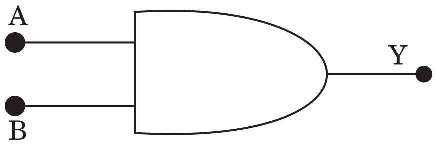
➢ Boolean expression for ***OR gate:*** Y = A + B



The truth table for OR gate is shown below:

A	*B*	*Output Y*
0	*0*	*0*
0	*1*	*1*
1	*0*	*1*
1	*1*	*1*

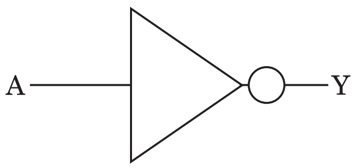
➢ Boolean expression for ***AND gate***: Y = A.B



The truth table for AND gate is shown below:

A	*B*	*Output Y*
0	*0*	*0*
0	*1*	*0*
1	*0*	*0*
1	*1*	*1*

➢ Boolean expression for ***NOT gate:*** $Y = \overline{A}$



The truth table for NOT gate is shown below:

A	*Output Y*
0	*1*
1	*0*

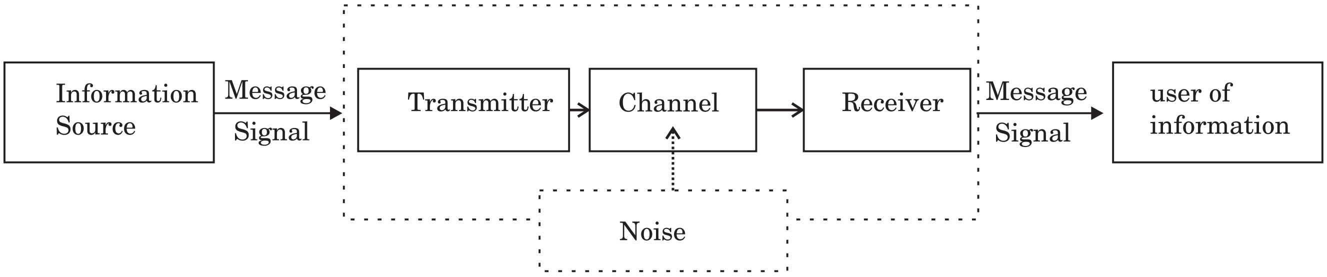
- ***Integrated circuits:*** When a entire circuit (including all passive components and active devices) is fabricated on a single chip or block of a semiconductor then it is known as integrated circuit(IC). The most widely used technology for making IC's is monolithic Integrated circuit.

[Topic 1] Communication

Summary

- Communication is a two way process in which exchange of information takes place either in verbal or written form.
- ***Elements of communication system:*** There are three essential elements of communication transmitter, medium/channel and receiver.

Communication System



Transmitter transmits the signals through channel which is a physical medium and the receiver receives the signals.

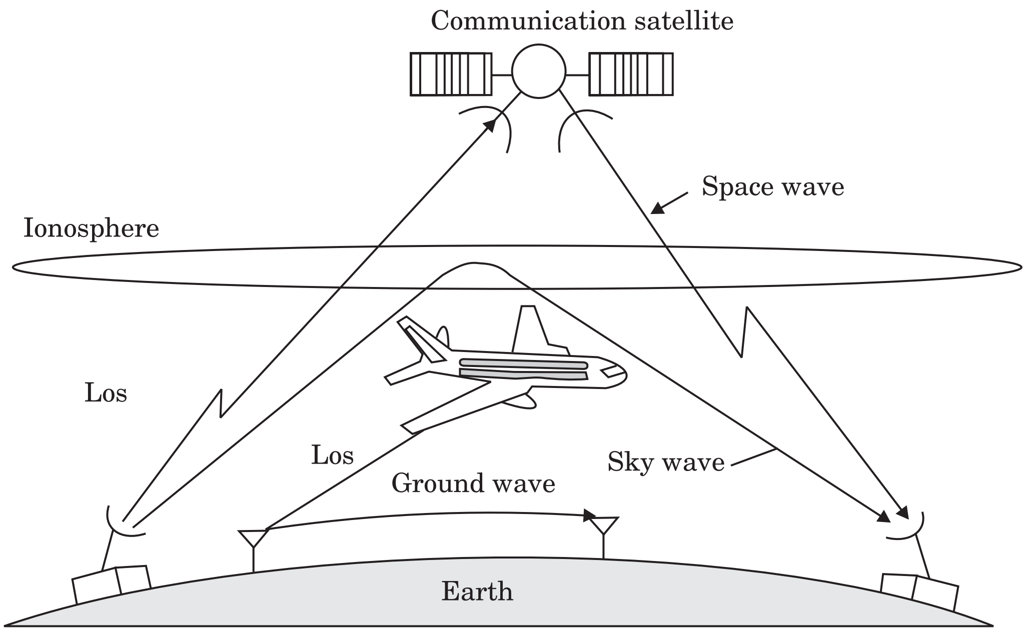
The two basic types of communication modes are point-to-point and broadcast.

