BOARD OF OPEN SCHOOLING AND SKILL EDUCATION

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The Pathways To Higher Studies

Physics

Class-XII

PHYSICS

CLASS 12

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Board of Open Schooling and Skill Education

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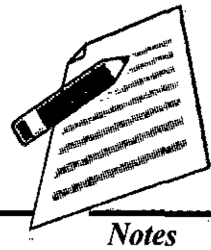
CLASS–12

Physics



Notes

Syllabus

Course Structure

Units	Topics	Marks
I	**Electrostatics**	
Chapter 1	Electric Charges and Fields	
Chapter 2	Electrostatic Potential and Capacitance	15
II	**Current Electricity**	
Chapter 3	Current Electricity	
III	**Magnetic Effect of Current & Magnetism**	
Chapter 4	Moving Charges and Magnetism	
Chapter 5	Magnetism and Matter	
IV	**Electromagnetic Induction & Alternating Current**	16
Chapter 6	Electromagnetic Induction	
Chapter 7	Alternating Current	
V	**Electromagnetic Waves**	
Chapter 8	Electromagnetic Waves	
VI	**Optics**	17
Chapter 9	Ray Optics and Optical Instruments	
Chapter 10	Wave Optics	
VII	**Dual Nature of Matter**	
Chapter 11	Dual Nature of Radiation and Matter	
VIII	**Atoms & Nuclei**	10
Chapter 12	Atoms	
Chapter 13	Nuclei	
IX	**Electronic Devices**	
Chapter 14	Semiconductor Electronics	
X	**Communication Systems**	12
Chapter 15	Communication Systems	
XI	**Practical Work**	30
Total		**100**

Course Syllabus detailed

Unit I: Electrostatics

Chapter 1: Electric Charges and Fields

- Electric Charges –
  - Conservation of charge
  - Coulomb's law-force between two-point charges
  - Forces between multiple charges
  - Superposition principle
  - Continuous charge distribution
- Electric field, electric field due to a point charge, electric field lines, electric dipole, electric field due to a dipole, torque on a dipole in uniform electric field.
- Electric flux, statement of Gauss's theorem and its applications to find field due to infinitely long straight wire, uniformly charged infinite plane sheet and uniformly charged thin spherical shell (field inside and outside).

Chapter-2: Electrostatic Potential and Capacitance

- Electric potential, potential difference, electric potential due to a point charge, a dipole and system of charges
- Equipotential surfaces, electrical potential energy of a system of two-point charges and of electric dipole in an electrostatic field
- Conductors and insulators, free charges and bound charges inside a conductor
- Dielectrics and electric polarisation, capacitors and capacitance, combination of capacitors in series and in parallel, capacitance of a parallel plate capacitor with and without dielectric medium between the plates, energy stored in a capacitor.

Unit II: Current Electricity

Chapter 3: Current Electricity

- Electric current, flow of electric charges in a metallic conductor, drift velocity, mobility and their relation with electric current
- Ohm's law, electrical resistance, V-I characteristics (linear and non-linear), electrical energy and power, electrical resistivity and conductivity
- Carbon resistors, colour code for carbon resistors; series and parallel combinations of resistors; temperature dependence of resistance
- Internal resistance of a cell, potential difference and EMF of a cell, combination of cells in series and in parallel
- Kirchhoff's laws and simple applications
- Wheatstone bridge, metre bridge

- Potentiometer –
  - Principle and its applications to measure potential difference and for comparing EMF of two cells
  - Measurement of internal resistance of a cell

Unit III: Magnetic Effects of Current and Magnetism

Chapter 4: Moving Charges and Magnetism

- Concept of magnetic field –
  - Oersted's experiment
- Biot - Savart law and its application to current carrying circular loop
- Ampere's law and its applications to infinitely long straight wire
- Straight and toroidal solenoids
- Force on a moving charge in uniform magnetic and electric fields
- Cyclotron
- Force on a current-carrying conductor in a uniform magnetic field
- Force between two parallel current-carrying conductors-definition of ampere
- Torque experienced by a current loop in uniform magnetic field; moving coil galvanometer-its current sensitivity and conversion to ammeter and voltmeter.

Chapter 5: Magnetism and Matter

- Current loop as a magnetic dipole and its magnetic dipole moment
- Magnetic dipole moment of a revolving electron
- Magnetic field intensity due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis
- Torque on a magnetic dipole (bar magnet) in a uniform magnetic field –
  - Bar magnet as an equivalent solenoid
  - Magnetic field lines
  - Earth's magnetic field
  - Magnetic elements
- Para-, dia- and ferro - magnetic substances, with examples
- Electromagnets and factors affecting their strengths
- Permanent magnets

Unit IV: Electromagnetic Induction and Alternating Currents

Chapter 6: Electromagnetic Induction

- Electromagnetic induction –

- Faraday's laws
- Induced EMF and current
- Lenz's Law
- Eddy currents

- Self and mutual induction.

Chapter 7: Alternating Current

- Alternating currents –
  - Peak and RMS value of alternating current/voltage
  - Reactance and impedance
  - LC oscillations (qualitative treatment only)
  - LCR series circuit
  - Resonance
  - Power in AC circuits
  - Wattless current
- AC generator and transformer

Unit V: Electromagnetic waves

Chapter 8: Electromagnetic Waves

- Basic idea of displacement current, Electromagnetic waves, their characteristics, their transverse nature (qualitative ideas only).
- Electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays) including elementary facts about their uses.

Unit VI: Optics

Chapter 9: Ray Optics and Optical Instruments

- Ray Optics –
  - Reflection of light
  - Spherical mirrors
  - Mirror formula
  - Refraction of light
  - Total internal reflection and its applications
  - Optical fibres
  - Refraction at spherical surfaces
  - Lenses
  - Thin lens formula
  - Lens maker's formula

- Magnification, power of a lens, combination of thin lenses in contact combination of a lens and a mirror
- *Refraction and dispersion of light through a prism.*
- Scattering of light - blue colour of sky and reddish appearance of the sun at sunrise and sunset
- Optical instruments: Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers

Chapter 10: Wave Optics

- Wave optics: Wave front and Huygens's principle, reflection and refraction of plane wave at a plane surface using wave fronts
- Proof of laws of reflection and refraction using Huygens's principle
- Interference Young's double slit experiment and expression for fringe width, coherent sources and sustained interference of light
- Diffraction due to a single slit, width of central maximum
- Resolving power of microscopes and astronomical telescopes
- Polarisation, plane polarised light Brewster's law, uses of plane polarised light and Polaroid's

Unit VII: Dual Nature of Matter and Radiation

Chapter 11: Dual Nature of Radiation and Matter

- Dual nature of radiation
- Photoelectric effect
- Hertz and Lenard's observations
- Einstein's photoelectric equation-particle nature of light
- Matter waves-wave nature of particles, de Broglie relation
- Davisson-Germer experiment (experimental details should be omitted; only conclusion should be explained).

Unit VIII: Atoms & Nuclei

Chapter 12: Atoms

- Alpha-particle scattering experiment
- Rutherford's model of atom
- Bohr model
- Energy levels
- Hydrogen spectrum

Chapter 13: Nuclei

- Composition and size of –
  - Nucleus
  - Atomic masses
  - Isotopes
  - Isobars
  - Isotones
- Radioactivity alpha, beta and gamma particles/rays and their properties
- Radioactive decay law
- Mass-energy relation –
  - Mass defect
  - Binding energy per nucleon and its variation with mass number
  - Nuclear fission
  - Nuclear fusion

Unit IX: Electronic Devices

Chapter 14: Semiconductor Electronics: Materials, Devices and Simple Circuits

- Energy bands in conductors, semiconductors and insulators (qualitative ideas only)
- Semiconductor diode - I-V characteristics in forward and reverse bias, diode as a rectifier
- Special purpose p-n junction diodes: LED, photodiode, solar cell and Zener diode and their characteristics, zener diode as a voltage regulator
- Junction transistor, transistor action, characteristics of a transistor and transistor as an amplifier (common emitter configuration), basic idea of analog and digital signals, Logic gates (OR, AND, NOT, NAND and NOR).

Unit X: Communication Systems

Chapter 15: Communication Systems

- Elements of a communication system (block diagram only)
  - Bandwidth of signals (speech, TV and digital data)
  - Bandwidth of transmission medium
- Propagation of electromagnetic waves in the atmosphere, sky and space wave propagation, satellite communication
- Need for modulation, amplitude modulation and frequency modulation, advantages of frequency modulation over amplitude modulation
- Basic ideas about internet, mobile telephony and global positioning system (GPS).

1 ELECTRIC CHARGES AND FIELDS

Electric Charges –

- Conservation of charge
- Coulomb's law-force between two-point charges
- Forces between multiple charges
- Superposition principle
- Continuous charge distribution

Electric field, electric field due to a point charge, electric field lines, electric dipole, electric field due to a dipole, torque on a dipole in uniform electric field.

Electric flux, statement of Gauss's theorem and its applications to find field due to, infinitely long straight wire, uniformly charged infinite plane sheet and uniformly charged thin spherical shell (field inside and outside).

Objective of the chapter

The main objective of this chapter is to make student understand about the concepts of charge and its related law's. Electric flux Gauss's theorem and its applications has also been explained in this chapter.

Introduction

You may have seen a spark (or a crackle sound), when we take off our synthetic clothes. Have you ever tried to find any explanation for this phenomenon? Do you know the reason for lightning?

The above phenomenon can be explained on the basis of static electricity. Static means anything that does not change with time. Electrostatics deals with the properties of charges at rest.

Electric Charge

It is found experimentally that the charges are of two types:

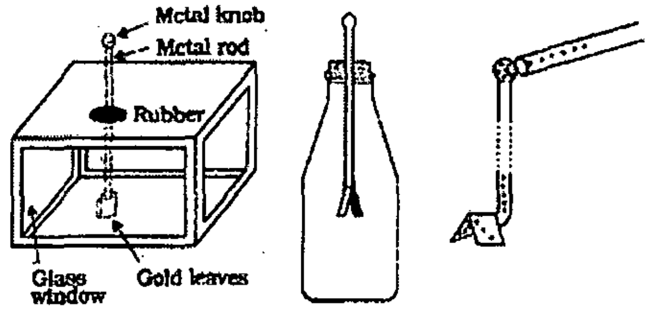
1. Positive charge
2. Negative change

The unit of charge is Coulomb (c).

Note: Positively charged body means deficiency of electrons in the body and a negatively charged body means excess of electrons.

Gold-Leaf electroscope: A simple apparatus to detect charge on a body is called a gold-leaf electroscope.

Apparatus: It consists of a vertical metal rod placed in a box. Two thin gold leaves are attached to its bottom end as shown in figure.



Working: A charged object touches the metal knob at the top of the rod. Charge flows on to the leaves and they diverge. The degree of divergence is an indicator of the amount of charge.

Conductors and Insulators

Conductors: Conductors are those substances which allow passage of electricity through them.

Insulators: Insulators are those substances which do not allow passage of electricity through them.

1. Earthing (Or) Grounding:

When a charged body bring in contact with earth, all the excess charge pass to the earth through the connecting conductor. This process of sharing the charges with the earth is called grounding or earthling. Earthing provides protection to electrical circuits and appliances.

Charging by Induction

A body can be charged in different ways.

1. Charging by friction
2. Charging by conduction
3. Charging by induction

1. Charging by friction:

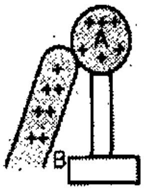
When two bodies are rubbed each other, electrons in one body (in which electrons are held less tightly) transferred to second body (in which electrons are held more tightly).

Explanation: When a glass rod is rubbed with silk, some of the electrons from the glass are transferred to silk. Hence glass rod gets +ve charge and silk gets -ve charge.

2. Charging by conduction:

Charging a body with actual contact of another body is called charging by conduction.

Explanation:



If a neutral conducting body (A) is brought in contact with positively charged conducting body (B), the neutral body gets positively charged.

3. Charging by induction:

The phenomenon by which a neutral body gets charged by the presence of neighbouring charged body is called electrostatic induction.

Explanation:

Step I: Place two metal spheres on an insulating stand and bring in contact as shown in figure (a).

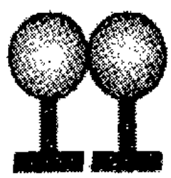


Figure (a)

Step II: Bring a positively charged rod near to these spheres. The free electrons in the spheres are attracted towards the rod. Hence, one side of the sphere becomes negative and the other side becomes positive as shown in figure (b).

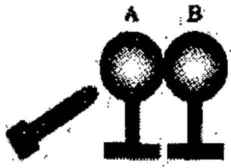


Figure (b)

Step III: Separate the spheres by a small distance by keeping the rod near to sphere A. The two spheres are found to be oppositely charged as shown in figure (c).

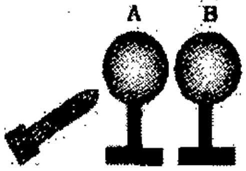


Figure (c)

Step IV: Remove the rod, the charge on spheres rearrange themselves as shown in figure (d).

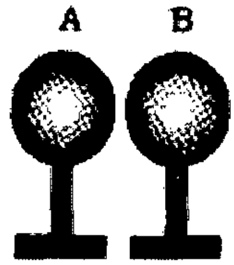


Figure (d)

In this process, equal and opposite charges are developed on each sphere.

Basic Properties of Electric Charge

1. Unlike charges attract and like charges repel.
2. Charge is conserved: Changes can neither be created nor be destroyed.

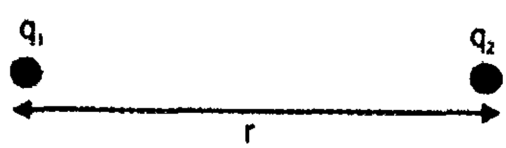
   Explanation: When a glass rod is rubbed with silk, some of the electrons from the glass are transferred to silk. Hence glass rod gets +ve change and silk gets -ve changes.
3. Electric Charge is Quantized: Change on anybody is the integral multiple of electronic charge. This is called quantization of charge.

   i.e. $q = \pm ne$, $n = 1, 2, 3, \ldots\ldots\ldots$
4. Additivity of Charges: If a system contains n charges q1, q2, q3,........qn, then the total change of the system is q1 + q2 + q3 +......+qn.

Coulomb's Law

Statement: The force between two stationary electric charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.

Explanation:



Consider two-point charges q1 and q1. which are separated by a distance 'r'. The force between the changes.

$\mathrm{F}=\frac{1}{4\pi\varepsilon_{0}}\frac{\mathrm{q}_{1}\mathrm{q}_{2}}{\mathrm{r}^{2}}$ vector form: The force F12 (on the first charge by second} is given by (vector form)

$$\vec{F_{12}} = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2} \hat{r_{12}}$$

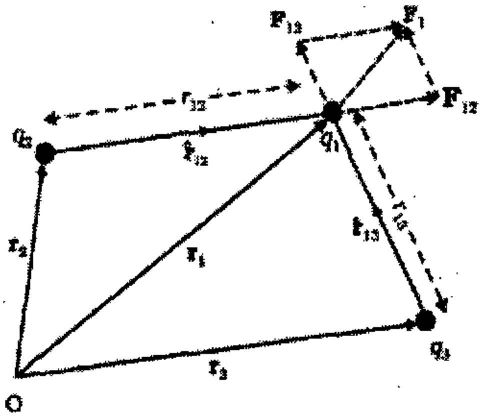
Where $\frac{1}{4\pi\varepsilon_0} = 9x10^9 Nm^2 / c^2$

and $\hat{r_{12}}$ is the unit vector

Forces Between Multiple Charges

Super position principle: If the system contains a number of interacting changes, then the force on a given charge is equal to the vector sum of the forces exerted on it by all remaining charges.

Explanation:



Consider a system of three charges q1 q2 and q3 as shown in figure.

The force on q1 due to q2

\(\over right arrow{F_{12}}=\frac{1}{4 \pi \varepsilon_{0} r_{12}^{2}} r_{12}^{\wedge}\)

Similarly the force q1 due to q3\(\over right arrow{F_{13}}=\frac{1}{4 \pi \varepsilon_{0}} \frac{q_{1} q_{2}}{r_{13}^{2}} r_{13}^{\wedge}\)

The total force F1 on q1 (due to q2 and q3) can be written as

$$\vec{F_1} = \vec{F_{12}} + \vec{F_{13}}$$

$$\vec{F_1} = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r_{12}^2} \hat{r_{12}} + \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_3}{r_{13}^2} \hat{r_{13}}$$

System of 'n' charges: If system contains 'n' charges, total force acting on q1 due to all other charges.

$$\vec{F_1} = \vec{F_{12}} + \vec{F_{13}} + \vec{F_{14}} + \ldots\ldots\ldots\ldots \vec{F_{1n}}$$

CLASS–12

Physics

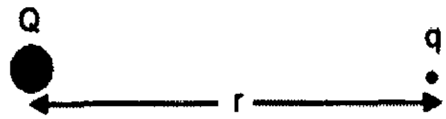
Notes

Electric Field

The concept electric field is introduced to explain the interaction between two charges.

Electric field intensity: Strength or intensity of the electric field at any point is defined as the force acting on a unit positive charge placed at that point.

Mathematical expression of electric field intensity:



Consider a charge q (test charge) at a distance 'r' from a source charge Q.

The force acting on q due to Q.

$\mathrm{F}=\frac{1}{4 \pi \varepsilon_{0}} \frac{\mathrm{Qq}}{\mathrm{r}^{2}}$

If q = 1, the force acting on this unit charge due to Q

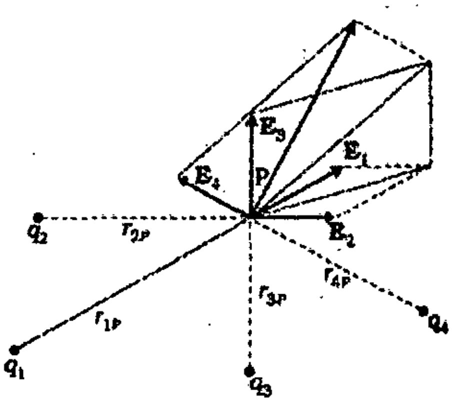
$\mathrm{F}=\frac{1}{4 \pi \varepsilon_{0}} \frac{\mathrm{Q}}{\mathrm{r}^{2}}$

This force is called electric field intensity at a distance 'r' due to the charge Q.

ie; $E=\frac{1}{4 \pi \varepsilon_{0}} \frac{Q}{r^{2}}$

1. Electric field due to a system of charges:

Consider a system of charges q1, q2.......... qn. Let P be point at distances r1p, r2p,...........rnp from charges. q1, q2,........qn respectively. According to super position principle, total electric field at 'p' due to all other charges,



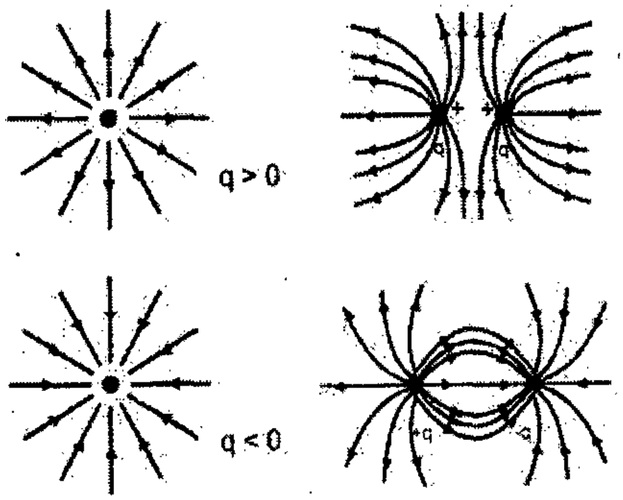
$$\vec{E}=\vec{E}_1+\vec{E}_2+\ldots\ldots\ldots\ldots\ldots\ldots+\vec{E}_n$$

2. Physical Significance Of Electric Field:

- Electric field explains the electrical environment of a system of charges.
- Electric field help us to explain the interaction between two charges at rest or in motion.

Electric Field Lines

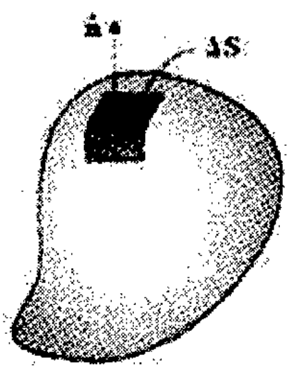
Properties of Electric Lines of Force



(Field lines due to some simple charge configurations)

1. An electric line of force originates from positive charge and ends on negative charge.
2. The tangent drawn at a point on an electric line of force will give the direction of electric field at that point.
3. Two lines of force never intersect each other. (If they cut each other, at the point of intersection there will be two tangents. This indicates that there will be two directions of electric field at the same point which is impossible).
4. The number of electric lines of force passing normally through an area is directly proportional to the strength of the electric field.
5. The relative density of the field lines indicates the relative strength of electric field.
6. Electric field lines due to static charge never form closed loops.
7. In a uniform electric field, lines of force are parallel.

Electric Flux



Consider a closed surface. Let $\Delta\vec{S}$ be a small area element on the surface. The electric field lines (E) pass through this area element at an angle θ. Electric flux ΔΦ through an area element $\Delta\vec{S}$ is defined by

$$\Delta\phi = \vec{E}.\vec{\Delta s}$$

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

The direction of area vector $d\vec{S}$ is perpendicular to the surface.

Electric Dipole

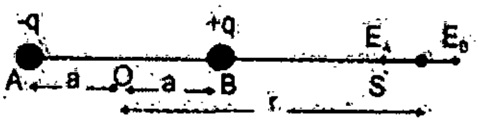
Electric dipole: A pair of equal and opposite charges separated by small distance is called electric dipole. Dipole moment (p): Electric dipole moment (p) is defined as product of magnitude of charge and dipole length.

Dipole moment p = q × 2a

q – charge, 2a – dipole length

Dipole moment is a vector, directed from negative to positive charge.

1. Electric field at a point on the axial line of an electric dipole: Consider an electric dipole of moment P = 2aq. Let 'S' be a point at a distance 'r' from the centre of the dipole.



Electric field at 'S' due to point charge at 'A'

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

Directed as shown in figure. Electric field at 'S' due to point charge at 'B'

$$E_B = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-a)^2}$$

Directed as shown in figure. Therefore, resultant electric field at 'S'

And its magnitude E = EB + -EA

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

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

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

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

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

$P = q \times 2a$

We can neglect a2 because a<<r.