- ***Transducer:*** A device which transforms the energy from one form into another. Example: Loudspeaker.
- ***Signal:*** An information transformed into electrical form for suitable transmission is termed as signal. Signals can be of two types: analog or digital.
- ***Noise:*** The unwanted signals which have a tendency to create the disturbancein the transmission and processing of message is called noise.
- ***Transmitter:*** The device that processes the incoming message signal in order to make it suitable for transmission through a channel and subsequent reception is known as transmitter.
- ***Receiver:*** In order to extract the appropriate message signals from the received signals at the channel output, receiver is used.
- ***Attenuation:*** When signals are propagated through a medium, some of their strength is lost which is known as attenuation.
- ***Amplification:*** The process of increasing the amplitude and the strength of a signal using an electronic circuit is called amplification.
- ***Range:*** The largest distance between a source and a destination is called range up to which the signal is received with sufficient strength.
- ***Bandwidth:*** The range of frequency over which an equipment operates or the portion of the spectrum occupied by the signal is called bandwidth.
- ***Repeater:*** A combination of transmitter and receiver is the repeater which amplifies the signals picked up from the transmitter and then retransmits those signals to the receiver. In order to extend the range of the communication system, the repeaters are used.
- ***Bandwidth of signals:*** The difference between the upper and lower frequencies of the signals is termed as bandwidth of signals. The different bandwidths of the different kinds of signals is shown in the following table:

Types of Signals	*Bandwidth*
Speech signal	*2800 Hz*
Music signal	*20 KHz*
Video signal	*4.2 MHz*
TV signal	*6 MHz*

- ***Bandwidth of transmission medium:*** Free space, wire, fibre optic cable and optical fibre are the common transmission media. The bandwidths are different for various transmission media.
- ***Propagation of Electromagnetic Waves:*** In radio waves communication, the EM waves are radiated at the transmitter by antenna.
- ***Ground wave propagation:*** The ground wave propagation is also termed as surface wave propagation.The radio waves are travelled along the earth surface in this type of propagation. It is necessary for the antenna to be of a size which is comparable to the wavelength of the signal so that the signals can be radiated with high efficiency. As the frequency increases, the attenuation also increases.
- ***Sky wave propagation:*** It is used for long distance communication in the frequency range from few MHz to 40MHz. It uses the phenomenon of bending of EM waves so that they are diverted towards the earth is similar to total internal reflection in optics.
- ***Space wave propagation:*** For long distance transmission, antennas are used to radiatesignals into space. In order to travel from transmitting antenna to the receiving antenna, space wave takes the straight line path.They are useful for line-of-sight (LOS) communication and satellite communication.
- The range d_T of an antenna of height h_T that radiates electromagnetic waves is given by $\sqrt{2Rh_T}$; R = radius of the earth.
- To find out the maximum distance of line of sight (d_M) between antennas with heights hT and h_R:

$$d_M = \sqrt{2Rh_T} + \sqrt{2Rh_R}$$



[Topic 2] Modulation

Summary

- ***Modulation*** is the process by which a low frequency is superimposed on a high frequency carrier signal so that the low frequency can be transmitted to long distance.
- ***Demodulation:*** The reverse process of modulation is called as demodulation in which the information from the carrier wave is retrieved at the receiver.
- ***Need of Modulation:***

➢ As there is a need of a very large antenna for low frequency signals, signals from different stations mixes up and the attenuation is large, so the modulation is needed.

➢ The size of antenna is given by $\frac{\lambda}{4}$ and low frequency implies larger wavelength so the size of antenna is not achievable.

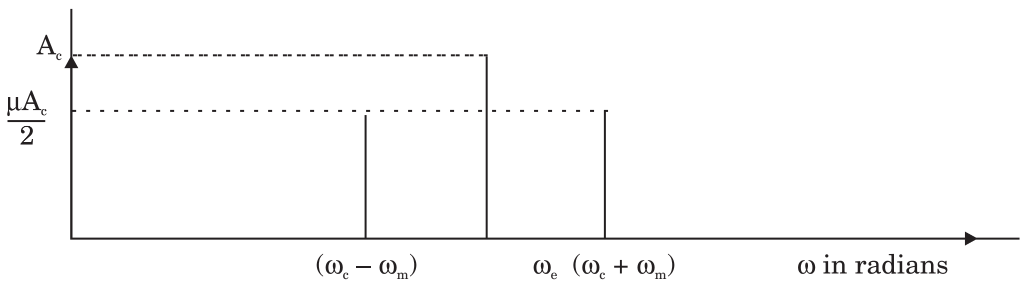
➢ There are 4 types of modulation: Amplitude modulation, Frequency modulation, Pulse modulation and Phase modulation

- ***Amplitude Modulation:*** The alteration of the amplitude of the carrier in accordance with the information signal is amplitude modulation. The following expression represent the AM of a carrier wave having amplitude and frequency f_c:

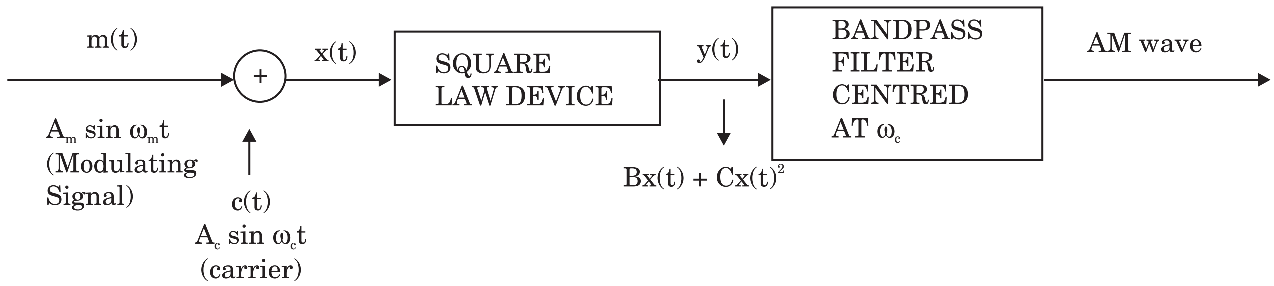
$$C_m(t) = A_c A \sin \omega_c t + \frac{\mu A_c}{2} \cos(\omega_c - \omega_m)t - \frac{\mu A_c}{2} \cos(\omega_c + \omega_m)t$$

The amplitude of the modulating wave is A_m and the frequency is f_m.

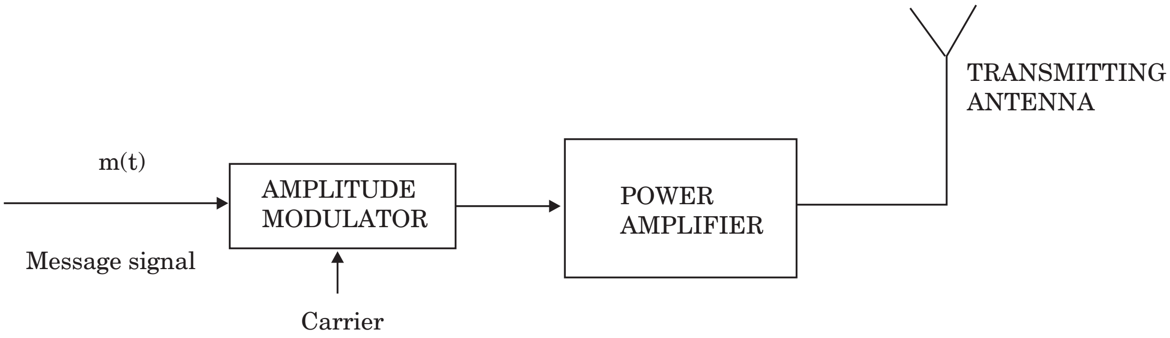
Modulation index $\mu = \frac{A_m}{A_c}; \mu \le 1$.