□ Electric field at S,

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2P}{r^3}$$

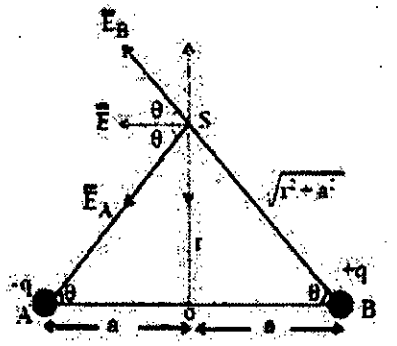
This can be written in vector form as

$$\vec{E}_S = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{P}}{r^3}$$

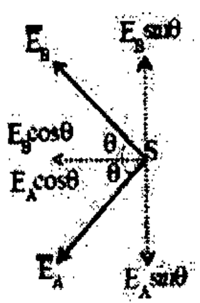
The direction is along EB.

The field due to an electric dipole is directed from negative charge to positive charge along the axial line.

2. Electric field due to a dipole at a point on the perpendicular bisector of the dipole (at a point on the equatorial line).



Consider a dipole of dipole moment P = 2aq. Let 'S' be a point on its equatorial line at a distance 'r' from its centre. The magnitudes of electric field at 'S' due to +q and -q are equal and acts as shown in figure. To find the resultant electric field resolve



Notes

Their normal components cancel each other whereas their horizontal components add up to give the resultant field at 'S'.

E = EAcos θ + EBcos θ = 2 EB cos θ

$$\left(\text{Since } E_A = E_B = \frac{1}{4\pi\varepsilon_0}\frac{q}{\left(r^2+a^2\right)}\right)$$

$$\text{Cos}\theta = \frac{a}{\sqrt{\left(r^2+a^2\right)}}$$

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

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2aq}{(r^2+a^2)^{3/2}}$$

$$\text{But } (r^2+a^2)^{3/2} \approx (r^2)^{3/2} = r^3 \text{ (since a<<r)}$$

$$\vec{E}(s) = \frac{1}{4\pi\varepsilon_0}\frac{P}{r^3} \quad \text{where P=2aq}$$

The direction of the field due to the dipole at a point on the equatorial line is opposite to the direction of dipole moment.

3. Physical significance of dipole: The molecules of dielectrics may be classified into two classes:

(i) Polar molecules: In polar molecule, the centres of negative charges and positive charges do not coincide. Therefore, they have a permanent

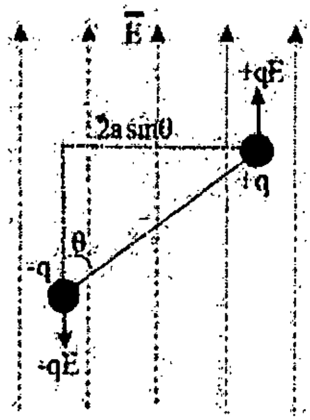
Example: H20, HCl, etc.

(ii) Nonpolar molecule: In nonpolar molecule, the centres of negative charges and positive charges coincide. Therefore they have no permanent electric dipole moment.

Example: C02, CH4, etc.

Note: In the presence of external electric field, a nonpolar molecule becomes a polar molecule.

Dipole in A Uniform External Field



Consider an electric dipole of dipole moment $P = 2aq$ kept in a uniform external electric field, inclined at an angle θ to the field direction.

Equal and opposite forces $+qE$ and $-qE$ act on the two charges. Hence the net force on the dipole is zero. But these two equals and opposite forces whose lines of action are different. Hence there will be a torque.

torque = any one force × perpendicular distance (between the line of action of two forces)

$\tau = qE \times 2\, a \sin\theta$

Since $P = 2aq$

$\tau = P\, E \sin\theta$

Vectorialy $\vec{\tau} = \vec{P} \times \vec{E}$

This torque tries to align the dipole along the direction of the external field.

Special Case:

- When $\theta = 0$; $\tau = 0$
- When $\theta = 90$; $\tau = PE$, the maximum.

Note: In uniform electric field dipole has only rotational motion

Dipole in non-uniform electric field:

In non-uniform electric field, the net force and torque acting on the dipole will not be zero. Hence the dipole undergoes for both translational and rotational motion.

Continuous Charge Distribution

Charges on a body may be distributed in different ways according to the nature of body. Depending upon this distribution of charge, we deal with different types of charge densities,

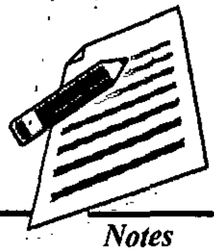
1. Line charge density, λ
2. Surface charge density, σ or
3. Volume charge density, ρ

1. Linear charge density (λ): Charge per unit length is called linear charge density. If ΔQ is the charge contained in a line element Δl,

   Linear charge density $\lambda = \frac{\Delta Q}{\Delta l}$
2. Surface charge density (σ): Charge per unit area is called surface charge density. If ΔQ is the charge contained in an area element Δs, surface charge density can be written as

   $\sigma = \frac{\Delta Q}{\Delta S}$
3. Volume charge density (ρ): Charge per unit volume is called volume change density. If ΔQ is the charge contained in a volume Δv, volume charge density.

   $\rho = \frac{\Delta Q}{\Delta v}$



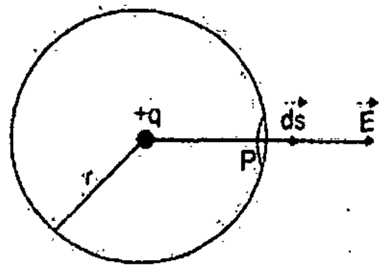
Gauss's Law

Gauss's theorem states that the total electric flux over a closed surface is 1/ε0 times the total charge enclosed by the surface.

Gauss's theorem may be expressed

$$\int \vec{E}.d\vec{s} = \frac{1}{\varepsilon_0} q \quad \text{or} \quad \phi = \frac{1}{\varepsilon_0} q$$

Proof:



Consider a charge +q. which is kept inside a sphere of radius 'r'.

The flux at 'P' can be written as, $\phi = \int \vec{E}.d\vec{s}$

But electric field at P, $E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$

$$\therefore \quad \vec{E}.\vec{ds} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} ds$$

Integrating on both sides we get,

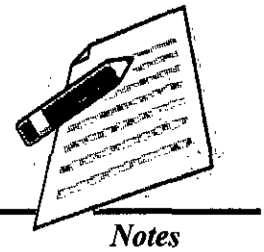
$$\int \vec{E}.\vec{ds} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\int ds$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} 4\pi r^2 \qquad \left[\therefore \int ds = 4\pi r^2\right]$$

$$\int \vec{E}.d\vec{s} = \frac{1}{\varepsilon_0} q$$

Important points regarding Gauss's law:

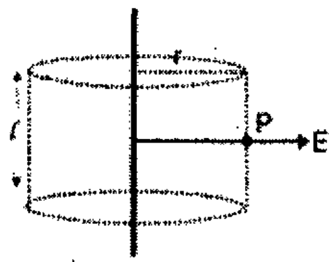
- Gauss's law is true for any closed surface.
- Total charge enclosed by the surface must be added (algebraically). The charge may be located anywhere inside the surface.
- The surface that we choose for the application of Gauss's law is called the Gaussian surface.
- Gauss's law is used to find electric field due to system of charges having some symmetry.
- Gauss's law is based on the inverse square of distance. Any violation of Gauss's law will indicate departure from the inverse square law.



Applications of Gauss's Law

Gauss's law can be used to find electric field due to system of some symmetric charge configurations. Some examples are given below.

1. Field Due to An Infinitely Long Straight Uniformly Charged Wire:



Consider a thin infinitely long straight rod conductor having change density λ. (λ = \(\frac{q}{l} \))

To find the electric field at P, we imagine a Gaussian surface passing through P.

Then according to Gauss's law, we can write,

$$\int \vec{E}.d\vec{s} = \frac{1}{\varepsilon_0}q$$

$$\int E ds \cos\theta = \frac{1}{\varepsilon_0}q \qquad (\theta=0^0)$$

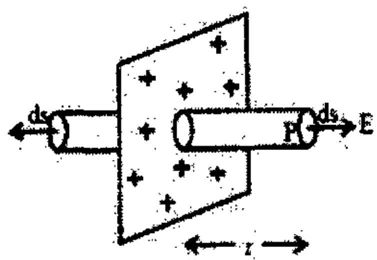
$$E\int ds = \frac{\lambda l}{\varepsilon_0} \qquad (\text{since } q = \lambda l)$$

Integrating over the Gaussian surface, we get (we need not integrate the upper and lower surface because, electric lines do not pass through these surfaces.)

$$E2\pi rl = \frac{\lambda l}{\varepsilon_0} \qquad (\text{L.S.A. of cylinder} = 2\pi rl)$$

$$E = \frac{1}{2\pi rl}\frac{\lambda l}{\varepsilon_0} \qquad E = \frac{1}{2\pi\varepsilon_0}\frac{\lambda}{r}$$

2. Field Due to A Uniformly Charged Infinite Plane Sheet



Consider an infinite thin plane sheet of change of density σ. To find electric field at a point P (at a distance 'r' from sheet), imagine a Gaussian surface in the form of cylinder having area of cross section 'ds'.

According to Gauss's law we can write,

$$\int \vec{E}.d\vec{s} = \frac{1}{\varepsilon_0} q$$

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

(Since $q = \sigma ds$)

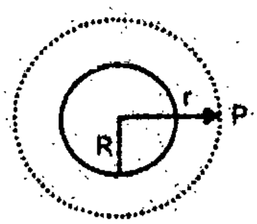
But electric field passes only through end surfaces, so we get $\int ds = 2ds$

ie. $$E\,2ds = \frac{\sigma ds}{\varepsilon_0}$$

$$E = \frac{\sigma ds}{2ds\varepsilon_0}, \qquad E = \frac{\sigma}{2\varepsilon_0}$$

E is directed away from the charged sheet, if a is positive and directed towards the sheet if a is negative.

3. Field Due to A Uniformly Charged Thin Spherical Shell: Consider a uniformly changed hollow spherical conductor of radius R. Let 'q' be the total charge on the surface.



To find the electric field at P (at a distance r from the centre), we imagine a Gaussian spherical surface having radius 'r'.

Then, according to Gauss's theorem we can write,

$$\int \vec{E}.d\vec{s} = \frac{1}{\varepsilon_0} q$$

The electric field is constant, at a distance 'r'. So, we can write,

$$E\int ds = \frac{1}{\varepsilon_0} q$$

$$E.4\pi r^2 = \frac{1}{\varepsilon_0} q$$

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

Case I: Electric field inside the shell is zero.

Case II: At the surface of shell $r = R$

$$\therefore\ E = \frac{1}{4\pi\varepsilon_0} \frac{q}{R^2}$$

Summary of the chapter

Electric Charge

The term "electricity" is derived from Elektron, a Greek word meaning amber. The properties of matter, atoms and molecules are determined by the magnetic and electric forces present in them. There are also only 2 kinds of an entity called the electric charge. An experiment conducted also suggested that there are two kinds of electrification wherein (i) like charges repel and (ii) unlike charges attract each other. The property that differentiates these 2 kinds of charges is called the polarity of charge.

Conductors and Insulators

When an experiment was conducted on electric charges due to frictional electricity, it was found that conductors assist in the movement of electric charge, but insulators do not behave in the same manner. Metal, Earth, Human Bodies are all examples of conductors, while porcelain, nylon, wood all offer high resistance to the passage of electricity through them, as they are insulators.

What are the properties of Electric charge?

An electric charge has three fundamental properties:

- **Quantization**- This property states that the total charge of a body represents the integral multiple of a basic quantum of charge.
- **Additive**- This property of electric charges represents the total charge of a body as the algebraic sum all the singular charges acting on the system.
- **Conservation**- This property states that the total charge of a system remains unaffected with time. In other words, when objects get charged due to friction, a transfer of charge from the one object to another occurs. Charges can neither be created nor destroyed.

Coulomb's Law

The coulomb's law states that the mutual electrostatic force existing between two point charges A and B is proportional to their product which is AB and inversely proportional to the square of the distance between them (r_{AB}). The equation is $F_{BA}= force\, on\, B\, due \, to \, A = k(AB)\div r_{AB}^{2}$

Mathematically,

This law consists of constant terms which are also called a constant of proportionality and is represented by 'k' and its values are $k=9 * 10^{9} Nm^{2}C^{-2}$ $Nm^{2} C^{-2}$

Multiple choice Questions

1. Which one of the following is the unit of electric field?
   (a) Coulomb
   (b) Newton
   (c) Volt
   (d) N/C
   Answer: (d) N/C
2. Three charges + 3q + q and Q are placed on a st. line with equal separation. In order to make the net force on q to be zero, the value of Q will be:
   (a) +3q
   (b) +2q
   (c) -3q
   (d) -4q
   Answer: (a) +3q
3. If an electric dipole is kept in a uniform electric field then resultant electric force on it is :
   (a) always zero
   (b) never zero
   (c) depend upon capacity of dipole
   (d) None
   Answer: (a) always zero
4. The number of electron-taken out from a body to produce 1 coulomb of charge will be :
   (a) 6.25 × 1018
   (b) 625 × 1018
   (c) 6.023 × 1023
   (d) None
   Answer: (a) 6.25 × 1018

5. The work done in rotating an electric dipole in an electric field:
   (a) $W = ME (1 - \cos\theta)$
   (b) $W = ME \tan\theta$
   (c) $W = ME \sec\theta$
   (d) None
   Answer: (a) $W = ME (1 - \cos\theta)$
6. If sphere of bad conductor is given charge then it is distributed on:
   (a) surface
   (b) inside the surface
   (c) only inside the surface
   (d) None
   Answer: (d) None
7. Electric field in a cavity of metal:
   (a) depends upon the surroundings
   (b) depends upon the size of cavity
   (c) is always zero
   (d) is not necessarily zero
   Answer: (d) is not necessarily zero
8. The dielectric constant of a metal is:
   (a) 0
   (b) 1
   (c) ∞
   (d) -1
   Answer: (c) ∞
9. 1 coulomb is equal to:
   (a) 3×109 e.s.u.
   (b) $\frac{1}{3} \times 109$ e.s.u.
   (c) 3×1010 e.s.u.
   (d) $\frac{1}{3} \times 1010$ e.s.u.
   Answer: (a) 3×109 e.s.u.
10. Each of the two-point charges are doubled and their distance is halved. Force of interaction becomes p times, w here p is:
   (a) 1
   (b) 4
   (c) $\frac{1}{16}$
   (d) 16
   Answer: (d) 16

Review Questions

1. Derive an expression for the electric field at a point
   a. the axial position of an electric dipole.
   b. on the equatorial position of an electric dipole.

   Derive an expression for the torque on an electric dipole in a uniform electric field.
2. State Gauss theorem and apply it to find the electric field due to a uniformly charged spherical conducting shell at a point
   a. Outside the shell
   b. Inside the shell
   c. on the shell

   Also Draw a graph showing a variation of electric field E with distance r from center of the uniformly charged spherical conducting shell
3. State Gauss theorem and apply it to find the electric field intensity due to an infinitely long straight wire of linear charge density λ C/m
4. State Coulomb's law and express it in vector form. Derive it using Gauss theorem.
5. A charge q is uniformly distributed over a ring of radius r. Derive an expression for electric field at a point on the axis on the ring. Also shows that for point at large distance from center of the ring, it behaves like a point charge only

2 ELECTROSTATIC POTENTIAL AND CAPACITANCE

- Electric potential, potential difference, electric potential due to a point charge, a dipole and system of charges
- Equipotential surfaces, electrical potential energy of a system of two-point charges and of electric dipole in an electrostatic field
- *Conductors and insulators, free charges and bound charges inside a conductor*
- Dielectrics and electric polarisation, capacitors and capacitance, combination of capacitors in series and in parallel, capacitance of a parallel plate capacitor with and without dielectric medium between the plates, energy stored in a capacitor.

> **Objective of the chapter**
>
> The main objective of this chapter is to make student understand about the concepts of Electric potential including a dipole and system of charges. Conductors and insulators have also been explained in this chapter.

Introduction

The electric field strength is a vector quantity, while the electric potential is a scalar quantity. Both these quantities are interrelated.

Electrostatic Potential

1. Electric potential: The electric potential at a point is the work done by an external agent in moving a unit positive charge from infinity to that point against the electric field *(without acceleration)*

Explanation: If W is the work done in moving a charge 'q' from infinity to a point, then the potential at

that point is, V = \(\frac{w}{q} \)

Potential difference: Electric potential difference between two points is the work done in moving a unit positive charge from one point to another.

The potential difference between points A and B is

VAB = VA – VB

VA and VB are the potentials at points A and B respectively.

Potential energy difference: Potential energy difference is the work done to bring a q charge from one point to another point without acceleration.

Relation between potential difference and potential energy difference:

$$V_A - V_B = \left(\frac{U_A - U_B}{q}\right)$$

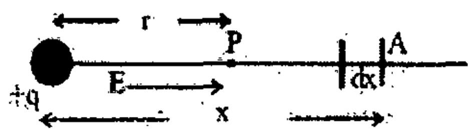
where UA and UB are the potential energies at points A and B respectively.

Electric field is conservative: Electric field is conservative. A conservative field is defined as the field in which work done is zero in a complete round trip.

(or)

A conservative field is one in which work done is independent of path.

Potential Due to A Point Charge



Let P be a point at a distance Y from a charge +q. Let A be a point at a distance 'x' from q , and E is directed along with PA. Consider a positive charge at A. Then the electric field intensity at A' is given by

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{x^2}$$

If this unit charge is moved (opposite to E) through a distance dx, the work done dw = – Edx

[-ve sign indicates that dx is opposite to E]

So the potential at 'P' is given by

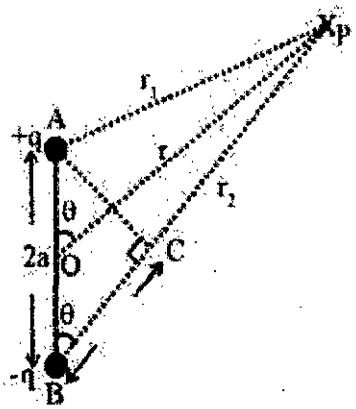
$$V = -\int_{\infty}^{r} E\,dx \qquad V = -\int_{\infty}^{r} \frac{1}{4\pi\varepsilon_0}\frac{q}{x^2}\,dx$$

$$V = \frac{-q}{4\pi\varepsilon_0}\int_{\infty}^{r} x^{-2}\,dx \qquad V = \frac{-q}{4\pi\varepsilon_0}\left[\frac{-1}{x}\right]_{\infty}^{r}$$

$$V = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{x}\right]_{\infty}^{r} \qquad V = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r} - \frac{1}{\infty}\right]$$

$$\boxed{V = \frac{+q}{4\pi\varepsilon_0}\frac{1}{r}} \qquad \left(\text{since } \frac{1}{\infty} = 0\right)$$

Potential due to an electric dipole



Consider dipole of length ‘2a’. Let P be a point at distance r1 from +q and r2 from -q. Let ‘r’ be the distance of P from the centre ‘O’ of the dipole. Let θ be angle between dipole and line OP.

The potential due to +q, $V_+ = \frac{1}{4\pi\varepsilon_0}\frac{+q}{r_1}$

The potential due to -q, $V_- = \frac{1}{4\pi\varepsilon_0}\frac{-q}{r_2}$

Therefore, total potential,

$$V = \frac{1}{4\pi\varepsilon_0}\frac{+q}{r_1} + \frac{1}{4\pi\varepsilon_0}\frac{-q}{r_2}$$

$$= \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) = \frac{q}{4\pi\varepsilon_0}\left(\frac{r_2 - r_1}{r_1 r_2}\right) \text{———(1)}$$

From ΔABC, we get (r2 – r1) = 2a cosθ

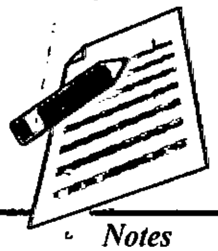
we can also take r2 = r1 = r (since ‘2a’ is very small) Substituting these values in equation (1), we get

$$V = \frac{q}{4\pi\varepsilon_0}\left(\frac{2a\cos\theta}{r^2}\right)$$

$$V = \frac{1}{4\pi\varepsilon_0}\frac{P\cos\theta}{r^2} \qquad \text{(since P =q2a)}$$

But $\vec{P}.\hat{r} = P\cos\theta$, **where** $\hat{r} = \frac{\vec{r}}{|r|}$

$$V = \frac{1}{4\pi\varepsilon_0}\frac{\vec{P}.\hat{r}}{r^3}$$



Notes

Case 1: If the point lies along the axial line of the dipole, then $\theta = 0°$

Therefore $V = \frac{1}{4\pi\varepsilon_0} \frac{P\cos 0}{r^2}$

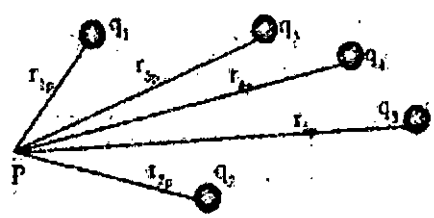
$$\boxed{V = \frac{1}{4\pi\varepsilon_0} \frac{P}{r^2}}$$

Case 2: If the point lies along the equatorial line of the dipole, then $\theta = 90°$

$$V = \frac{1}{4\pi\varepsilon_0} \frac{P\cos 90}{r^2}$$

$V = 0$

Potential Due to A System of Charges



Consider a system of charges q1, q2,……,qn with position vectors r1P, r2P……..,rnP relative to

some origin. The potential V1 at P due to the charge q1 is

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

where r1P is the distance between q1 and P. Similarly, the potential V2 at P due to q2,

$$V_2 = \frac{1}{4\pi\varepsilon_0} \frac{q_2}{r_{2P}}$$

where r2P is the distances of P from charges q2. By the superposition principle, the potential V at P due to the total charge configuration is the algebraic sum of the potentials due to the individual charges.

ie. V = V1 + V2 +……+ Vn

$$V = \frac{1}{4\pi\varepsilon_0} \frac{q_1}{r_{1P}} + \frac{1}{4\pi\varepsilon_0} \frac{q_2}{r_{2P}} + \dots\dots\dots\dots + \frac{1}{4\pi\varepsilon_0} \frac{q_n}{r_{nP}}$$

$$V = \frac{1}{4\pi\varepsilon_0} \left(\frac{q_1}{r_{1P}} + \frac{q_2}{r_{2P}} + \dots\dots\dots\dots + \frac{q_n}{r_{nP}} \right)$$

Equipotential Surface

The surface over which the electric potential is same is called an equipotential surface.

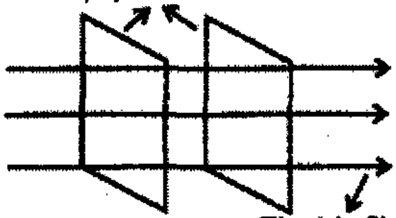
Properties:

1. Direction of electric field is perpendicular to the equipotential surface.
2. No work is done to move a charge from one point to another along the equipotential surface.

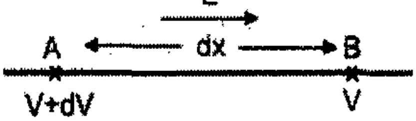
Example:

1. Surface of a charged conductor.
2. All *points equidistant from a point charge.*

Equipotential surfaces for a uniform electric filed:



1. Relation Between Electric Field and Potential:



Consider two points A and B, separated by very small distance dx. Let the potential at A and B be V+ dV and V respectively. The electric field is directed from A to B. If a unit +ve charge is moved through a distance 'dx' against this field, work done,

dw = -Edx _____ (1)

For unit charge dw = dv

□ dv = – Edx

or

$$\boxed{E = \frac{-dV}{dx}}$$

Electric field intensity at a point is the negative rate of change of potential with distance.

CLASS–12

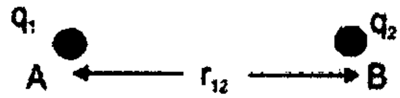
Physics

Notes

Potential Energy of System of Charges

1. Potential Energy of System of Two Charges:

The potential energy of a system of two charges is defined as the work done in assembling this system of charges at the given position from infinite separation.



Consider two charges q1 and q2 separated by distance r. Imagine q1 to be at A and q2 at infinity. Electric potential at B due to charge q1 is given by

$$V_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_{12}}$$

which is the work done in bringing unit positive charge from infinity to B. Therefore, the work done in bringing charge q2 from infinity to B is

W = potential difference × charge

$W = (V1 - V\infty)\, q2$

potential at infinity. $V\infty = 0$

$W = V1 \times q2$

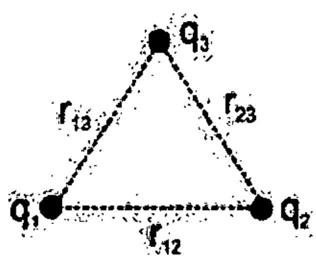
$$W=\frac{1}{4\pi\varepsilon_{0}}\frac{q_{1} q_{2}}{r_{12}}$$

This work done is stored as potential energy. Hence potential energy between the charges q1 and q2

$$\text{i.e. } \boxed{U_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}}$$

2. Potential Energy of System of Three Charges:

Consider three charges q1, q2, and q3 separated by distances r12, r23 and r13.



The electric potential energy of this system is the sum of potential of each pair. Hence, we can write

U = U12 + U23 + U13

$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r_{12}} + \frac{1}{4\pi\varepsilon_0}\frac{q_2q_3}{r_{23}} + \frac{1}{4\pi\varepsilon_0}\frac{q_1q_3}{r_{13}}$$

$$\boxed{U = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1q_2}{r_{12}} + \frac{q_2q_3}{r_{23}} + \frac{q_1q_3}{r_{13}}\right)}$$

Potential Energy In An External Field

1. Potential energy of a single charge:

Consider a point O in an electric field. Let V be the electric potential at O. Hence work done in bringing a charge q from infinity to the point O is,

W = Vq.

This work done is stored in the form of electrostatic potential energy (U) of the charge q.

□ The potential energy of the charge q in an electric field is U = Vq

Where V is the potential at that point.

2. Potential energy of a system of two charges in an electric field:

Consider an electric field. Let 1 and 2 be two points in the field and V1 and V2 be the potential at these points. Two charges q1 and q2 are located at 1 and 2.

Potential energy of the charge q1 in the external filed is, U1 = V1 q1

Potential energy of the charge q2 in the external field is, U2 = V2q2

Potential energy between the system of two charges q1 and q2

$$U_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r_{12}}$$

where r12 is the distance between the charges According to the principle of superposition, the potential energy of the system of two charges in an electric field is

U = U1 + U2 + U12

$$U = V_1q_1 + V_2q_2 + \frac{1}{4\pi\varepsilon_0} \times \frac{q_1q_2}{r_{12}}$$

3. Potential energy of a dipole in an external field:

Consider a dipole of dipole moment 'P' suspended in a uniform electric field of intensity 'E'.

Let θ be the angle between P and E.

Then we know torque $\tau = PE\sin\theta$

Let the dipole be turned through an angle $d\theta$

then work done $dw = \tau d\theta$

$= PE\sin\theta\, d\theta$

Total work done in rotating the dipole from $\theta 1$ to $\theta 2$

$$W = \int_{\theta_1}^{\theta_2} PE\sin\theta\, d\theta$$

$W = PE(\cos\theta 1 - \cos\theta 2)$

This work done is stored as potential energy.

Electrostatics of Conductors

The electrostatic properties of conductors are given below:

1. Inside a conductor, the electrostatic field is zero:

   In the static situation, there is no current found inside the conductor. Hence, we conclude that the electric field is zero inside the conductor the vanishing of the electric field inside the metal cavity is called electrostatic shielding.
2. At the surface of a charged conductor, the electrostatic field must be normal to the surface at every point.
3. The interior of a conductor can have no excess charge in the static situation.
4. Electrostatic potential is constant throughout the volume of the conductor and has the same value (as inside) on its surface.
5. Electric field at the surface of a charged conductor

   $\bar{E}=\frac{\sigma}{\varepsilon_{0}} \hat{n}$

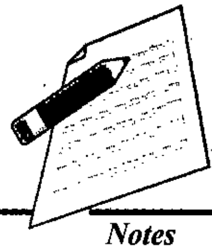
   where σ is the surface charge density and is a unit vector normal to the surface in the outward direction.
6. Electric field inside a metal cavity is zero. Vanishing of electric inside a metal cavity is called electrostatic shielding. Sensitive electrical instruments can be protected from external electric field by placing it in a metal cavity.

Dielectrics and Polarization

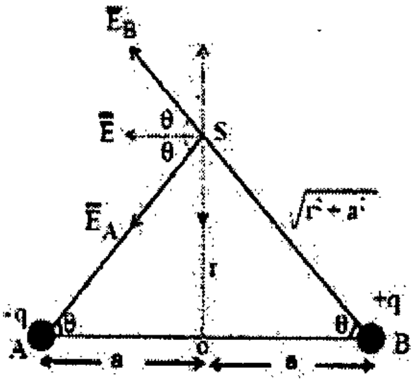
Dielectrics (insulator): Dielectrics are non-conducting substances. They have no charge carriers. The molecules of dielectrics may be classified into two classes.

1. Polar molecule
2. Nonpolar molecule

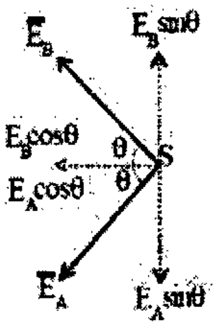
Electric field due to a dipole at a point on the perpendicular bisector of the dipole (at a point on the equatorial line).



Notes



Consider a dipole of dipole moment P = 2aq. Let 'S' be a point on its equatorial line at a distance 'r' from its centre. The magnitudes of electric field at 'S' due to +q and -q are equal and acts as shown in figure. To find the resultant electric field resolve.



Their normal components cancel each other whereas their horizontal components add up to give the resultant field at 'S'.

E = EAcos θ + EBcos θ = 2 EB cos θ

$$\left(\text{Since } E_A = E_B = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r^2+a^2)}\right)$$

$$\text{Cos}\theta = \frac{a}{\sqrt{(r^2+a^2)}}$$

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

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2aq}{(r^2+a^2)^{3/2}}$$

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

$$\vec{E}(s) = \frac{1}{4\pi\varepsilon_0}\frac{P}{r^3} \quad \text{where } P=2aq$$

CLASS–12

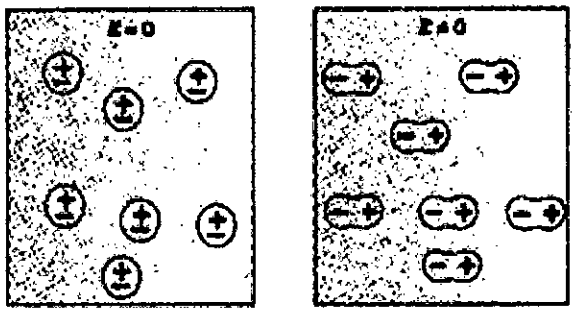
Physics

Notes

The direction of the field due to the dipole at a point on the equatorial line is opposite to the direction of dipole moment.

1. Dielectrics in external electric field

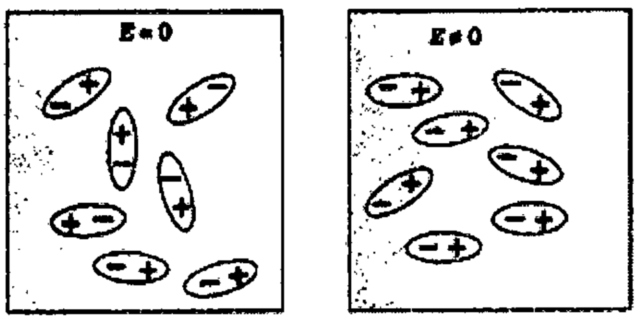
(a) Nonpolar dielectrics in external field:



(a) Non-polar molecules

Considers nonpolar dielectrics in an external electric field. In electric field, the positive and negative changes of a nonpolar molecule are displaced in opposite directions. Thus, dipole moment is induced in a nonpolar molecule. The induced dipole moments of different molecules add up giving a net dipole moment.

(b) Polar dielectrics in external electric field:



(b) Polar molecules

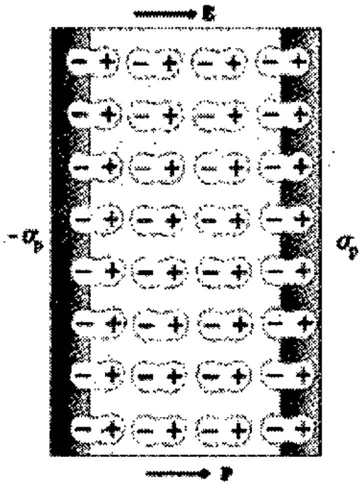
The permanent dipoles in a polar dielectric are arranged randomly. So total dipole moment is zero. But when we apply external electric field, the individual dipole tends to align in the direction of electric field. The induced dipole moments of different molecules add up giving a net dipole moment.

Electric susceptibility: Non-polar dielectrics and polar dielectrics can produce net dipole moment in the external electric field. The dipole moment per unit volume is called polarization and is denoted as P. For linear isotropic dielectrics.

$\bar{P}=\chi_{0} \bar{E}$

where χe is a constant and is known as the electric susceptibility of the dielectric medium.

How does the polarized dielectric modify the external field inside it?

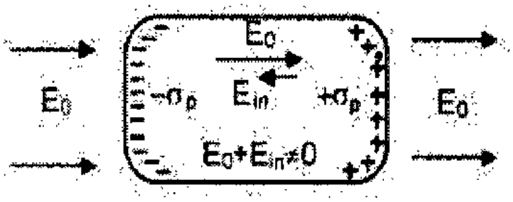


Consider a dielectric slab placed inside a uniform external electric field E0. This field produces a uniform polarization as shown in the figure. Any region inside the dielectric, the net charge is zero.

This is due to the cancellation of positive charge of one dipole with negative charge of adjacent dipole. But the positive ends of the dipole do not cancel at right surface and the negative ends at the left surface.

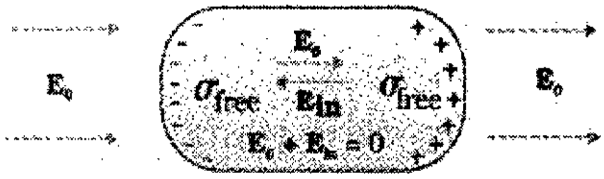
This surface charges (-σp and +σp) produce a field $\left(\vec{E}_{in}\right)$ opposite to the external field. Hence total electric field is reduced inside the dielectric field which is shown in the figure below.

ie; E0 + Ein ≠ 0



Dielectric

How does a metal modify the external electric field applied on it?



Conductor

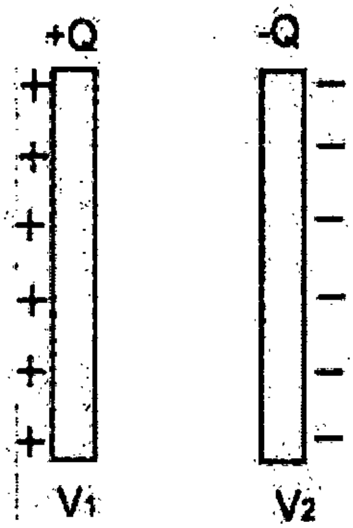
When a conductor placed in an electric field, the free charges are moved in opposite direction as shown in figure. This rearrangement of charges in a metal produce an internal field (Ein) inside the metal. This internal field cancels the external field. Thus, the net electric field inside the metal becomes zero.

ie; E0 + Ein = 0

Capacitors and Capacitance

Capacitor: Capacitor is a system of two conductors separated by an insulator for storing electric charges.

Capacitance of a capacitor:



Consider two-conductor having charges +Q and -Q and potentials V1 and V2. The amount of charge Q on a plate is directly proportional to the potential difference (v1 – v2) between the plates,

ie. $Q\ \alpha\ V1 - V2$

(or) $Q\ \alpha\ V$ (where $V = V1 - V2$)

$\boxed{Q = CV}$

The constant C is called the capacitance of the capacitor. If V = 1, we get Q = C. Hence capacitance of a capacitor may be defined as the amount of charge required to raise the potential difference between two plates by one volt.

Dielectric strength:

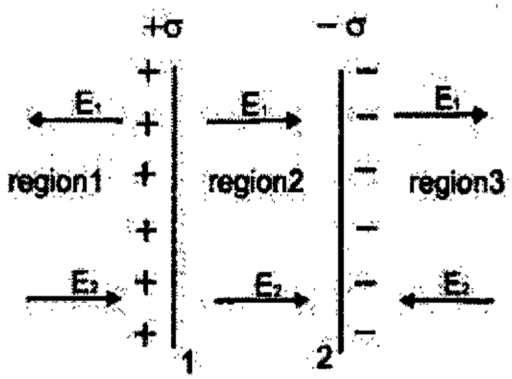
What happens to the charge stored in capacitor when the p.d. between two plates increases?

When the p.d. between two plates increases, electric field in between two plates increases. This high electric field can ionize the surrounding air (or medium) and accelerate the charges to the oppositely charged plates and neutralize the charge on the plate. This is called electric break down.

The maximum electric field that a dielectric medium can withstand without break down (of its insulating property) is called its dielectric strength. The dielectric strength of air is 3 × 106 v/m.

The Parallel Plate Capacitor

Electric field due to a capacitor:



Consider a parallel plate capacitor consists of two large conducting plates 1 and 2 separated by a small distance d. Let +σ and -σ be the surface charge densities of first and second plates respectively. (Here, we take, electric field towards right is taken as positive and left as negative.)

Region I: This region lies above plate 1.

E = E+ + E– ie.

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

$$E = 0$$

Region II: This region lies below plate 2.

E = E– + E+ ie.

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

E = 0

Electric field in between two plates: In the inner region between plates 1 and 2, the electric field due to two charged plates add up.

ie. $E = \dfrac{\sigma}{2\varepsilon_0} + \dfrac{\sigma}{2\varepsilon_0}$ $\quad \boxed{E = \dfrac{\sigma}{\varepsilon_0}}$

(a) Expression for capacitance of a capacitor: Potential difference between two plates

V= Ed

$$V = Ed$$

$$= \frac{\sigma}{\varepsilon_0} d \qquad \left(\because E = \sigma/_{\varepsilon_0}\right)$$

$$V = \frac{Q}{A\varepsilon_0} d \quad \text{.........} \quad (1) \qquad \left(\sigma = Q/_{A}\right)$$

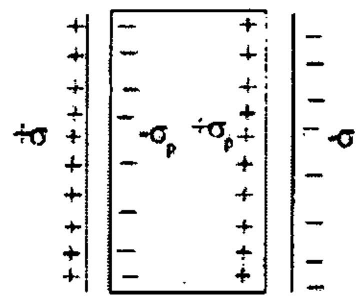
Capacitance C of the parallel plate capacitor,

$$C = \frac{Q}{V} \quad \text{............}(2)$$

Sub. eq. (1) in eq. (2)

$$C = \frac{Q}{\frac{Q}{A\varepsilon_0} d} \qquad \boxed{C = \frac{A\varepsilon_0}{d}}$$

Effect of Dielectric on Capacitance



Consider a capacitor of area A and charge densities +σ and -σ. Let d be the distance between the plates. If a dielectric slab is placed inside this capacitor, it undergoes polarization. Let +σp and-σp be polarized charge densities due to polarization.

Due to polarization electric field in between the plate becomes

$E=\frac{\sigma}{K \varepsilon_{0}}$ _____(1)

The potential difference between the plates,

V = Ed _____(2)

Sub (1) in (2)

$\mathrm{V}=\frac{\sigma}{\mathrm{K} \mathrm{s}_{0}} \mathrm{d}$

Then the capacitance of capacitor

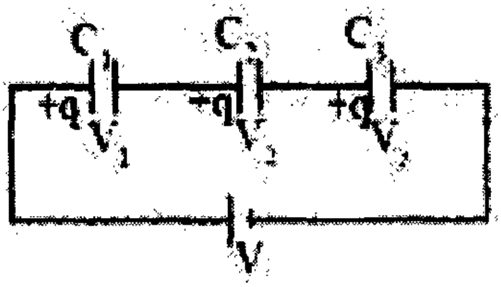
$$C = \frac{Q}{V} = \frac{Q}{\frac{\sigma}{K\varepsilon_0} d} = \frac{\sigma_A}{\frac{\sigma}{K\varepsilon_0} d}$$

$$\boxed{C = \frac{A\varepsilon_0 K}{d}}$$

The product ε0 K is the permittivity of the medium.

Combination of Capacitors

1. Capacitors in series: Let three capacitors C1, C2 and C3 be connected in series to p.d of V. Let V1, V2 and V3 be the voltage across C1, C2, and C3.



The applied voltage can be written as

V = V1 + V2 + V3 ______(1)

Charge 'q' is same as in all the capacitor. So,

$$V_1 = \frac{q}{C_1}, \quad V_2 = \frac{q}{C_2}, \text{ and } V_3 = \frac{q}{C_3}$$

Substituting these values in (1),

$$V = \frac{q}{C_1} + \frac{q}{C_2} + \frac{q}{C_3} \text{ ——— } (2)$$

If these capacitors are replaced by a equivalent capacitance 'C', then

$V = \frac{q}{C}$

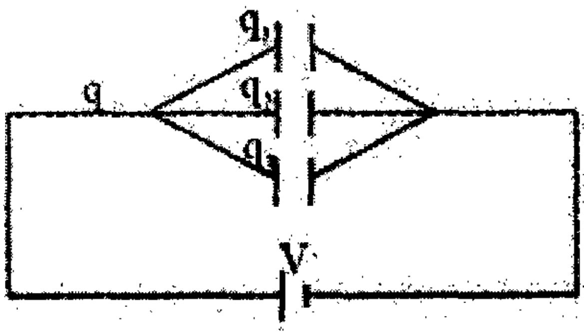
Hence eq(2) can be written as

$$\frac{q}{C} = \frac{q}{C_1} + \frac{q}{C_2} + \frac{q}{C_3}$$

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

Effective capacitance is decreased by series combination.

2. Capacitors in parallel:



Let three capacitors C1, C2 and C3 be connected in parallel to p.d of V. Let q1, q2, and q3 be the

charges on C1, C2 and C3.

If 'q' is the total charge, then'q'can be written as

q = q1 + q2 + q3

But q1 = C1V, q2 = C2V and q3 = C3V

Hence eq (2) can be written as

CV = C1V + C2V + C3V

$$\boxed{C = C_1 + C_2 + C_3}$$

Effective capacitance increases in parallel connection.

Energy Stored in A Capacitor

Energy of a capacitor is the work done in charging it. Consider a capacitor of capacitance 'C'.

Let 'q' be the charge at any instant and 'V' be the potential. If we supply a charge 'dq' to the capacitor, then work done can be written as,

dw = Vdq

dw = $\frac{q}{C}$dq (since V = $\frac{q}{C}$)

□ Total work done to charge the capacitor (from '0' to 'Q') is

$$W = \int_0^Q \frac{q}{C} dq \qquad W = \frac{1}{C}\frac{\left[q^2\right]_0^Q}{2} \qquad W = \frac{1}{C}\frac{Q^2}{2}$$

But Q = CV

W = $\frac{1}{2}$ CV2

This work done is stored in the capacitor as electric potential energy.

□ Energy stored in the capacitor is,

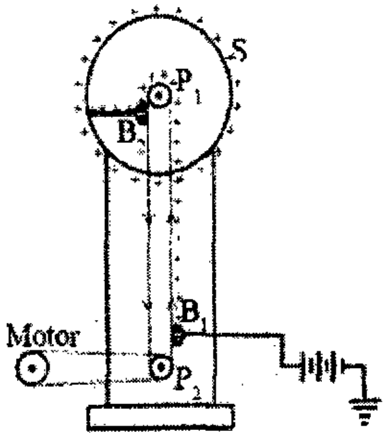
$$\boxed{U = \frac{1}{2}CV^2}$$

Van De Graff Generator

Van de Graff generator is used to produce very high voltage.

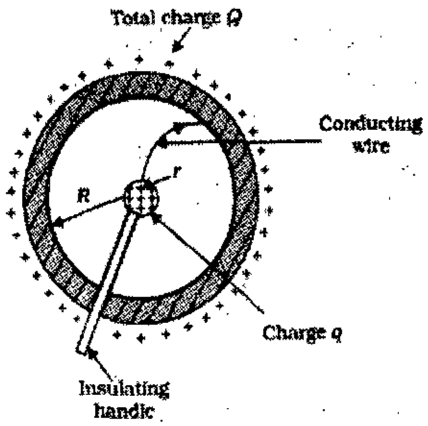
Principle: If two charged concentric hollow spheres are brought in to contact, charge will always flow from inner sphere to the outer sphere.

Construction and working:



The vande Graff generator consists of a large spherical metal shell, placed on an insulating stand. Let p1 and p2 be two pulleys. Pulley p1 is at the center of the spherical shell S. A belt is wound around two pulleys p1 and p2. This belt is rotated by a motor. Positive charges are sprayed by belt. Brush B2 transfer these charges to the spherical shell. This process is continued. Hence a very high voltage is produced on the sphere.

Why does the charge flow from inner sphere to outer sphere?



Let 'r' and 'R' be the radius of inner sphere and outer sphere carrying charges q and Q respectively.