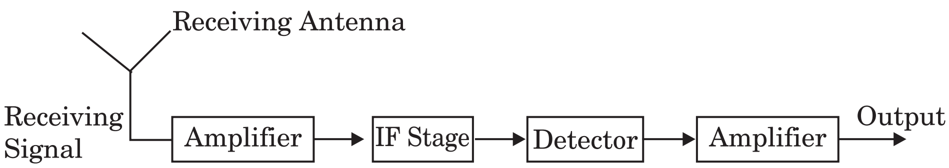
- ***Production of AM wave:*** The following block diagram shows the production of AM wave:



The block of transmitter is as follows:



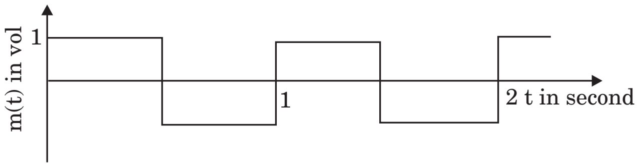
- ***Detection of AM wave:*** Detected signals need modification as they may not be strong enough to use. The block diagram of receiver is given below:



PREVIOUS YEARS'
EXAMINATION QUESTIONS
TOPIC 2

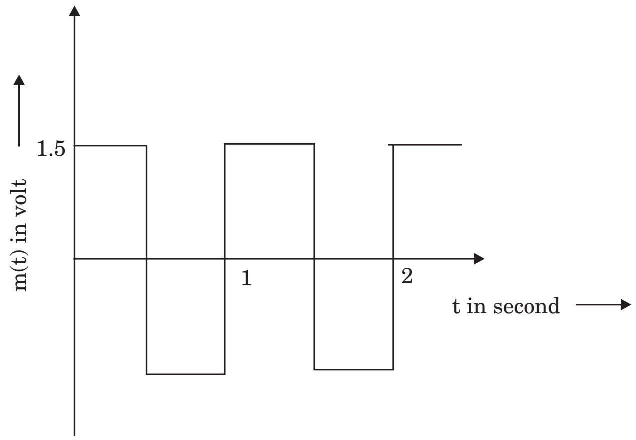
1 Mark Questions

1. The carrier wave is represented by $C(t) = 5 \sin (10\pi t)V$. A modulating signal is a square wave as shown.



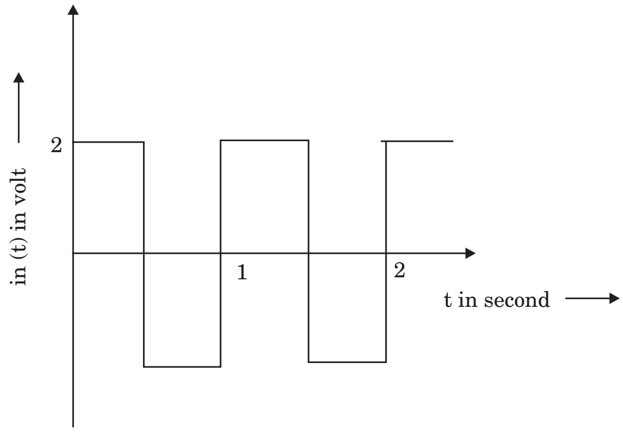
Determine modulation index. **[CBSE 2014]**

2. The carrier, wave of a signal is given by $C(t) = 3 \sin (8\pi t)$ volt. The modulating signal is a square wave as shown. Find its modulation index.



[CBSE 2014]

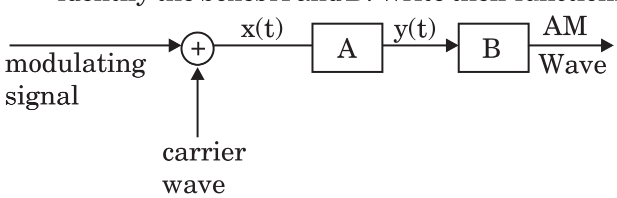
3. The carrier wave is given by $C(t) = 2 \sin (\omega t)$ volt. The modulating signal is a square wave as shown. Find modulation index.



[CBSE 2014]

2 Marks Questions

4. (i) Define modulation index.
   (ii) Why is the amplitude of modulating signal kept less than the amplitude of carrier wave? **[CBSE 2011]**
5. 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.



[CBSE 2012]