The potential on the outer sphere,

V(R) = Potential due to outer charge + potential due to inner charge

$$\text{ie. } V_{(R)} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R} + \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$$

Potential on the inner sphere. V(r) = Potential due to outer charge + Potential due to inner charge

ie. $V_{(r)} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R} + \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

□ Potential difference between the two spheres

$$V_{(r)} - V_{(R)} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R} + \frac{1}{4\pi\varepsilon_0}\frac{q}{r} - \left[\frac{1}{4\pi\varepsilon_0}\frac{Q}{R} + \frac{1}{4\pi\varepsilon_0}\frac{q}{R}\right]$$

$$V_{(r)} - V_{(R)} = \frac{1}{4\pi\varepsilon_0} q\left[\frac{1}{r} - \frac{1}{R}\right] \text{............(1)}$$

The above equation shows that the inner sphere will be always at a higher potential. Hence, the charge always flows from the inner sphere to the outer sphere.

Summary of the chapter

1. Electrostatics deals with forces between charges at rest. But if there is a force on a charge, how can it be at rest? Thus, when we are talking of electrostatic force between charges, it should be understood that each charge is being kept at rest by some unspecified force that opposes the net Coulomb force on the charge.
2. A capacitor is so configured that it confines the electric field lines within a small region of space. Thus, even though field may have considerable strength, the potential difference between the two conductors of a capacitor is small.
3. Electric field is discontinuous across the surface of a spherical charged shell. It is zero inside and σ ε0 nˆ outside. Electric potential is, however continuous across the surface, equal to q/4πε 0R at the surface.
4. The torque p × E on a dipole causes it to oscillate about E. Only if there is a dissipative mechanism, the oscillations are damped and the dipole eventually aligns with E.
5. Potential due to a charge q at its own location is not defined – it is infinite.
6. In the expression qV(r) for potential energy of a charge q, V(r) is the potential due to external charges and not the potential due to q. As seen in point 5, this expression will be ill-defined if V (r) includes potential due to a charge q itself.
7. A cavity inside a conductor is shielded from outside electrical influences. It is worth noting that electrostatic shielding does not work the other way round; that is, if you put charges inside the cavity, the exterior of the conductor is not shielded from the fields by the inside charges

Multiple choice Questions

1. The dimensions of fall of potential per unit distance are given by:

   (a) [MLT-3 A-1]

   (b) [ML2T-2A-1]

   (c) [ML2T-2A-3]

   (d) [MLT-2A-2]

   Answer: (c) [ML2T-2A-3]

2. Which of the following is blocked by a capacitor?

   (a) A.C.

   (b) D.C.

   (c) Both A.C. and D.C.

   (d) Neither A.C. nor D. C

   Answer: (b) D.C.

3. Two copper spheres of the same radius, one solid and the other hollow, are charged to the same potential. Which will have more charge?

   (a) Solid sphere

   (b) Hollow sphere

   (c) Both will have an equal charge

   (d) None of these

   Answer: (c) Both will have an equal charge

4. The capacitance of a capacitor will decrease if we introduce a slab of:

   (a) copper

   (b) aluminium

   (c) zinc

   (d) None of these

   Answer: (d) None of these

5. Two capacitors of capacitance 6 μF and 4 μF are put in series across a 120 V battery. What is the potential difference across the 4 μF capacitor?

   (a) 72 V

   (b) 60 V

   (c) 48 V

   (d) zero

   Answer: (a) 72 V

6. In which of the following forms is the energy stored in a capacitor?

   (a) Charge

   (b) Potential

(c) Capacitance

(d) Electric field

Answer: (d) Electric field

7. Two conducting spheres of radii r1 and r2 are equally charged. The ratio of their potential is

   (a) $(r1/r2)^2$

   (b) $(r1r2)^2$

   (c)(r1/r2)

   (d) (r2/r1)

   Answer: (b) $(r1r2)^2$

8. Twenty-seven drops of mercury are charged simultaneously to the same potential of 10 volts. What will be potential if all the charged drops are made to combine to form one large drop ?

   (a) 180 V

   (b) 90 V

   (c) 120 V

   (d) 45 V

   Answer: (b) 90 V

9. The P.E. of an electric dipole is maximum when it makes an angle θ with electric field. The value of θ is:

   (a) π2

   (b) π

   (c) zero

   (d) 3π2

   Answer: (b) π

10. The amount of work required to increase the distance between -6μC and 4μC from 6 cm to 18 cm will be:

    (a) 1.8 J

    (b) 2.4 J

    (c) 1.8 μJ

    (d) 2.4 μJ

    Answer: (b) 2.4 J

Review Questions

1. What is an equipotential surface?
2. Define potential energy of a point charge ' ' q in an external electric field ' ' E
3. In the derivation for the potential energy of a dipole in an external field, why /2 θ π v = is assumed?
4. What is electrostatic shielding? Mention one application of electrostatic shielding

5. What are the factors on which the capacitance of a capacitor depends?
6. Draw the curves representing the variation of electrostatic potential and field with distance of the point.
7. Arrive the expression for the potential due to a system of charges.
8. Explain how a dielectric develops a net dipole moment in an external electric field?
9. Derive the expression for potential energy of a system of two charges in an external field.

3 CURRENT ELECTRICITY

- Electric current, flow of electric charges in a metallic conductor, drift velocity, mobility and their relation with electric current
- Ohm's law, electrical resistance, V-I characteristics (linear and non-linear), electrical energy and power, electrical resistivity and conductivity
- Carbon resistors, colour code for carbon resistors; series and parallel combinations of resistors; temperature dependence of resistance
- Internal resistance of a cell, potential difference and EMF of a cell, combination of cells in series and in parallel
- Kirchhoff's laws and simple applications
- Wheatstone bridge, metre bridge
- Potentiometer –
  - o Principle and its applications to measure potential difference and for comparing EMF of two cells
  - o Measurement of internal resistance of a cell

Objective of the chapter

The main objective of this chapter is to make student understand about the concepts of **Current Electricity**. Apart from that related topics like Ohm's law, Kirchhoff's laws and Potentiometer has also been explained in this chapter.

Introduction

Electric Current (I)

The rate of flow of charge through any cross-section of a wire is called electric current flowing through it.

Electric current (I) = q / t. Its SI unit is ampere (A).

The conventional direction of electric current is the direction of motion of positive charge.

The current is the same for all cross-sections of a conductor of non-uniform cross-section. Similar to the water flow, charge flows faster where the conductor is smaller in cross-section and slower where the conductor is larger in cross-section, so that charge rate remains unchanged.

If a charge q revolves in a circle with frequency f, the equivalent current,

$i = qf$

(In a metallic conductor current flows due to motion of free electrons while in electrolytes and ionized gases current flows due to electrons and positive ions.)

Types of Electric Current

According to its magnitude and direction electric current is of two types

(i) **Direct Current (DC)** Its magnitude and direction do not change with time. A ceil, battery or DC dynamo are the sources of direct current.

(ii) Alternating Current (AC) An electric current whose magnitude changes continuously and changes its direction periodically is called alternating current. AC dynamo is source of alternating current.

Current Density

The electric current flowing per unit area of cross-section of conductor is called current density.

Current density $(J) = I / A$

Its S1 unit is ampere metre^{-2} and dimensional formula is $[AT^{-2}]$.

It is a vector quantity and its direction is in the direction of motion positive charge or in the direction of flow of current.

Thermal Velocity of Free Electrons

Free electrons in a metal move randomly with a very high speed of the order of 10^5 ms^{-1}. This speed is called thermal velocity of free electron.

Average thermal velocity of free electrons in any direction remains zero.

Drift Velocity of Free Electrons

When a potential difference is applied across the ends of a conductor, the free electrons in it move with an average velocity opposite to direction of electric field. which is called drift velocity of free electrons.

Drift velocity $v_d = eE\tau / m = eV\tau / ml$

where, τ = relaxation time, e = charge on electron,

E = electric field intensity, l = length of the conductor,

V = potential difference across the ends of the conductor

m = mass of electron.

Relation between electric current and drift velocity is given by

$v_d = I / Ane$

Mobility

The drift velocity of electron per unit electric field applied is mobility of electron.
Mobility of electron (μ) = vd / E
Its SI unit is m2s-1V-1 and its dimensional formula is [M-1T2A].

Ohm's Law

If physical conditions of a conductor such as temperature remains unchanged, then *the electric current (I) flowing through the conductor is directly proportional to the* potential difference (V) applied across its ends.

I □ V

or V = IR

where R is the electrical resistance of the conductor and R = Ane2 τ / ml.

Electrical Resistance

The obstruction offered by any conductor in the path of flow of current is called its electrical resistance.

Electrical resistance, R = V / I

Its SI unit is ohm (Ω) and its dimensional formula is [ML2T-3A-2].

Electrical resistance of a conductor R = ρl / A

where, l = length of the conductor, A = cross-section area and

ρ = resistivity of the material of the conductor.

Resistivity

Resistivity of a material of a conductor is given by

ρ = m / n2 τ

where, n = number of free electrons per unit volume.

Resistivity of a material depend on temperature and nature of the material.

It is independent of dimensions of the conductor, i.e., length, area of cross-section etc.

Resistivity of metals increases with increase in temperature as

ρt = ρo (1 + αt)

where ρo and ρt are resistivity of metals at O°C and t°C and α temperature coefficient of resistivity of the material.

For metals α is positive, for some alloys like nichrome, manganin and constantan, α is positive but very low.

For semiconductors and insulators. A is negative.

Resistivity is low for metals, more for semiconductors and very high alloys like nichrome, constantan etc.

(In magnetic field the resistivity of metals increases. But resistivity of ferromagnetic *materials such as iron, nickel, cobalt etc. decreases in magnetic field.)*

Electrical Conductivity

The reciprocal of resistivity is called electrical conductivity.

Electrical conductivity (σ) = $1 / \rho = 1 / RA = ne2\ \tau / m$

Its SI units is ohm-1 m-1 or mho m-1 or Siemen m-1.

Relation between current density (J) and electrical conductivity (σ) is given by

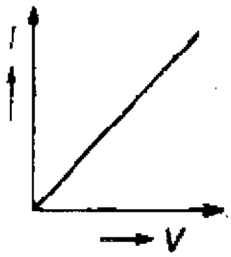
$J = \sigma E$

where, E = electric field intensity.

Ohmic Conductors

Those conductors which obey Ohm's law, are called ohmic conductors e.g., all metallic conductors are ohmic conductor.

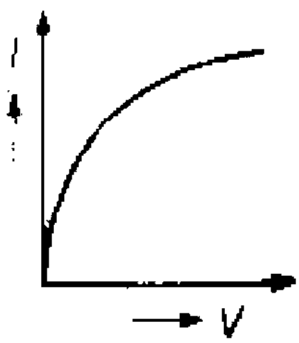
For ohmic conductors V – I graph is a straight line.



Non-ohmic Conductors

Those conductors which do not obey Ohm's law, are called non-ohmic conductors. E.g., diode valve, triode valve, transistor, vacuum tubes etc.

For non-ohmic conductors V – I graph is not a straight line.



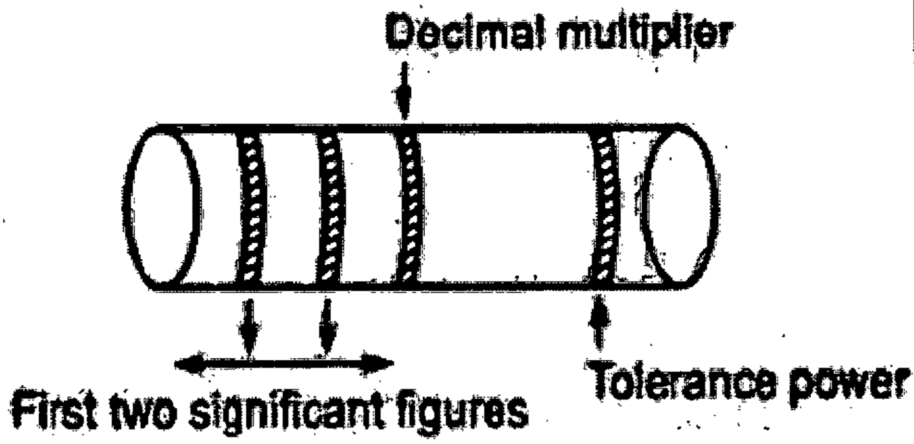
Superconductors

When few metals are cooled, then below a certain critical temperature their electrical resistance suddenly becomes zero. In this state, these substances are called **superconductors** and this phenomenon is called **superconductivity**.

Mercury become superconductor at 4.2 K, lead at 7.25 K and niobium at 9.2 K

Colour Coding of Carbon Resistors

The resistance of a carbon resistor can be calculated by the code given on it in the form of coloured strips.



Colour coding

Colour	Figure
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

Tolerance power

Colour	Tolerance
Gold	5%
Silver	10%
No colour	20%

This colour coding can be easily learned in the sequence "B B ROY Great Bratain Very Good Wife".

Combination of Resistors

1.In Series

(i) Equivalent resistance, R = R1 + R2 + R3

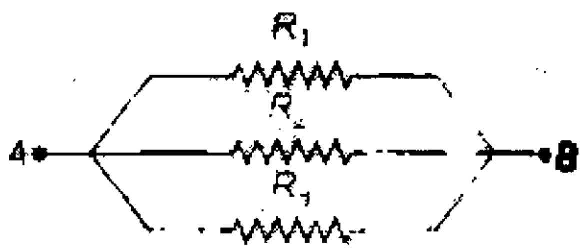
(ii) Current through each resistor is same.

(iii) Sum of potential differences across individual resistors is equal to the potential difference, applied by the source.

2. In Parallel

Equivalent resistance

1 / R = 1 /R1 + 1 / R2 + 1 / R3



Potential difference across each resistor is same.

Sum of electric currents flowing through individual resistors is equal to the be electric current drawn from the source.

Electric Cell

An electric cell is a device which converts chemical energy into electrical energy.

Electric cells are of two types

(i) **Primary Cells** Primary cells cannot be charged again. Voltaic, Daniel and Leclanche cells are primary cells.

(ii) **Secondary Cells** Secondary cells can be charged again and again. Acid and alkali accumulators are secondary cells.

Electro – motive – Force (emf) of a Cell

The energy given by a cell in flowing unit positive charge throughout the circuit completely one time, is equal to the emf of a cell.

Emf of a cell (E) = W / q.

Its SI unit is volt.

Terminal Potential Difference of a Cell

The energy given by a cell in flowing unit positive charge through till outer circuit one time from one terminal of the cell to the other terminal of the cell.

Terminal potential difference (V) = W / q.

Its SI unit is volt.

Internal Resistance of a Cell

The obstruction offered by the electrolyte of a cell in the path of electric current is called internal resistance (r) of the cell. Internal resistance of a cell

(i) Increases with increase in concentration of the electrolyte.

(ii) Increases with increase in distance between the electrodes.

(iii) Decreases with increase in area of electrodes dipped in electrolyte.

Relation between E. V and r

$E = V + Ir$

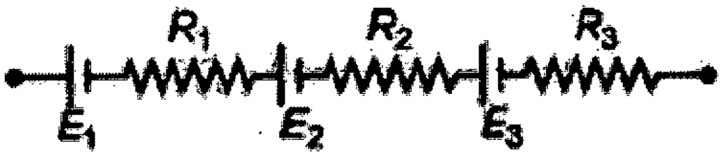
$r = (E / V - 1) R$

If cell is in charging state, then

$E = V - Ir$

Grouping of Cells

(i) **In Series** If n cells, each of emf E and internal resistance r are connected in series to a resistance R. then equivalent emf



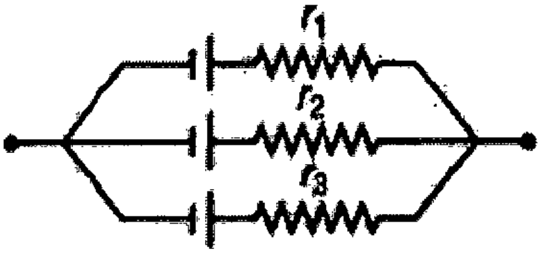
$E_{eq} = E_1 + E_2 + \dots + E_n = nE$

Equivalent internal resistance $r_{eq} = r_1 + r_2 + \dots + r_n = nr$

Current In the circuit $I = E_{eq} / (R + r_{eq}) = nE / (R + nr)$

(ii) **In Parallel** If n cells. each of emf E and internal resistance r are connected to in parallel. then equivalent emf. $E_{eq} = E$

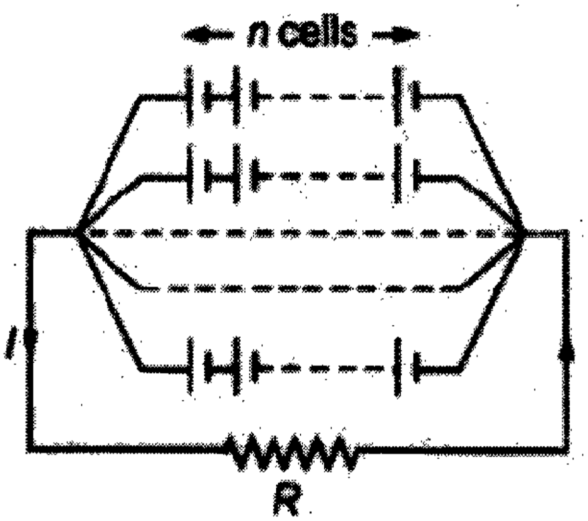
Equivalent internal resistance



$1 / r_{eq} = 1 / r1 + 1 / r1 + \ldots + 1 / rn = n / r$ or $r_{eq} = r / n$

Current In the circuit $I = E / (R + r / n)$

(iii) **Mixed Grouping** of Cells If n cells, each of emf E and internal resistance r are connected in series and such m rows are connected in parallel, then



Equivalent emf, E_{eq}

Equivalent Internal resistance r_{eq}

Current in the circuit, $I = nE / (R + nr / m)$

or $I = mnE / mR + nr$

Note Current in this circuit will be maximum when external resistance is equal to the equivalent internal resistance, i.e.,

$R = nr / m$ □ $mR = nr$

Kirchhoff's Laws

There are two Kirchhoff's laws for solving complicated electrical circuits

(i) **Junction Rule** The algebraic sum of all currents meeting at a junction in a closed circuit is zero, i.e., $\Sigma I = 0$.

This law follows law of conservation of charge.

(ii) **Loop Rule** The algebraic sum of all the potential differences in any closed circuit is zero, i.e.,

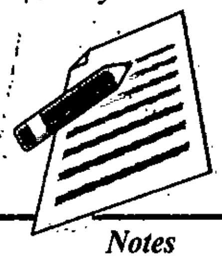
$\Sigma V = 0$ □ $\Sigma E = \Sigma IR$

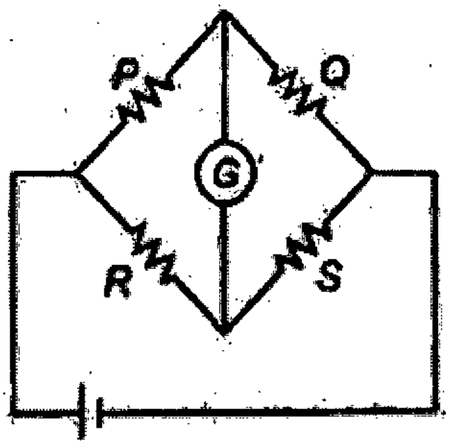
This law follows law of conservation of energy.

Balanced Wheatstone Bridge

Wheatstone bridge is also known as a **metre bridge** or **slide wire bridge**.

This is an arrangement of four resistance in which one resistance is unknown and rest known. The Wheatstone bridge as shown in figure. The bridge is said to be balanced when deflection in galvanometer is zero, i.e., $i_g = 0$.





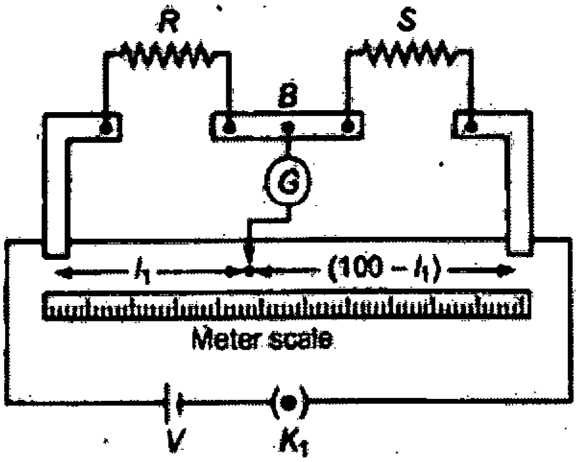
Principle of Wheatstone Bridge

P / Q = R / S

The value of unknown resistance S can find. as we know the value of P, Q and R. It may be remembered that the bridge is most sensitive, when all the four resistances are of the same order.

Meter Bridge

This is the simplest form of Wheatstone bridge and is especially useful for comparing resistance more accurately.

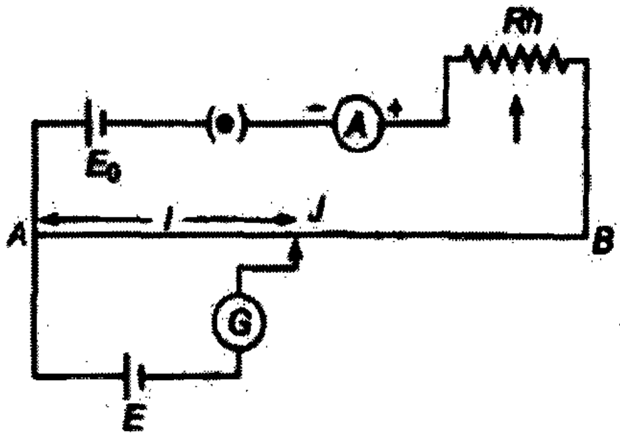


R / S = l1 / (100 – l1)

where l1 is the length of wire from one end where null point is obtained.

Potentiometer

Potentiometer is an ideal device to measure the potential difference between two points. It consists of a long resistance wire AB of uniform cross section in which a steady direct current is set up by means of a battery.



If R be the total resistance of potentiometer wire L its total length, then potential gradient, i.e., fall in potential per unit length along the potentiometer will be

$K = V / L = IR / L$

$= E_o R / (R_o + R)L$

where, E_o = emf of battery and R_o = resistance inserted by means of rheostat Rh.

Determination of emf of a Cell using Potentiometer

If with a cell of emf E on sliding the contact point we obtain zero deflection in galvanometer G when contact point is at J at a length I from the end where positive terminal of cell has been joined. then fall in potential along length i is just balancing the emf of cell. Thus, we have

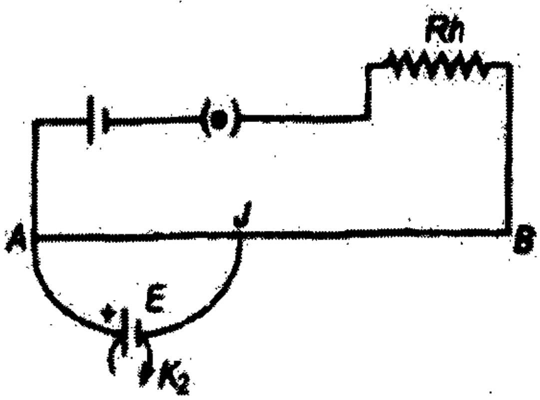
$E = Kl$

or $E_1 / E_2 = l_1 / l_2$

Determination of Internal Resistance of a Cell using Potentiometer

The arrangement is shown in figure. If the cell E is in open circuit and balancing length l_1, then

$E = Kl_1$



But if by inserting key K2 circuit of cell is closed, then often difference V is balanced by a length l_2 of potential where

$V = Kl2$

Internal resistance of cell

$r = E - V / V, R = l1 - l2 / l2 * R$

Important Points

- Potentiometer is an ideal voltmeter.
- Sensitivity of potentiometer is increased by increasing length of potentiometer wire.
- If n identical resistances are first connected in series and then in parallel. the ratio of the equivalent resistance.

  $Rs / Rp = n2 / 1$
- If a skeleton cube is made with 12 equal resistance, each having a resistance R, then the net resistance across
  1. The diagonal of cube = 5 / 6 R
  2. The diagonal of a face = 3 / 4 R
  3. along a side = 7 / 12 R
- If a resistance wire is stretched to a greater length, keeping volume constant, then

  $R \square l2 \square R1 / R2 = (l1 / l2)2$

  and $R \square 1 / r4 \square R1 / R2 = (r2 / r1)4$

  where l is the length of wire and r is the radius of cross-section area of wire.

Summary

Current: - Current strength, in a conductor, is defined as the rate of flow of charge across any cross section of the conductor.

$I = q/t = ne/t$

For non-uniform flow,

$I = dq/dt$

Or, q = ? I dt

Units of electric current: -

(a) C.G.S. electro-static unit (esu):- 1 esu of current (stat-ampere) = 1 esu of charge/1 second

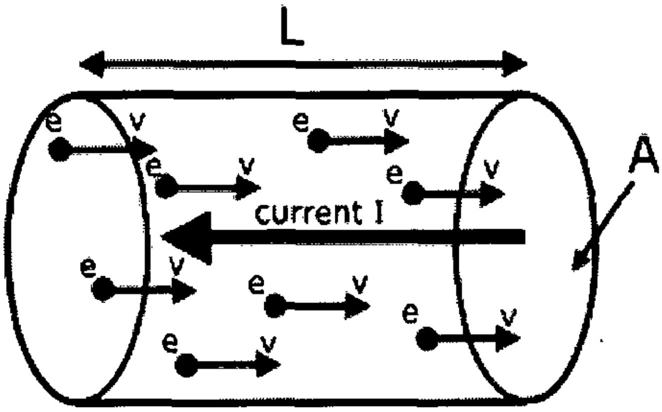
(b) C.G.S. electro-static unit (emu):- 1 emu of current (ab-ampere) = 1 emu of charge/1 second

(c) S. I unit (ampere):- 1 ampere = 1 coulomb/1 second

(d) 1 A = 3×109esu of current or stat-ampere

(e) 1 A = 1/10 emu of current or abampere

Drift velocity: -The velocity with which the free electrons are drifted towards the positive terminal, under the action of the applied field, is called the drift velocity of the free electrons.



$V = (eV/ml)\tau$

Here, e is the charge of electron, V is the potential difference, m is the mass and τ is the relaxation time.

Electric current and Drift velocity: - $I= q/t = nAve$

Ohm's Law for conductors: - At constant temperature current flowing through a conductor of uniform area of cross-section, is proportional to the difference of potential across its terminals.

(a) $V = IR$, Here, $R = (ml/nAe2)\ (1/\tau)$

(b) $R=\rho l/A$

(c) $\rho = 1/\sigma$

(d) $vd = (qE\tau/m)$

(e) $I = neAvd$

(f) $\rho = m/ne2\tau$

(g) $\sigma = ne2\tau/m$

Resistance (R):- Resistance of a conductor is defined as the ratio between potential differences between the two ends of the conductor to the current flowing through it.

$R= V/I$

Multiple choice Questions

1. Consider a current carrying wire current I in the shape of a circle. Note that as the current progresses along the wire, the direction of j (current density) changes in an exact manner, while die current/remain unaffected. The agent that is essentially responsible for is

   (a) source of emf.

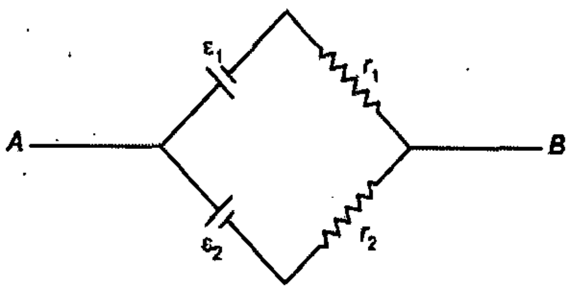
   (b) electric field produced by charges accumulated on the surface of wire.

   (c) the charges just behind a given segment of wire which push them just the right way by repulsion.

   (d) the charges ahead.

   Answer: b

2. Two batteries of ε1 and ε2 (ε2 > ε1) and internal resistance r1 and r2 respectively are connected in parallel as shown in figure.



   (a) The equivalent emf εeq of the two cells is between ε1 and ε2 i.e. ε1 < εeq < ε2.

   (b) The equivalent emf εeq is smaller than ε1.

   (c) The eeq is given by εeq= ε1 + ε2 always.

   (d) zeq is independent of internal resistances r1 and r2.

   Answer: a

3. A resistance R is to be measured using a meter bridge. Student chooses the standard resistance S to be 100 Ω He finds the null point at l1 = 2.9 cm. He is told to attempt to improve the accuracy. Which of the following is a useful way?

   (a) He should measure l1 more accurately.

   (b) He should change Sto 1000 Ω and repeat the experiment.

   (c) He should change S to 3 Ω and repeat the experiment.

   (d) He should give up hope of a more accurate measurement with a meter bridge.

   Answer: c

4. Two cells of emf's approximately 5 V and 10 V are to be accurately compared using a potentiometer of length 400 cm. [NCERT Exemplar]

   (a) The battery that runs the potentiometer should have voltage of 8 V.

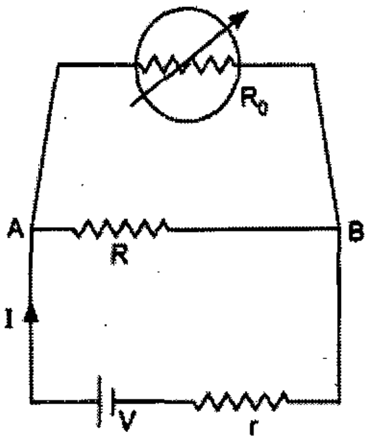
   (b) The battery of potentiometer can have a voltage of 15 V and R adjusted so that the potential drop across the wire slightly exceeds 10 V.

(c) The first portion of 50 cm of wire itself should have a potential drop of 10 V.

(d) Potentiometer is usually used for comparing resistances and not voltages.

Answer: b

5. Consider a simple circuit shown in figure stands for a variable resistance R'. R' can vary from R0 to infinity, r is internal resistance of the battery (r << R << R0).



(a) Potential drop across AB is not constant as R0 is varied.

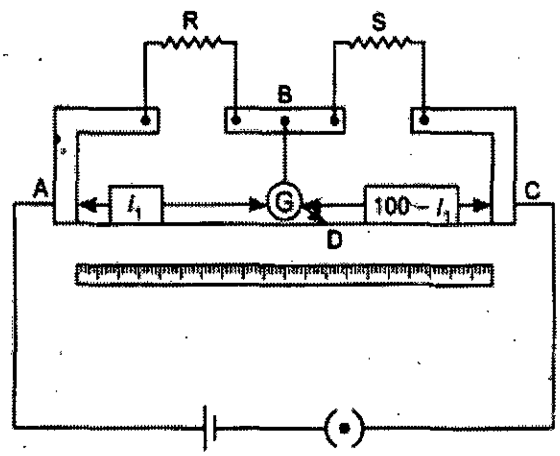
(b Current through R0 is nearly a constant as R0 is varied.

(c) Current I depends sensitively on R0.

(d) I≥Vr+R always.

Answer: d

6. In a meter bridge, the point D is a neutral point (figure).



(a) The meter bridge can have other neutral point for this set of resistances.

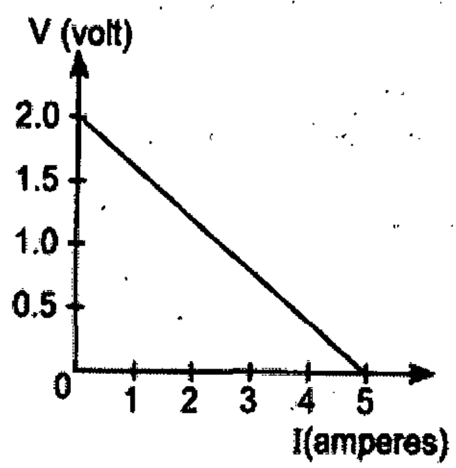
(b) When the jockey contacts a point on meter wire left of D, current flows to B from the wire.

(c) When the jockey contacts a point on the meter wire to the right of D, current flows from B to the wire through galvanometer.

(d) When R is increased, the neutral point shifts to left.

Answer: c

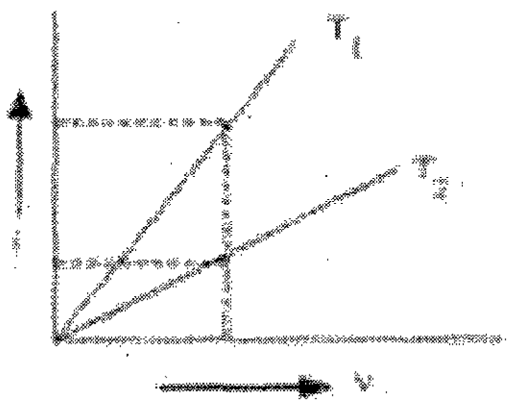
7. Which of the following is wrong? Resistivity of a conductor is
   (a) independent of temperature.
   (b) inversely proportional to temperature.
   (c) independent of dimensions of conductor.
   (d) less than resistivity of a semiconductor.
   Answer: a
8. Drift velocity vd varies with the intensity of electric field as per the relation
   (a) vd □ E
   (b) vd □ 1E
   (c) vd = constant
   (d) vd □ E^2
   Answer: a
9. For measurement of potential difference, a potentiometer is preferred over voltmeter because
   (a) potentiometer is more sensitive than voltmeter.
   (b) the resistance of potentiometer is less than voltmeter.
   (c) potentiometer is cheaper than voltmeter.
   (d) potentiometer does not take current from the circuit.
   Answer: Explanation: (d) Potentiometer works on null deflection method.
10. For a cell, the graph between the potential difference (V) across the terminals of the cell and the current (I) drawn from the cell is shown in the figure.



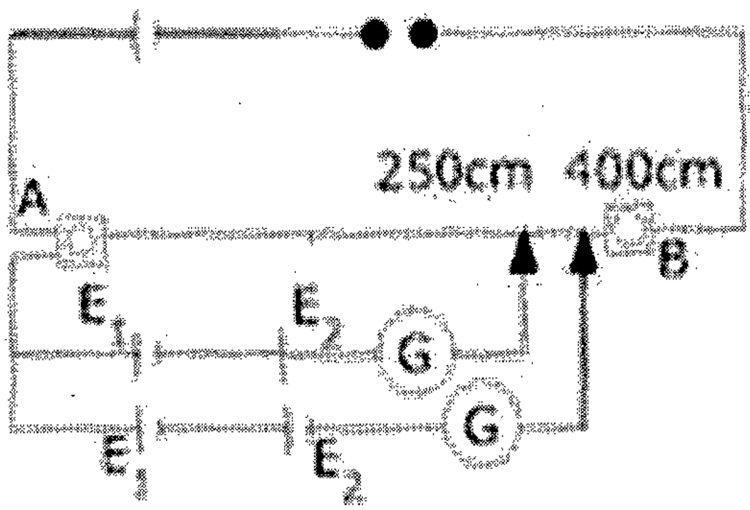
The e.m.f. and the internal resistance of the cell are
(a) 2V, 0.5 Ω
(b) 2V, 0.4 Ω
(c) > 2V, 0.5 Ω
(d) > 2V, 0.4 Ω
Answer: b

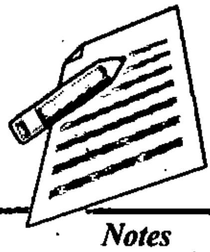
Review Questions

1. Two electric bulbs A and B are marked 220V, 40 w and 220V, 60 W respectively. Which one has a higher resistance?
2. A Carbon resistor has three strips of red colour and a gold strip. What is the value of resistor? What is its tolerance?
3. Determine the voltage drop across the resistor R1 in the circuit given below with E= 60V, $R_1=18\Omega$, $R_2=10\Omega$ $R_3=5\Omega$ and $R_4=10\Omega$?
4. Two heated wires of same dimensions are first connected in series and then it's parallel to a source of supply. What will be the ratio of heat produced in the two cases?

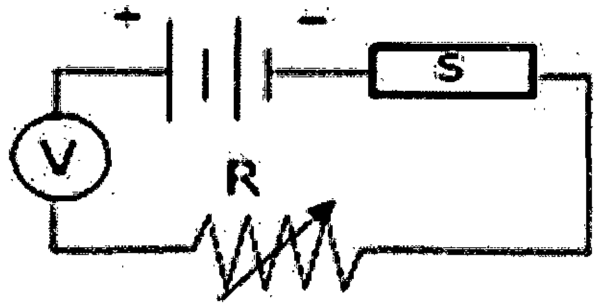


5. V.I graph for a metallic wire at two different temperatures T_1 *and* T_2 is shown in figure. Which of these two temperatures is higher and why?
6. A set of n-identical resistors, each of resistance R ohm when connected in series have an effective resistance of X ohm and when the resistors are connected in parallel the effective resistance is Y ohm. Find the relation
7. Show the resistance of a conductor is given by $R=\dfrac{ml}{ne^2\tau A}$





8. Figure shows a piece of pure semiconductor S in series with a variable resistor Rand a source of constant voltage V. Would you increase and decrease the value of R to keep the reading of ammeter (A) constant, when semiconductor S is heated? Give reasons.



9. Why is constantan or manganin used for making standard resistors?
10. What are ohmic and non-ohmic resistors? Give one example of each?

4 MOVING CHARGES AND MAGNETISM

- Concept of magnetic field –
  - Oersted's experiment
- Biot - Savart law and its application to current carrying circular loop
- Ampere's law and its applications to infinitely long straight wire
- Straight and toroidal solenoids
- Force on a moving charge in uniform magnetic and electric fields
- Cyclotron
- Force on a current-carrying conductor in a uniform magnetic field
- Force between two parallel current-carrying conductors-definition of ampere
- Torque experienced by a current loop in uniform magnetic field; moving coil galvanometer-its current sensitivity and conversion to ammeter and voltmeter.

Objective of the chapter

The main objective of this chapter is to make student understand about the concepts of Moving Charges and Magnetism. Topics like Ampere's law, Cyclotron and Torque experienced by a current loop in uniform magnetic field have also been explained in this chapter.

Introduction

Oersted's Experiment

A magnetic field is produced in the surrounding of any current carrying conductor. The direction of this magnetic field can be obtained by Ampere's swimming rule.

SI unit of magnetic field is Wm-2 or T (tesla).

The strength of magnetic field is called one tesla, if a charge of one coulomb, when moving with a velocity of 1 ms-1 along a direction perpendicular to the direction of the magnetic field experiences a force of one newton.

1 tesla (T) = 1 weber metre-2 (Wbm-2)

= 1 newton ampere-1 metre-1 (NA-1 m-1)

CGS units of magnetic field are called gauss or oersted.

1 gauss = 10-4 tesla.

Maxwell's Cork Screw Rule

If a right-handed cork screw is imagined to be rotated in such a direction that tip of the screw points in the direction of the current, then direction of rotation of thumb gives the direction of magnetic line of force.

The conventional sign for a magnetic field coming out of the plane and normal to it is a dot i.e.,

The magnetic field perpendicular to the plane in the downward action is denoted by $\otimes$.

Ampere's Swimming Rule

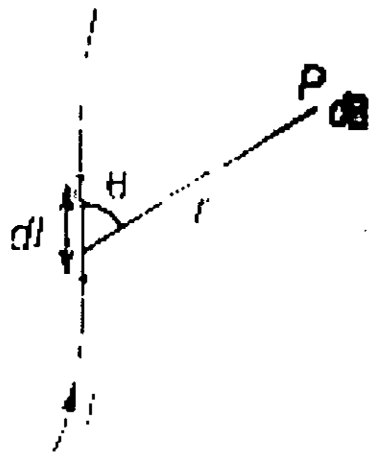
If a man is swimming along the wire in the direction of current his face turned towards the needle, so that the current enters through his feet, then north pole of the magnetic needle will be deflected towards his left hand.

Magnetic Field

The space in the surrounding of a magnet or any current carrying conductor in which its magnetic influence can be experienced.

Biot Savart's Law

The magnetic field produced by a current carrying element of length dl, carrying current I at a point separated by a distance r is given by



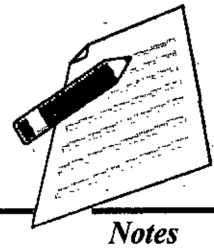
$dB = \mu o / 4 \pi Idl * r / r3$

or $dB = \mu o / 4 \pi Idl \sin \theta / r2$

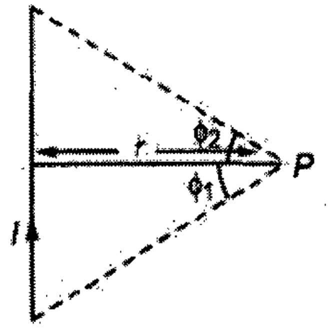
where, θ is the angle between the direction of the current and μo is absolute permeability of the free space.

SI unit of magnetic field is Wm-2 or (tesla) and CGS unit of magnetic field is gauss or oersted 1 gauss = 10-4tesla.

The direction of magnetic field dB is that of I dl * r .



Magnetic Field Due to a Straight Current Carrying Conductor



$$B = \frac{\mu_0}{4\pi} \frac{I}{r} (\sin \phi_1 + \sin \phi_2)$$

where φ1 and φ2 are angles, which the lines joining the two ends of the conductor to the observation point make with the perpendicular from the observation point to the conductor.

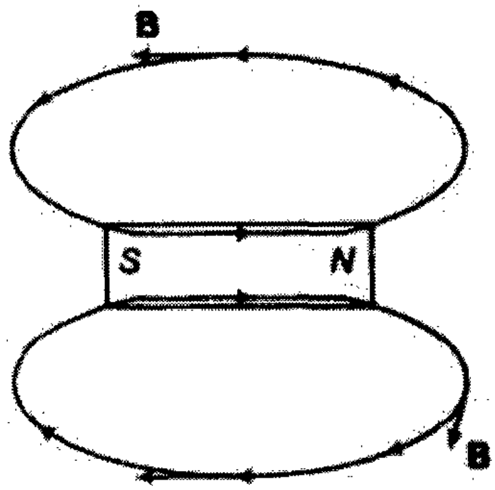
For infinite length conductor and observation point is near the centre of the conductor,

$B = \mu o / 4 \pi\, 2I / r$

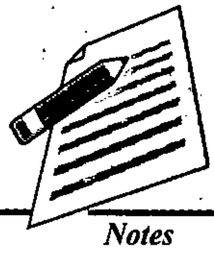
for infinite length conductor and observation point is near one end of the conductor,

$B = \mu o / 4 \pi\, I / r$

Magnetic Field Lines

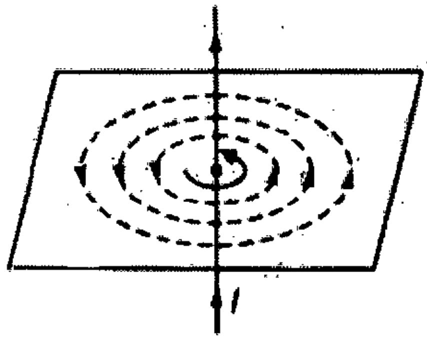


- They are used to res present magnetic B field in a region.
- They are closed continuous curves.
- Tangent drawn at any point gives the direction of magnetic field.
- They cannot interact.
- Outside a magnet, they are directed from north to south pole and inside a magnet they are directed from south to north.



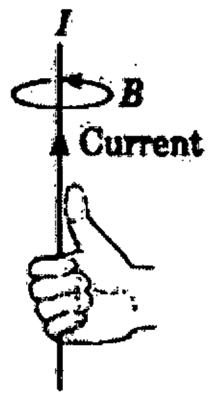
Notes

The magnetic field lines due to a straight current carrying conductor are concentric circles having centre at conductor and in a plane perpendicular to the conductor.



The direction of magnetic field lines can be obtained by Right Hand Thumb Rule

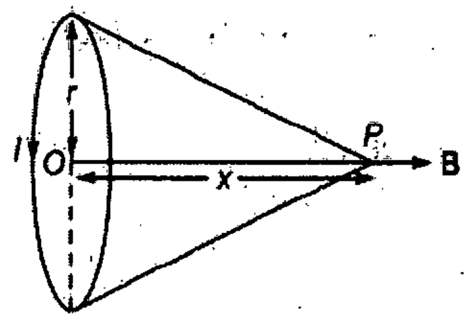
Right Hand Thumb Rule



If we hold a current carrying conductor in the grip of the right hand in such a way that thumb points in the direction of current, then curling of fingers represents the direction of magnetic field lines.

Magnetic Field on the Axis of a Current Carrying Circular Coil

Magnetic field at axis at a distance x from centre O.



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

where, r = radius of the coil, n = number of turns in the coil and I = current,

At centre of the coil, B = μo nl / 2 r

If we look at one face of the coil and the direction of current flowing through the coil is clockwise, then that face has south polarity and if direction of current is anti-clockwise, then that face has north polarity.

Magnetic Dipole

Every current carrying loop is a magnetic dipole. It has two poles south (S) and north (N).

This is similar to a bar magnet.

Each magnetic dipole has some magnetic moment (M). The magnitude of M is,

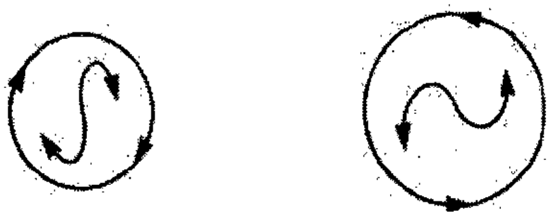
|M| = NiA

where, N = number of turns in the loop,

i = current in the loop and

A = area of cross-section of the loop.

The current carrying loop behaves as a small magnetic dipole placed along the axis one face of the loop behaves as north pole while the other face of loop behaves as south pole.



Ampere's Circuital Law

The line integral of magnetic field induction B around any closed path in vacuum is equal to 110 times the total current threading the closed path, i.e.,

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

where B is the magnetic field, dl is small element, μo is the absolute permeability of free space and I is the current.

Ampere's circuital law holds good for a closed path of any size and shape around a current carrying conductor because the relation is independent of distance form conductor.

Solenoid

A solenoid is a closely wound helix of insulated copper wire.

Magnetic field at a point well inside a long solenoid is given by

B = μo nl

where, n = number of turns per unit length and

I = current flowing through the solenoid

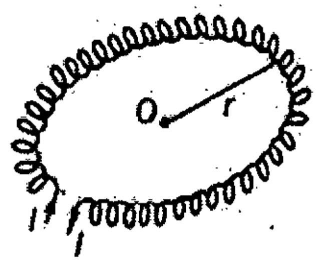
Magnetic field at a point on one end of a long solenoid is given by

$B = \mu o\ nl / 2$

Toroid

A toroidal solenoid is an anchor ring around which is large number of turns of a copper wire are wrapped.

A toroid is an endless solenoid in the form of a ring.



Magnetic field inside the turns of toroid is given by

$B = \mu o\ nl$

Magnetic field inside a toroid is constant and is always tangential to the circular closed path.

Magnetic field at any point inside the empty space surrounded by the toroid and outside the toroid, is zero, because net current enclosed by this space is zero.

Magnetic Field Due to a Current Carrying Long Circular Cylinder

Outside the cylinder ($r > R$)

$B = \mu / 2 \pi l / r$

Inside the cylinder when it is made of a thin metal sheet,

$B = O$

Inside the cylinder when current is uniformly distributed throughout the cross-section of the cylinder ($r < R$)

$B = \mu o\ \mu r / 2 \pi Ir / R2$

where, μo and μr are permeabilities of free space and material of the cylinder, I is current flowing through the cylinder and r is radius of the cylinder.

Force Acting on a Charge Particle Moving in a Uniform Magnetic Field

$F = q\ (v * B)$

or $F = |F| = Bqv \sin \theta$

where, B = magnetic field intensity,

q = charge on particle,

u = speed of the particle and

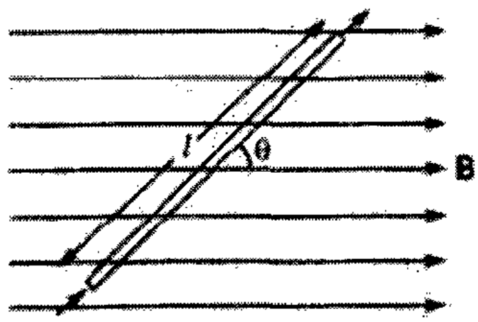
θ = angle between magnetic field and direction of motion.

This force is perpendicular to B as well as v.

Its direction can be obtained from Fleming's left-hand rule.

Magnetic force acting on a current carrying conductor in a uniform magnetic field is given by

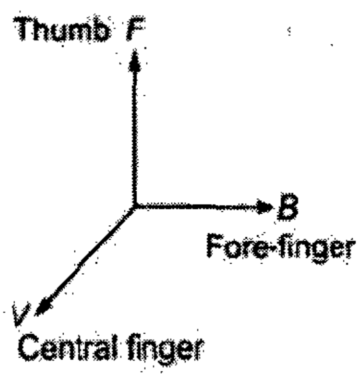
F = I (I * B)



$$F = BIl \sin\theta$$

Fleming's left-Hand Rule

If we stretch the thumb, the forefinger and the central finger if left hand in such a way that all three are perpendicular to each other, then if forefinger represents the direction of magnetic field, central finger represents the direction of current flowing through the conductor, then thumb will represent the direction of magnetic force.



Lorentz Force

The total force experienced by a charge moving inside the electric and magnetic fields is called Lorentz force. It is given by F = q(E * v * B)

Motion of a Charged Particle in a Uniform Magnetic Field

When charged particle enter normal to the magnetic field it follows a circular path.

The radius of the path, r = mv / Bq

□ r □ mv

and r □ 1 / (q / m)

Time period, $T = 2\pi m / Bq$

When charged particle enter magnetic field at any angle except 90°, then it follows helical path.

The radius of the path, $r = mv \sin\theta / Bq$

The distance travelled by the charged particle in one time period due to component of velocity $v \cos\theta$, is called pitch of the path

Pitch $= T * v \cos\theta = 2\pi mv \cos\theta / Bq$

Cyclotron

Cyclotron is a device used to accelerate positively charged particles such as proton, deuteron etc.

Principle of Cyclotron

A positively charged particle can be accelerated through a modera. electric field by crossing it again and again by use of strong magnetic field.

Radius of circular path, $r = mv / Bq$

Cyclotron frequency $v = Bq / 2\pi m$

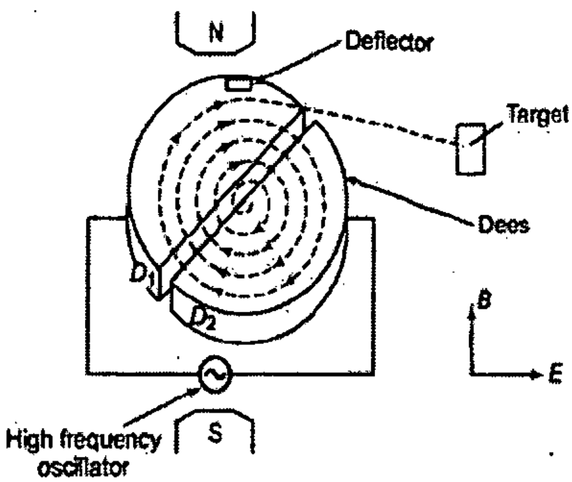
where m and q are mass and charge of the positive ion and B is strength of the magnetic field.

Maximum kinetic energy gained by the particle.

Emax = B2q2r2o / 2m

where, ro = maximum radius of circular path.

When a positive ion is accelerated by the cyclotron, it moves with greater and greater speed. As the speed of ion becomes comparable with that of light, the mass of the ion increases according to the relation.



$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Where, m = mass of the lOD.

mo = maximum mass of the ion.

v = speed of Ion and

c = speed of light.

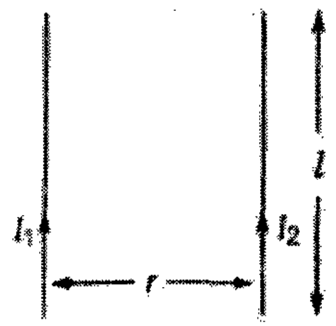
Limitations of the Cyclotron

(i) Cyclotron cannot accelerate uncharged particle like neutron.

(ii) The positively charged particles having large mass i.e., ions cannot move at limitless speed in a cyclotron.

Force between Two Infinitely Long Parallel Current Carrying Conductors

$$F = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{r} l$$



The force is attractive if current In both conductors is in same direction and repulsive if current 10 both conductors is in opposite direction.

(if the current is both parallel wires arc equal and In same direction, then magnetic field at a point exactly half way between the wires is zero.)

Torque acting on a Current Carrying Coil Placed Inside a Uniform Magnetic Field

Torque acting on a current carrying coil placed inside a uniform magnetic field is given

τ = NBIA sin θ

Where, N = number of turns in the coil,

E = magnetic field intensity,

I = current 10 the coil and

A = area of cross-section of the coil;

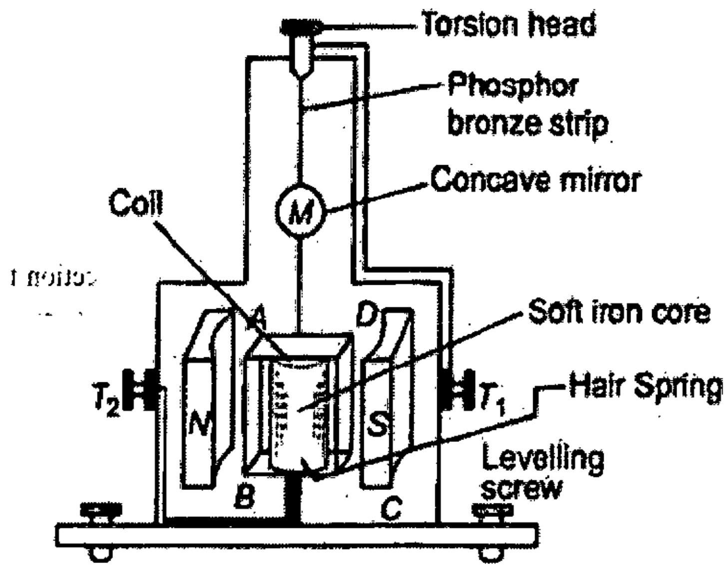
θ = angle between magnetic field and normal to the plane of the coil.

Moving Coil Galvanometer

It is a device used for the detection and measurement of the currents.

In equilibrium, deflecting torque = restoring torque

$$NBIA = k\theta \quad \text{or} \quad I = \frac{k}{NBA}\theta$$



where, k = restoring torque per unit twist,

N = number of turns in the coil,

B = magnetic field intensity,

A = area of cross-section of the coil and

θ = angle of twist.

Current Sensitivity

The deflection produced per unit current in galvanometer is called its current sensitivity.

Current sensitivity

$Is = \theta / I = NBA / K$

Voltage Sensitivity

The deflection produced per unit voltage applied across the ends of galvanometer is called its voltage sensitivity.

Voltage sensitivity

$Vs = \theta / V = NBA / KR$

where R is the resistance of the galvanometer.

Therefore, for a sensitive galvanometer

(i) N should be large

(ii) B should be large

(iii) A should be large

(iv) K should be small

Ammeter

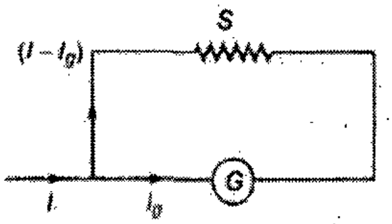
An ammeter is a low resistance galvanometer used for measuring the current in a circuit.

It is always connected in series.

Conversion of a Galvanometer into an Ammeter

A galvanometer can be converted into an ammeter by connecting a low resistance into its parallel.

If G is the resistance of a galvanometer and it give full scale deflection for current, Ig then required low resistance S, connected in its parallel for converting it into an ammeter of range I is given by



$$I_g \times GK = (I - I_g) \times S$$

$$S = \left(\frac{I_g}{I - I_g}\right) G$$

The resistance of an ideal ammeter is zero.

Voltmeter

A voltmeter is a high resistance galvanometer used for measuring the potential difference between two points.

It is always connected in parallel.

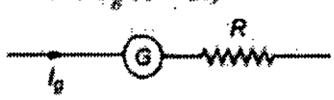
The resistance of an ideal voltmeter is infinity.

Conversion of a Galvanometer into a Voltmeter

A galvanometer can be converted into a voltmeter by connecting a high resistance into its series.

If a galvanometer of resistance G show full scale deflection for current Ig then required high resistance R, connected in series for converting it into a voltmeter of range V is given by

$$V = I_g (G + R)$$



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

Summary of the chapter

1. Electrostatic field lines originate at a positive charge and terminate at a negative charge or fade at infinity. Magnetic field lines always form closed loops.
2. The discussion in this Chapter holds only for steady currents which do not vary with time. When currents vary with time Newton's third law is valid only if momentum carried by the electromagnetic field is taken into account.
3. Recall the expression for the Lorentz force, F = q (v × B + E) This velocity dependent force has occupied the attention of some of the greatest scientific thinkers. If one switches to a frame with instantaneous velocity v, the magnetic part of the force vanishes. The motion of the charged particle is then explained by arguing that there exists an appropriate electric field in the new frame. We shall not discuss the details of this mechanism. However, we stress that the resolution of this paradox implies that electricity and magnetism are linked phenomena (electromagnetism) and that the Lorentz force expression does not imply a universal preferred frame of reference in nature.
4. Ampere's Circuital law is not independent of the Biot-Savart law. It can be derived from the Biot-Savart law. Its relationship to the Biot-Savart law is similar to the relationship between Gauss's law and Coulomb's law.

Multiple choice Questions

1. The current sensibility of a moving coil galvanometer increases with decrease in:

   (a) magnetic field

   (b) area of a coil

   (c) number of turns

   (d) None of these

   Answer: (d) None of these

2. A current carrying coil is placed in a uniform magnetic field. If the coil turns through an angle θ, then the torque is directly proportional to:

   (a) sin θ

   (b) cos θ

   (c) cot θ

   (d) tan θ

   Answer: (b) cos θ

3. The sensitivity of a tangent galvanometer can be increased by increasing:

   (a) the radius of the coil

   (b) the external magnetic field

   (c) the number of turns of the coil

   (d) all the above

   Answer: (b) the external magnetic field

4. The permeability of a paramagnetic substance is:

   (a) very large

   (b) small but more than unity

   (c) less than unity

   (d) negative

   Answer: (b) small but more than unity

5. Which of the following shows that the earth behaves as a magnet?

   (a) Repulsion between like poles .

   (b) Attraction between unlike poles

   (c) Null points in the magnetic field of a bar magnet

   (d) No existence of isolated magnetic poles

   Answer: (c) Null points in the magnetic field of a bar magnet

6. What is the angle of dip at the magnetic poles?

   (a) 30°

   (b) 0°

   (c) 45°

   (d) None of these

   Answer: (d) None of these

7. A charged particle of mass m and charge q travels on a circular path of radius r i.e., perpendicular to the magnetic field B. The time taken by particle to complete on revolution is :

   (a) $2\pi qBm$

   (b) $2\pi mqB$

   (c) $2\pi mqB$

   (d) $2\pi q2Bm$

   Answer: (b) $2\pi mqB$

8. Circular loop of radius 0.0157 m carries a current 2 A. The magnetic field at the centre of the loop is :

   (a) $1.57 \times 10-3$ Wb/m^2

   (b) $8.0 \times 10-5$ Wb/m^2

   (c) $2.0 \times 10-3$ Wb/m^2

   (d) $3.14 \times 10-1$ Wb/m^2

   Answer: (b) $8.0 \times 10-5$ Wb/m^2

9. What happens to the magnetic field at the centre of a circular current carrying coil if we double the radius of the coil keeping the current unchanged?

   (a) halved

   (b) doubled

   (c) quadrupled

   (d) remains unchanged

   Answer: (a) halved

10. When we double the radius of a coil keeping the current through it unchanged, what happens to the magnetic field directed along its axis at far off points?

    (a) halved

    (b) doubled

    (c) quadrupled

    (d) remains unchanged

    Answer: (d) remains unchanged

Review Questions

1. A steady current flows in the network shown in the figure. What will be the magnetic field at the centre of the network?
2. An – particle and a proton are moving in the plane of paper in a region where there is uniform magnetic field B directed normal to the plane of paper. If two particles have equal linear momenta, what will be the ratio of the radii of their trajectories in the field?
3. Give one difference each between diamagnetic and ferromagnetic substances. Give one example of each?

4. Write the expression for the force acting on a charged particle of charge q moving with velocity is in the presence of magnetic field B. Show that in the presence of this force.

   (a) The K.E. of the particle does not change.

   (b) Its instantaneous power is zero.

5. An electron of kinetic energy 25KeV moves perpendicular to the direction of a uniform magnetic field of 0.2 millitesla calculate the time period of rotation of the electron in the magnetic field?

6. It is desired to pass only 10% of the current through a galvanometer of resistance 90Ω. How much shunt resistance be connected across the galvanometer?

5 MAGNETISM AND MATTER

- Current loop as a magnetic dipole and its magnetic dipole moment
- Magnetic dipole moment of a revolving electron
- Magnetic field intensity due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis
- Torque on a magnetic dipole (bar magnet) in a uniform magnetic field –
    - o Bar magnet as an equivalent solenoid
    - o Magnetic field lines
    - o Earth's magnetic field
    - o Magnetic elements
- Para-, dia- and ferro - magnetic substances, with examples
- Electromagnets and factors affecting their strengths
- Permanent magnets

Objective of the chapter

The main objective of this chapter is to make student understand about the concepts of Magnetism and Matter.

Torque on a magnetic dipole, Electromagnets and concepts like Permanent magnets has also been explained in this chapter.

Introduction

Natural Magnet

A natural magnet is an ore of iron (Fe3O4), which attracts small pieces of iron, cobalt and nickel towards it.

Magnetite or lode stone is a natural magnet.

Artificial Magnet

A magnet which is prepared artificially is called an artificial magnet, e.g., a bar magnet, an electromagnet, a magnetic needle, a horse-shoe magnet etc.

According to molecular theory, every molecular of magnetic substance (whether magnetised or not) is a complete magnet itself.

The poles of a magnet are the two points near but within the ends of the magnet, at which the entire magnetism can be assumed to be concentrated.

The poles always occur in pairs and they are of equal strength. Like poles repel and unlike poles attract.

Properties of Magnet

(i) A freely suspended magnet always aligns itself into north-south direction.

(ii) Like magnetic poles repel and unlike magnetic poles attract each other.

(iii) Magnetic poles exist in pair.

Coulomb's Law

The force of interaction acting between two magnetic poles is directly proportional to the product of their pole strengths and inversely proportional to the square of the distance between them.

F = μo / 4π . m1m2 / r2

where m1, m2 = pole strengths, r = distance between poles and μo = permeability of free space.

Magnetic Dipole

Magnetic dipole is an arrangement of two unlike magnetic poles of equal pole strength separated by a very small distance, e.g., a small bar magnet, a magnetic needle, a current carrying loop etc.

Magnetic Dipole Moment

The product of the distance (2 l) between the two poles and the pole strength of either pole is called magnetic dipole moment.

Magnetic dipole moment

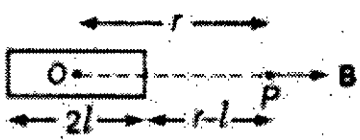
M = m (2 l)

Its SI unit is 'joule/tesla' or 'ampere-metre2'.

Its direction is from south pole towards north pole.

Magnetic Field Due to a Magnetic Dipole

(1) On Axial Line

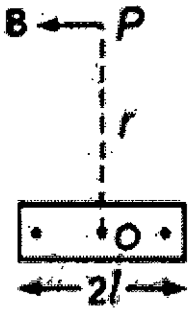


$$B = \frac{\mu_0}{4\pi} \frac{2Mr}{(r^2 - l^2)^2}$$

If $r >> l$, then

$B = \mu_0 / 4 \pi \, 2M / r^3$

(ii) On Equatorial Line



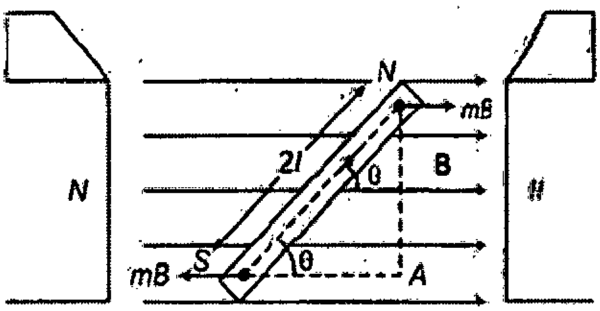
$B = \mu_0 / 4 \pi \, M / (r^2 + l^2)^{3/2}$

If $r >> l$, then

$B = \mu_0 / 4 \pi \, 2M / r^3$

Torque Acting on a Magnetic Dipole

When a Magnetic Dipole (M) is placed in a uniform magnetic field (B), then a Torque acts on it, which is given by



$\tau = M * B$

or $\tau = MB \sin \theta$

Where θ is angle between the dipole axis and magnetic field.

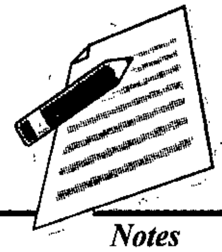
Potential Energy of a Magnetic Dipole in a Uniform Magnetic Field

The work done in rotating the dipole against the action of the torque is stored as potential energy of the dipole.

Potential Energy, $U = W = - MB \cos \theta = - M . B$

Current Carrying Loop

A current carrying loop behaves as a magnetic dipole. If we look the upper face of the loop and current is flowing anti-clockwise, then it has a north polarity and if current is flowing clockwise. Then it has a south polarity.



Magnetic dipole moment of a current carrying loop is given by

M = IA

For N such turns M = NIA

Where I = current and A = area of cross-section of the coil.

Gauss's Law in Magnetism

Surface integral of magnetic field over any closed or open surface is always m.

$$\oint_S \mathbf{B} \cdot d\mathbf{S} = 0$$

This law tells that the net magnetic flux through any surface is always zero.

[When in an atom any electron revolves in an orbit it is equivalent to a current loop. Therefore, atom behaves as a magnetic dipole].

Magnetic Moment of an Atom

Magnetic moment of an atom M = 1 / 2 eωr2

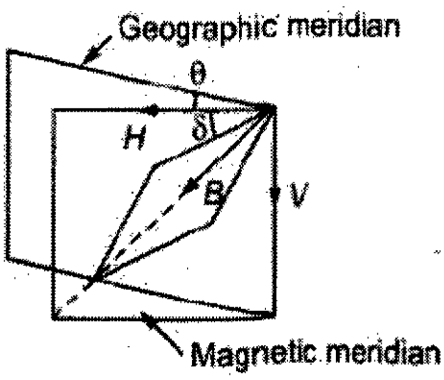
where e = charge on an electron, ω = angular velocity of electron and r = radius of orbit.

or M = n eh / 4πm

where h = Planck's constant and m ~ mass of an electron and eh / 4πm = μB, called Bohr magneton and its value is 9.27 * 10-24 A-m2.

Earth's Magnetism

Earth is a huge magnet. There are three components of earth's magnetism



(i) Magnetic Declination (θ) The smaller angle subtended between the magnetic meridian and geographic meridian is called magnetic declination.

(ii) Magnetic Inclination or Magnetic Dip (δ) The smaller angle sub tended between the magnetic axis and horizontal is called magnetic inclination on magnetic dip.

(iii) Horizontal Component of Earth's Magnetic Field (H) If B is the intensity of earth's magnetic field then horizontal component of earth's magnetic field $H = B \cos \delta$.

It acts from south to north direction.

Vertical component of earth's magnetic field

$V = B \sin \delta$

□ $B = \sqrt{H^2 + V^2}$

and $\tan \delta = V / H$

Angle of dip is zero at magnetic equator and 90° at poles.

Magnetic Meridian

A vertical plane passing through the magnetic axis is called magnetic mendian.

Geographic Meridian

A vertical plane passing through the geographic axis is called geographic meridian.

Magnetic Map

Magnetic map is obtained by drawing lines on the surface of earth. which passes through different places having same magnetic elements.

The main lines drawn on earth's surface are gl en below

(i) **Isogonic Line** A line joining places of equal declination is called on isogonic line.

(ii) **Agonic Line** A line joining places of zero declination is called an agonic line

(iii) **Isoclinic Line** A line joining places of equal inclination or dip is called an aclinic line,

(iv) **Aclinic Line** A hne joining places of zero inclination or dip is called an aclinic line.

(v) **Isodynamic Line** A line joining places of equal horizontal component of earth's magnetic field (H) is called an isodynamic line.

Magnetic Latitude

(i) If at any place, the angle of dip is δ and magnetic latitude is λ then $\tan \delta = 2 \tan \lambda$

(ii) The total Intensity of earth's magnetic field

$I = I_0 \sqrt{1 + 3 \sin^2 \lambda}$

where $I_o = M / R^3$

It is assumed that a bar magnet of earth has magnetic moment M and radius of earth is R.

(Magnetic maps are maps obtained by drawing lines passing through different places on the surface of earth, having the same value of a magnetic element.)

Neutral Points

Neutral point of a bar magnet is a point at which the resultant magnetic field of a bar magnet and horizontal component of earth's magnetic field are zero.

When north pole of a bar magnet is placed towards south pole of the earth. then neutral point is obtained on axial line.

$B = \mu_o / 4\pi \; 2Mr / (r^2 - l^2)^2 = H$

If r > > l, then $B = \mu o / 4\pi\ 2M / r3 = H$

When north pole of a bar magnet is placed towards north pole of the earth, then neutral point is obtained on equatorial line

$B = \mu o / 4\pi\ 2Mr / (r2 + l2)2 = H$

If r > > l, then $B = \mu o / 4\pi\ 2M / r3 = H$

Tangent Law

When a bar magnet is freely suspended under the combined effect of two uniform magnetic fields of intensities B and H acting at 90° to each other, then it bar magnet comes to rest making an angle 0 with the direction of H, then

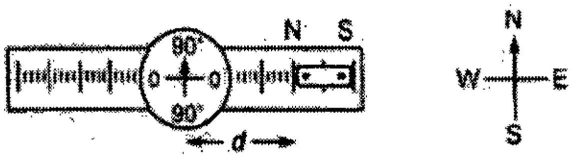
$B = H \tan \theta$

Deflection Magnetometer

It is a device used to determine M and H. Its working is based on tangent law.

Deflection magnetometer can be used into two settings

(i) **Tangent A setting** In this setting the arms of the magnetometer are along east-west and magnet is parallel to the arms.

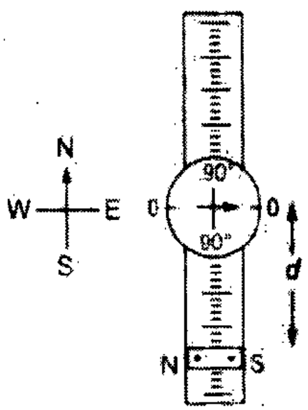


In equilibrium

$B = H \tan \theta$

$\mu o / 4\pi\ 2M / d3 = H \tan \theta$

(ii) **Tangent B setting** In this setting the arms of the magnetometer are along north-south and magnet is perpendicular to these arm in equilibrium



$\mu o / 4\pi\ M / d3 = H \tan \theta$

In above setting the experiment can be performed in two ways.

Notes

(a) **Deflection method** In this method one magnet is used at a time and deflection in galvanometer is observed. Ratio of magnetic dipole moments of the magnets

$M1 / M2 = \tan\theta1 / \tan\theta2$

where $\theta1$ and $\theta2$ are mean values of deflection for two magnets.

(b) Null method In this method both magnets are used at a time and no deflection condition is obtained. If Magnets are at distance d1 and d2 then

$M1 / M2 = (d1 / d2)3$

Tangent Galvanometer

It is a device used for detection and measurement of low electric currents. Its working is based on tangent law. If θ is the deflection produced in galvanometer when I current flows through it, then

$I = 2R / N\mu o\ H \tan\theta = H / G \tan\theta = K \tan\theta$

Where $G = N\mu / 2R$ is called galvanometer constant and $K = H / G$, is called reduction factor of tangent galvanometer.

Here N is number of turns in the coil and R is radius of the coil.

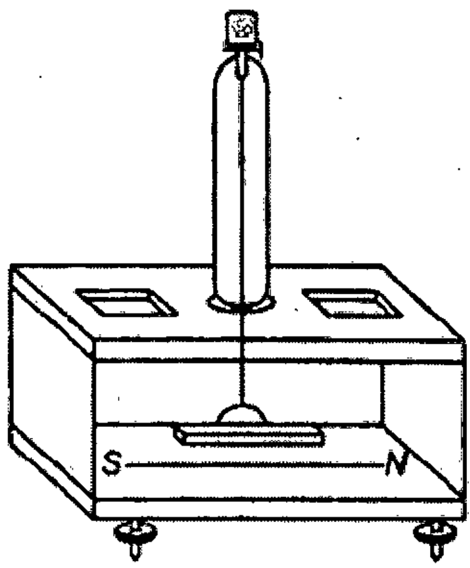
Tangent galvanometer is also called moving magnet type galvanometer.

Vibration Magnetometer

It is based on simple harmonic oscillations of a magnet suspended in uniform magnetic field.

Time period of vibrations is given by

$T = 2\pi \sqrt{I / MH}$



where, I = moment of inertia of the magnet,

M = magnetic dipole moment of the magnet and

H = horizontal component of earth's magnetic field.

When two magnets of unequal size are placed one above the other and north poles of both magnets are towards geographic north then time period of oscillations is given by

$T1 = 2\pi\sqrt{}I1 + I2 / (M1 + M2) H$

If north pole of first magnet and south pole of second magnet is towards geographic north, then time period of oscillations is given by

$T2 = 2\pi\sqrt{}(I1 + I2) / (M1 - M2) H$

Then, $M1 / M2 = T22 + T21 / T22 - T21$

Magnetic Flux

The number of magnetic lines of force passing through any surface is called magnetic flux linked with that surface.

Magnetic flux (phi;) = $B \,.\, A = BA \cos \theta$

where B is magnetic field intensity or magnetic induction, A is area of the surface.

Its unit is 'weber'.

Magnetic Induction

The magnetic flux passing through per unit normal area, is called magnetic induction.

Magnetic induction $(B) = \varphi / A$

Its unit is 'waber/metre2'or 'tesla'.

Magnetic of Material

To describe the magnetic properties of materials, following terms are required

(i) **Magnetic Permeability** It is the ability of a material to permit the passage of magnetic lines of force through it.

Magnetic permeability $(\mu) = B / H$

where B is magnetic induction and H is magnetising force or magnetic intensity.

(ii) **Magnetising Force or Magnetic Intensity** The degree up to which a magnetic field can magnetise a material is defined in terms of magnetic intensity.

Magnetic intensity $(H) = B / \mu$

(iii) **Intensity of Magnetisation** The magnetic dipole moment developed per unit volume of the material is called intensity of magnetisation.

Intensity of magnetisation $(I) = M / V = m / A$

where V = volume and A = area of cross-section of the specimen.

Magnetic induction $B = \mu o (H + I)$

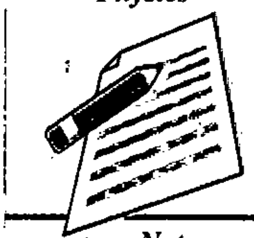
(iv) **Magnetic Susceptibility(χm)** The ratio of the intensity of magnetisation (1) induced in the material to the magnetising force (H) applied, is called magnetic susceptibility. Magnetic Susceptibility(χm) = I / H

[Relation between Magnetic Permeability and Susceptibility is given by

$\mu = \mu o (1 + \chi m)$]

CLASS–12

Physics



Notes

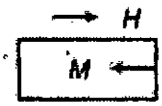
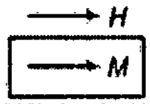
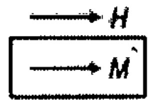
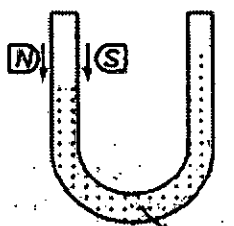
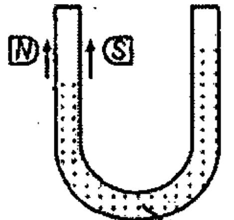
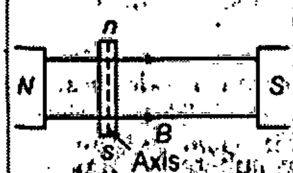
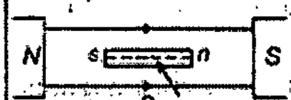
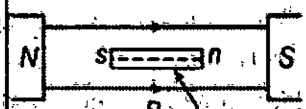
Classification of Magnetic Materials

On the basis of their magnetic properties magnetic materials are divided into three categories

(i) Diamagnetic substances

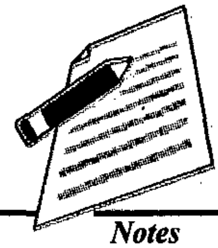
(ii) Paramagnetic substances

iii) Ferromagnetic substances

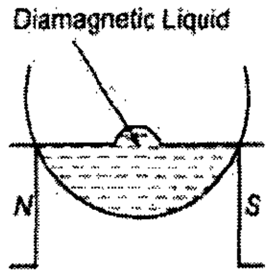
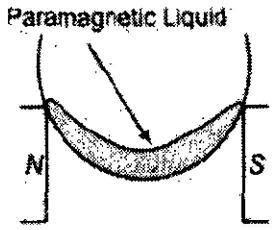
S. No.	Diamagnetic substances	Paramagnetic substances	Ferromagnetic substances
1.	These substances when placed in a magnetic field, acquire feeble magnetism opposite to the direction of the magnetic field. 	These substances when placed in a magnetic field, acquire feeble magnetism in the direction of the magnetic field. 	These substances when placed in a magnetic field are strongly magnetised in the direction of the field. 
2.	These substances are repelled by a magnet.	These substances are feebly attracted by a magnet.	These substances are strongly attracted by a magnet.
3.	When a diamagnetic solution is poured into a U-tube and one arm is placed between the poles of strong magnet, the level of solution in that arm is lowered. 	The level of the paramagnetic solution in that arm rises. 	No liquid is ferromagnetic.
4.	If a rod of diamagnetic material is suspended freely between two magnetic poles, its axis becomes perpendicular to the magnetic field. 	Paramagnetic rod becomes parallel to the magnetic field. 	Ferromagnetic rod also becomes parallel to the magnetic field. 

CLASS–12

Physics



Notes

S. No.	Diamagnetic substances	Paramagnetic substances	Ferromagnetic substances
5.	In non-uniform magnetic field, the diamagnetic substances are attracted towards the weaker fields, *i.e.*, they move from stronger to weaker magnetic field.	In non-uniform magnetic field they move from weaker to stronger part of the magnetic field slowly.	In non-uniform magnetic field they move from weaker to stronger magnetic field rapidly.
6.	Their permeability is less than one ($\mu < 1$).	Their permeability is slightly greater than one ($\mu > 1$).	Their permeability is much greater than one ($\mu >> 1$).
7.	Their susceptibility is small and negative. Their susceptibility is independent of temperature.	Their susceptibility is small and positive. Their susceptibility is inversely proportional to absolute temperature which is Curie's law, *i.e.*, $\chi \propto 1/T$	Their susceptibility is large and positive. They also follow Curie law, *i.e.*, ($\chi \propto 1/T$). At Curie temperature ferromagnetic substances change into paramagnetic substances.
8.	Shape of diamagnetic liquid in a glass crucible and kept over two magnetic poles. 	Shape of paramagnetic liquid in a glass crucible and kept over two magnetic poles. 	No liquid is ferromagnetic.
9.	In these substances the magnetic lines of force are farther than in air.	In these substances the magnetic lines of force are closer than in air.	In these substances the magnetic lines of force are much closer than in air.
10.	The resultant magnetic moment of these substances is zero.	These substances have a permanent magnetic moment.	These substances also have a permanent magnetic moment.

The atoms of a paramagnetic substance contain even number of electrons.

The atoms or molecules of a paramagnetic substance do not possess any net magnetic moment.

The atoms of a paramagnetic material contain odd number of electrons.

Every atom or molecule of a paramagnetic substance has its own magnet moment, i.e., its each atom or molecule is a tiny magnet.

In a ferromagnetic substance, there are several tiny regions called domains. Each domain contains approximately 1010 atoms.

Each domain is a strong magnet as all atoms or molecules in a domain have same direction of magnetic moment.

Curie Law in Magnetism

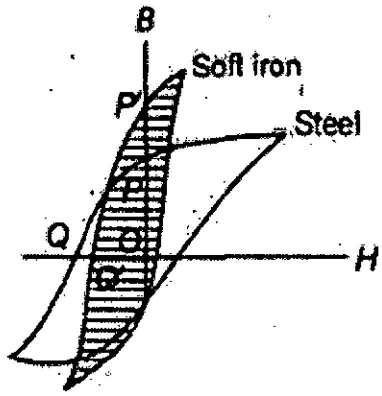
The magnetic susceptibility of a paramagnetic substance is inversely proportional to its absolute temperature.

$\chi m \propto 1 / T \Rightarrow \chi m\, T = \text{constant}$

where χm = magnetic susceptibility of a para magnetic substance and T = absolute temperature.

Hysteresis

The lagging of intensity of magnetisation (I) or magnetic induction (B) behind magnetising field (H), when a specimen of a magnetic substance is taken through a complete cycle of magnetisation is called hysteresis.



Retentivity or Residual Magnetism

The value of the intensity of magnetisation of a material, when the magnetising field is reduced to zero is called retentivity or residual magnetism of the material.

Coercivity

The value of the reverse magnetising field that should be applied to a given sample in order to reduce its intensity of magnetisation or magnetic induction to zero is called coercivity.

Permanent Magnets

Commonly steel is used to make a permanent magnet because steel has high residual magnetism and high coercivity.

Electromagnets

Electromagnets are made of soft iron because area of hysteresis loop for soft iron is small. Therefore, energy loss is small for a cycle of magnetisation and demagnetisation.

(Permanent magnets are made by the materials such as steel, for which residual magnetism as well as coercivity should be high. Electromagnets are made by the materials such as soft iron for which residual magnetism is high, coercivity is low and hysteresis loss is low).

Important Points

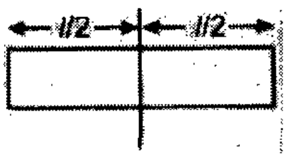
- Magnetic length = 5 / 6 * geometric length of magnet.
- About 90% of magnetic moment is due to spin motion of electrons and remaining 10% of magnetic moment is due to the orbital motion of electrons.
- When a magnet having magnetic moment, M is cut into two equal parts

  (i) Parallel to its length

  M' = m / 2 * l = M / 2

  (ii) Perpendicular to its length

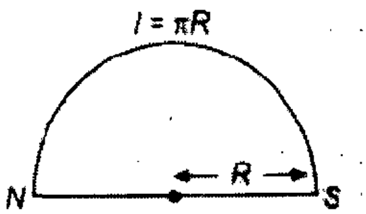
  M' = m * l / 2 = M / 2



- When a magnet of length l, pole strength m and of magnetic moment M is turned into a semi-circular arc then it new magnetic moment

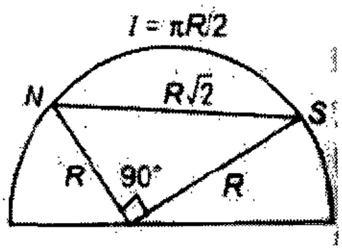
  $M' = m * 2R = m * 2 * l / \pi \ (\pi R = l)$

  $= 2M / \pi \ (M = m * l)$

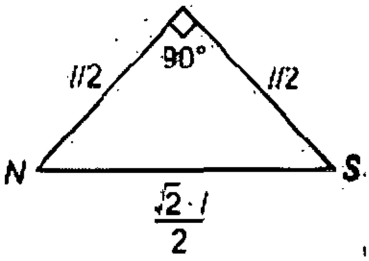


- A thin magnet of moment M is turned into an arc of 90°. Then new magnetic moment

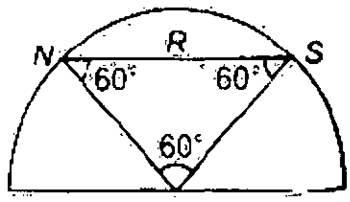
  $M' = 2\sqrt{2}M / \pi$



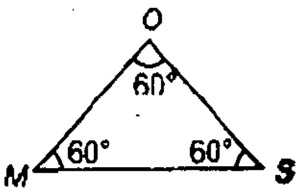
- A thin magnet of moment M is turned at mid-point 90°.Then new magnet moment $M' = M / \sqrt{2}$



- A thin magnet of moment M is turned into an arc of 60°. Then new magnetic moment
  $M = 3M / \pi$



- A thin magnet of moment M is bent at mid-point at angle 60°. Then new magnetic moment.
  $M' = M / 2$



- Original magnet MOS is bent at O, the mid-point at 60°.All sides are equal
- The mutual interaction force between two small magnets of moments M1 and M2 is given by
  F = K 6M1M2 / d4 in end- on position.

Here, d denotes the separation between magnets.

- Magnetic length = 5 / 6 * geometric length of magnet.
- Cause of diamagnetism is orbital motion and cause of paramagnetism is spin motion of electrons. Cause of ferromagnetism lies in formation of domains.
- The perpendicular bisector of magnetic axis is known as neutral axis of magnet. Magnetism at neutral axis is zero and at poles is maximum.
- For steel coercivity is large. However, retentivity is comparatively smaller in case of steel. So, steel is used to make permanent magnets.
- For soft iron, coercivity is very small and area of hysteresis loop is small. So, soft iron is an ideal material for making electromagnets.

Summary of the chapter

1. A satisfactory understanding of magnetic phenomenon in terms of moving charges/currents was arrived at after 1800 AD. But technological exploitation of the directional properties of magnets predates this scientific understanding by two thousand years. Thus, scientific understanding is not a necessary condition for engineering applications. Ideally, science and engineering go hand-in-hand, one leading and assisting the other in tandem.
2. Magnetic monopoles do not exist. If you slice a magnet in half, you get two smaller magnets. On the other hand, isolated positive and negative charges exist. There exists a smallest unit of charge, for example, the electronic charge with value $|e| = 1.6 \times 10–19$ C. All other charges are integral multiples of this smallest unit charge. In other words, charge is quantised. We do not know why magnetic monopoles do not exist or why electric charge is quantised.
3. A consequence of the fact that magnetic monopoles do not exist is that the magnetic field lines are continuous and form closed loops. In contrast, the electrostatic lines of force begin on a positive charge and terminate on the negative charge (or fade out at infinity).
4. The earth's magnetic field is not due to a huge bar magnet inside it. The earth's core is hot and molten. Perhaps convective currents in this core are responsible for the earth's magnetic field. As to what 'dynamo' effect sustains this current, and why the earth's field reverses polarity every million years or so, we do not know.
5. A miniscule difference in the value of χ, the magnetic susceptibility, yields radically different behaviour: diamagnetic versus paramagnetic. For diamagnetic materials $\chi = –10–5$ whereas $\chi = +10–5$ for paramagnetic materials.
6. There exists a perfect diamagnet, namely, a superconductor. This is a metal at very low temperatures. In this case $\chi = –1$, $\mu r = 0$, $\mu = 0$. The external magnetic field is totally expelled. Interestingly, this material is also a perfect conductor. However, there exists no classical theory which ties these two properties together. A quantum-mechanical theory by Bardeen, Cooper, and Schrieffer (BCS theory) explains these effects. The BCS theory was proposed in1957 and was eventually recognised by a Nobel Prize in physics in 1970.
7. The phenomenon of magnetic hysteresis is reminiscent of similar behaviour concerning the elastic properties of materials. Strain may not be proportional to stress; here H and B (or M) are not linearly related. The stress-strain curve exhibits hysteresis and area enclosed by it represents the energy dissipated per unit volume. A similar interpretation can be given to the B-H magnetic hysteresis curve.
8. Diamagnetism is universal. It is present in all materials. But it is weak and hard to detect if the substance is para- or ferromagnetic.
9. We have classified materials as diamagnetic, paramagnetic, and ferromagnetic. However, there exist additional types of magnetic material such as ferrimagnetic, anti-ferromagnetic, spin glass, etc. with properties which are exotic and mysterious.

Multiple choice Questions

1. S.I. unit of flux is:
   (a) Ohm
   (b) Weber
   (c) Tesla
   (d) None
   Answer: (b) Weber
2. What is the angle of dip at a place where the horizontal component of earth's magnetic field is equal to the vertical component?
   (a) 0°
   (b) 30°
   (c) 45°
   (d) 90°
   Answer: (c) 45°
3. Which of the following has a low value in ferrites?
   (a) Conductivity
   (b) Permeability
   (c) Magnetic susceptibility
   (d) All the above
   Answer: (a) Conductivity
4. The dimensional representation of magnetic flux density is :
   (a) [MLT-2]
   (b) [MLT-2A-1]
   (c) [MLT-2A-2]
   (d) [MT-2A-1]
   Answer: (d) [MT-2A-1]
5. Tangent law is applicable only when:
   (a) two uniform and mutually perpendicular magnetic fields exist
   (b) two magnetic fields exist
   (c) horizontal component of earth's magnetic field is present
   (d) uniform magnetic field are used
   Answer: (a) two uniform and mutually perpendicular magnetic fields exist
6. Ferrites may be:
   (a) anti-ferromagnetic
   (b) ferromagnetic
   (c) ferrimagnetic
   (d) None of the above
   Answer: (b) ferromagnetic

7. A magnetic bar of M magnetic moment is placed m the field of magnetic strength B, the torque acting on it is :

   (a) $\vec{M}.\vec{B}$

   (b) $-\vec{M}.\vec{B}$

   (c) $\vec{M} \times \vec{B}$.

   (d) $\vec{B} \times \vec{M}$

   Answer: (c) $\vec{M} \times \vec{B}$.

8. The magnetic lines of force inside a bar magnet:

   (a) do not exist

   (b) depends on area of cross-section of bar magnet

   (c) are from N-pole to S-pole of the magnet

   (d) are from S-pole to N-pole of the magnet.

   Answer: (d) are from S-pole to N-pole of the magnet.

9. A magnetic dipole moment is a vector quantity directed from:

   (a) S to N

   (b) N to S

   (c) E to W

   (d) W to E

   Answer: (a) S to N

10. What is the magnetic field in the empty space enclosed by the toroidal solenoid of radius 'R'? ,

    (a) Infinity

    (b) $\frac{\mu_0}{4\pi}.\frac{2\pi l}{R}$

    (c) $\frac{\mu_0}{4\pi}.(\frac{\pi l}{R})$

    (d) zero

    Answer: (d) zero

Review Questions

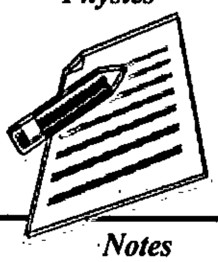
1. A bar magnet of magnetic moment M is aligned parallel to the direction of a uniform magnetic field B. What is the work done to turn the magnet, so as the align its magnetic moment?

   (i) Opposite to the field direction

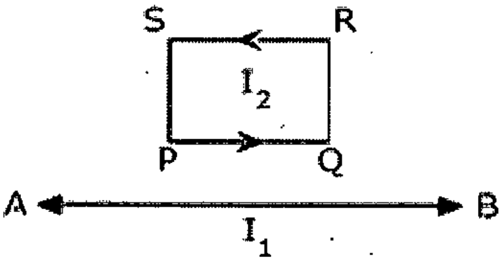
   (ii) Normal to the field direction?

2. An electron in the ground state of hydrogen atom is revolving in anti – clock wise direction in a circular orbit. The atom is placed normal to the electron orbit makes an angle of 30o in the magnetic field. Find the torque experienced by the orbiting electron?

3. Define angle of dip. Deduce the relation connecting angle of dip and horizontal component of earth's total magnetic field with the horizontal direction.



4. A point change +q is moving with speed υ perpendicular to the magnetic field B as shown in the figure. What should be the magnitude and direction of the applied electric field so that the net force acting on the charge is zero?
5. The energy of a charged particle moving in a uniform magnetic field does not change. Why?
6. In the figure, straight wire AB is fixed; white the loop is free to move under the influence of the electric currents flowing in them. In which direction does the loop begin to move? Justify.



7. State two factors by which voltage sensitivity of a moving coil galvanometer can be increased?

Unit IV: Electromagnetic Induction and Alternating Currents

6 ELECTROMAGNETIC INDUCTION

- Electromagnetic induction –
  - Faraday's laws
  - Induced EMF and current
  - Lenz's Law
  - Eddy currents
- Self and mutual induction.

Objective of the chapter

The main objective of this chapter is to make student understand about the concepts Electromagnetic Induction by explaining the Faraday's laws and Lenz's Law. Self and mutual induction has also been explained in this chapter.

Introduction

Whenever the magnetic flux linked with an electric circuit changes, an emf is induced in the circuit. This phenomenon is called **electromagnetic induction.**

Faraday's Laws of Electromagnetic Induction

(i) Whenever the magnetic flux linked with a circuit changes, an induced emf is produced in it.

(ii) The induced emf lasts so long as the change in magnetic flux continues.

(iii) The magnitude of induced emf is directly proportional to the rate of change in magnetic flux, i.e.,

$E \;\square\; d\varphi / dt \;\square\; E = -d\varphi / dt$

where constant of proportionality is one and negative sign indicates Lenz's law.

Here, flux = NBA cos θ, SI unit of φ = weber,

CGS unit of φ = maxwell, 1 weber = 108 maxwell;

Dimensional formula of magnetic flux

[φ] = [ML2T-2A-2]

Lenz's law

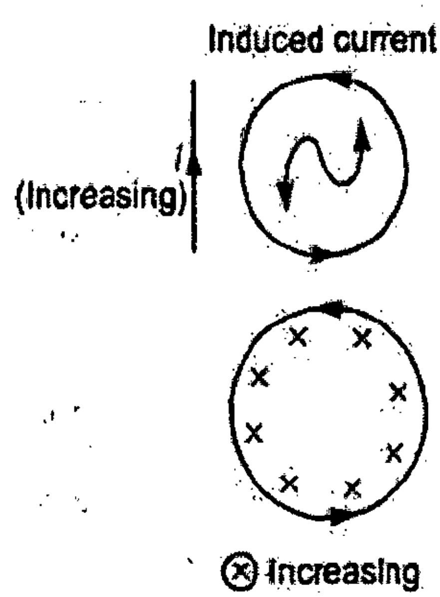
The direction of induced emf or induced current is always in such a way that it opposes the cause due to which it is produced.

Lenz's law is in accordance with the conservation of energy.

Note To apply Lenz's law, you can remember RIN or ® In (when the loop lies on the plane of paper)

(i) RIN In RIN, R stands for right, I stands for increasing and N for north pole (anticlockwise). It means, if a loop is placed on the right side of a straight current carrying conductor and the current in the conductor is increasing, then induced current in the loop is anticlockwise

(ii) ®IN In ® IN suppose the magnetic field in the loop is perpendicular to paper inwards ® and this field is increasing, then induced current in the loop is anticlockwise

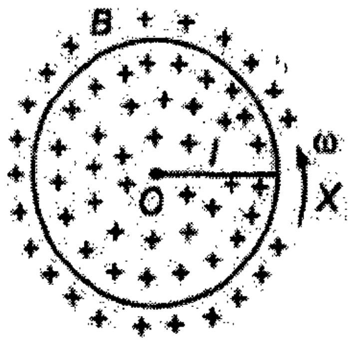


Motional Emf

If a rod of length 1 moves perpendicular to a magnetic field B, with a velocity v, then induced emf produced in it given by

E = B * v * I = bvl

If a metallic rod of length 1 rotates about one of its ends in a plane perpendicular to the magnetic field, then the induced emf produced across its ends is given by



E = 1 / 2 bωr2 = BAf

where, ω = angular velocity of rotation, f = frequency of rotation and A = πr2 = area of disc.

The direction of induced current in any conductor can be obtained from Fleming's right hand rule.

A rectangular coil moves linearly in a field when coil moves with constant velocity in a uniform magnetic field, flux and induced emf will be zero.

A rod moves at an angle θ with the direction of magnetic field, velocity E = – Blv sin θ.

An emf is induced

(i) When a magnet is moved with respect to a coil.

(ii) When a conductor falls freely in East-West direction.

(iii) When an aeroplane flies horizontally.

(iv) When strength of current flowing in a coil is increased or decreased, induced current is developed in the coil in same or opposite direction.

(v) When a train moves horizontally in any direction.

Fleming's Right Hand Rule

If we stretch the thumb, the forefinger and the central finger of right hand in such a way that all three are perpendicular to each other, th. if thumb represent the direction of motion, the forefinger represents tile direction of magnetic field, then central finger will represent the

direction of induced current.

If R is the electrical resistance of the circuit, then induced current in the circuit is given by I = E / R

If induced current is produced in a coil rotated in uniform magnetic field, then

I = NBA ω sin ωt / R = Io sin ωt

where, Io = NBA ω = peak value of induced current,

N = number of turns in the coil,

B= magnetic induction,

ω = angular velocity of rotation and

A = area of cross-section of the coil.

Eddy Currents

If a piece of metal is placed in a varying magnetic field or rotated high speed in a uniform magnetic field, then induced current set up the piece are like where pool of air, called eddy currents.

The magnitude 0f eddy currents is given by $i = - e / R = d\varphi / dt / R$, where R is the resistance.

Eddy currents are also known as Facault's current.

Self-Induction

The phenomena of production of induced emf in a circuit due to change in current flowing in its own, is called self-induction.

Coefficient of Self-Induction

The magnetic flux linked with a coil

$\varphi = LI$

where, L = = coefficient of self-induction.

The induced emf in the coil

$E = - L\, dl / dt$

it unit of self-induction is henry (H) and its dimensional formula is [ML2T -2A-2].

Self – inductance of a long solenoid is given by normal text

$L = \mu o\, N2\, A / 1 = \mu o\, n2\, Al$

where. N = total number of turns in the solenoid,

1 = length of the coil, n = number of turns in the coil and

A = area of cross-section of the coil.

If core of the solenoid is of any other magnetic material, then

$L = \mu o\, \mu r\, N2\, A / l$

Self – inductance of a toroid $L = \mu o\, N2\, A / 2\pi r$

Where, r = radius of the toroid

Energy stored in an inductor $E = 1 / 2\, LI2$

Mutual Induction

The phenomena of production of induced emf in a circuit due to the change in magnetic flux in its neighbouring circuit, is called mutual induction.

Coefficient of Mutual Induction

If two coils are coupled with each, other than magnetic flux linked with a Coil (secondary coil)

$\varphi = MI$

where M is coefficient of mutual induction and I is current flow in through primary coil.

The induced emf in the secondary coil

$E = -M\, dI / dt$

where dI / dt is the rate of change of current through primary coil.

The unit of coefficient of mutual induction is henry (H) and its dimension is $[ML^2T^{-2}A^{-2}]$.

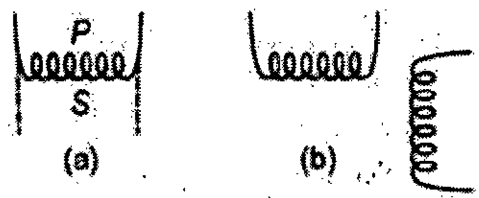
The coefficient of mutual induction depends on geometry of two coils, distance between them and orientation of the two coils.

Coefficient of Coupling

Two coils are said to be coupled if full a part of the fuse produced by one links with the other.

$K = \sqrt{M / L_1 L_2}$, where L_1 and L_2 are coefficients of self-induction of the two coils and M is coefficient of mutual induction of the two coils.

Coefficient of coupling is maximum (K = 1) in case (a), when coils are coaxial and minimum in case (b), when coils are placed a right angle.



Mutual inductance of two long coaxial solenoids is given by

$M = \mu N_1 N_2 A / l$

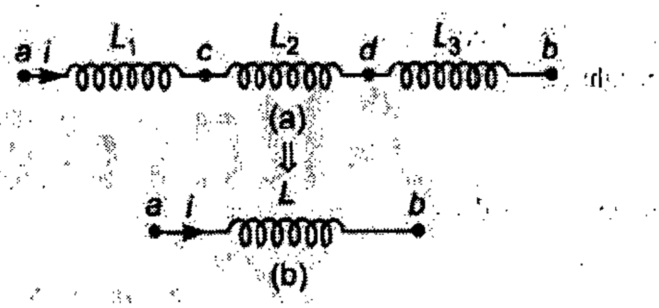
$= \mu n_1 n_2 A l$

where N_1 and N_2 are total number of turns in both coils, n_1 n_2 are number of turns per unit length in coils, A is area of cross-section of coils and l is length of the coils.

Grouping of Coils

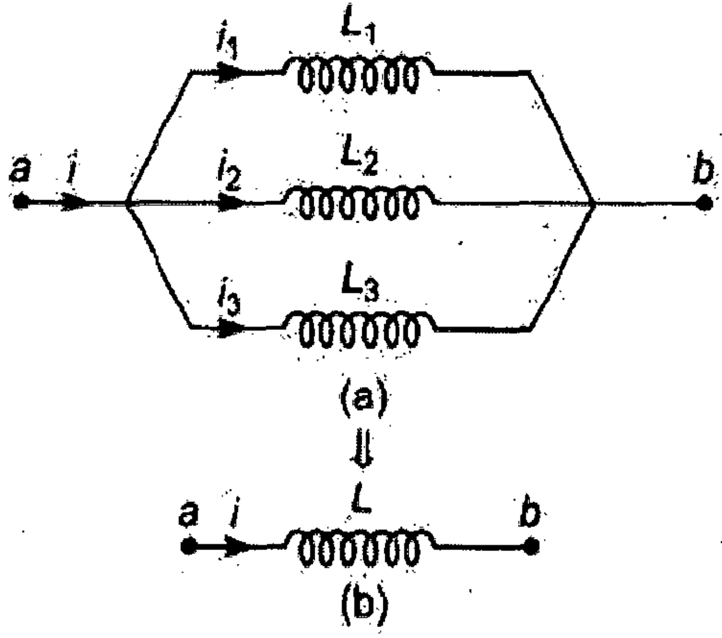
(a) When three coils of inductances L_1, L_2 and L_3 are connected in series and the coefficient of coupling K = 0, as in series, then

$L = L_1 + L_2 + L_3$



(b) When three coils of inductances L_1, L_2 and L_3 are connected in parallel and the coefficient of coupling K= 0 as in parallel, then

$L = 1 / L_1 + 1 / L_2 + 1 / L_3$



If coefficient of coupling K = 1, then

(i) **In series**

(a) If current in two coils are in the same direction, then

$L = L_1 + L_2 + 2M$

(b) If current in two coils are in opposite directions, then

$L = L_1 + L_2 - 2M$

(ii) **In parallel**

(a) If current in two coils are in same direction, then

$L = L_1 L_2 - M2 / L_1 + L_2 + 2M$

(b) If current in two coils are in opposite directions, then

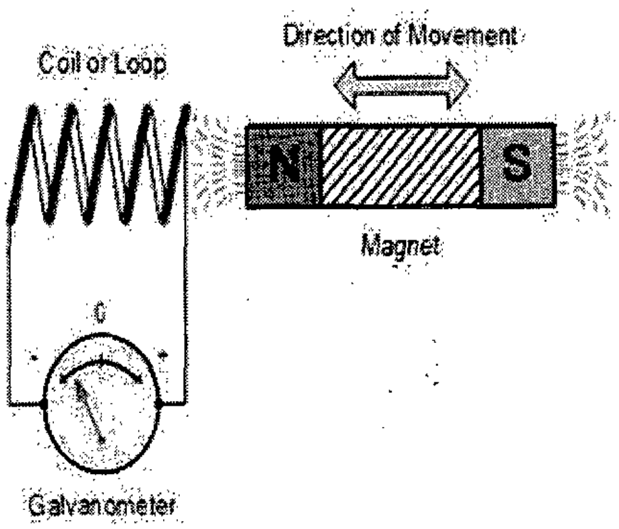
$L = L_1 L_2 - M2 / L_1 + L_2 - 2M$

Summary of the chapter

Electromagnetic induction

Suppose while shopping you go cashless and your parents use cards. The shopkeeper always scans or swipes the card. Shopkeeper does not take a photo of the card or tap it. Why does he swipe/scan it? And how does this swiping deduct money from the card? This happens because of the '**Electromagnetic Induction**'.

Can moving objects produce electric currents? How to determine a relationship between electricity and magnetism? Can you imagine the scenario if there were no computers, no telephones, no electric lights? The experiments of Faraday have led to the generation of generators and transformers.



Notes

The induction of an electromotive force by the motion of a conductor across a magnetic field or by a change in magnetic flux in a magnetic field is called **'Electromagnetic Induction'.**

This either happens when a conductor is set in a moving magnetic field (when utilizing AC power source) or when a conductor is always moving in a stationary magnetic field.

This law of electromagnetic induction was found by **Michael Faraday.** He organized a leading wire according to the setup given underneath, connected to a gadget to gauge the voltage over the circuit. So, when a bar magnet passes through the snaking, the voltage is measured in the circuit. The importance of this is a way of producing electrical energy in a circuit by using magnetic fields and not just batteries anymore. The machines like generators, transformers also the motors work on the principle of electromagnetic induction.

Multiple choice Questions

1. The north pole of a long bar magnet was pushed slowly into a short solenoid connected to a short galvanometer. The magnet was held stationary for a few seconds with the north pole in the middle of the solenoid and then withdrawn rapidly. The maximum deflection of the galvanometer was observed when the magnet was

   (a) moving towards the solenoid

   (b) moving into the solenoid

   (c) at rest inside the solenoid

   (d) moving out of the solenoid

   Answer: d

2. The magnetic flux linked with a coil of N turns of area of cross section A held with its plane parallel to the field B is

   (a) $\frac{NAB}{2}$ *(b)* NAB *(c)* $\frac{NAB}{4}$ *(d)* zero

   Answer: d

3. Faraday's laws are consequence of the conservation of

   (a) charge

   (b) energy

   (c) magnetic field

   (d) both (b) and (c)

   Answer: b

4. Two identical coaxial coils P and Q carrying equal amount of current in the same direction are brought nearer. The current in

   (a) P increases while in Q decreases

   (b) Q increases while in P decreases

   (c) both P and Q increases

   (d) both P and Q decreases

   Answer: d

5. Direction of current induced in a wire moving in a magnetic field is found using

   (a) Fleming's left-hand rule

   (b) Fleming's right hand rule

   (c) Ampere's rule

   (d) Right hand clasp rule

   Answer: b

6. Lenz's law is a consequence of the law of conservation of

   (a) charge

   (b) energy

(c) induced emf

(d) induced current

Answer: b

7. A solenoid is connected to a battery so that a steady current flow through it. If an iron core is inserted into the solenoid, the current will

   (a) increase

   (b) decrease

   (c) remain same

   (d) first increase then decrease

   Answer: b

8. Which of the following statements is not correct?

   (a) Whenever the amount of magnetic flux linked with a circuit changes, an emf is induced in circuit.

   (b) The induced emf lasts so long as the change in magnetic flux continues.

   (c) The direction of induced emf is given by Lenz's law.

   (d) Lenz's law is a consequence of the law of conservation of momentum.

   Answer: d

9. There is a uniform magnetic field directed perpendicular and into the plane of the paper. An irregular shaped conducting loop is slowly changing into a circular loop in the plane of the paper. Then

   (a) current is induced in the loop in the anti-clockwise direction.

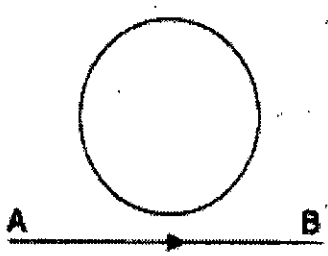
   (b) current is induced in the loop in the clockwise direction.

   (c) ac is induced in the loop.

   (d) no current is induced in the loop.

   Answer: a

10. In the given figure current from A to B in the straight wire is decreasing. The direction of induced current in the loop is A



   (a) clockwise

   (b) anticlockwise

   (c) changing

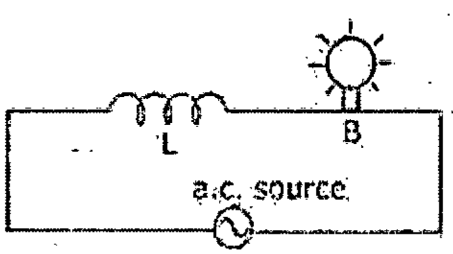
   (d) nothing can be said

   Answer: b

Notes

Review Questions

1. IF the rate of change of current of 2A/s induces an emf of 10mV in a solenoid. What is the self-inductance of the solenoid?
2. A circular copper disc. 10 cm in radius rotates at a speed of 2π rad/s about an axis through its centre and perpendicular to the disc. A uniform magnetic field of 0.2T acts perpendicular to the disc.
   1) Calculate the potential difference developed between the axis of the disc and the rim.
   2) What is the induced current if the resistant of the disc is 2Ω?
3. An ideal inductor consumes no electric power in a.c. circuit. Explain?
4. Capacitor blocks d.c. why?
5. Why is the emf zero, when maximum number of magnetic lines of force pass through the coil?
6. An inductor L of reactance X_L is connected in series with a bulb B to an a.c. source as shown in the figure.



   Briefly explain how does the brightness of the bulb change when
   (a) Number of turns of the inductor is reduced.
   (b) A capacitor of reactance $X_C = X_L$ is included in series in the same circuit.
7. A jet plane is travelling towards west at a speed of 1800 km/h. What is the voltage difference developed between the ends of the wing having a span of 25 m, if the Earth's magnetic field at the location has a magnitude of $5 \times 10^{-4} T$ and the dip angle is 30°.
8. A pair of adjacent coils has a mutual inductance of 1.5 H. If the current in one coil changes from 0 to 20 A in 0.5 s, what is the change of flux linkage with the other coil?

7 ALTERNATING CURRENT

- Alternating currents –
  - o Peak and RMS value of alternating current/voltage
  - o Reactance and impedance
  - o LC oscillations (qualitative treatment only)
  - o LCR series circuit
  - o Resonance
  - o Power in AC circuits
  - o Wattless current
- AC generator and transformer
- shell (field inside and outside).

Objective of the chapter

The main objective of this chapter is to make student understand about the concepts of Alternating Current. Reactance and impedance, Wattless current and topics like AC generator and transformer has also been explained in this chapter.

Introduction

Transient Current

An electric current which vary for a small finite time, while growing from zero to maximum or decaying from maximum to zero, is called a transient current.

Growth of Current in an Inductor

Growth of current in an inductor at any instant of time t is given by

$I = I_o(1 - e^{-Rt/L})$

where, I_o = maximum current, L = self-inductance of the inductor and R = resistance of the circuit.

Here $R / L = \tau$, is called time constant of a L – R circuit.

Time constant of a L – R circuit is the time in which current in the circuit grows to 63.2% of the maximum value of current.

Decay of current in an inductor at any time t is given by

$I = Ioe\ -Rt / L$

Time constant of a L – R circuit is the time in which current decays to 36.8% of the maximum value of current.

Charging and Discharging of a Capacitor

The instantaneous charge on a capacitor on charging at any instant of time t is given by

$q = qo(1 - e - t / RC)$

where RC = τ, is called time constant of a R – C circuit.

The instantaneous charge on a capacitor in discharging at any instant of time t is given by $q = qoe - t / RC$

Time constant of a R – C circuit is the time in which charge in the capacitor grows to 63.8% or decay to 36.8% of the maximum charge on capacitor.

Alternating Current

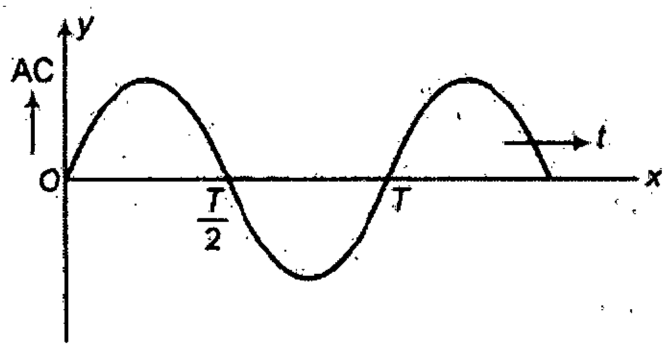
An electric current whose magnitude changes continuously with time and changes its direction periodically, is called an alternating current.

The instantaneous value of alternating current at any instant of time t is given by

$I = Io \sin \omega t$

where, 10 = peak value of alternating current.

The variation of alternating current with time is shown in graph given below



Mean or average value of alternating current for first half cycle

$Im = 2Io / \pi = 0.637\ Io$

Mean or average value of alternating current for next half cycle

$I'm = -2Io / \pi = -0.637\ Io$

Mean or average value of alternating current for one complete cycle = O.

Root mean square value of alternating current

$Iv = Irms = Io / \sqrt{2} = 0.707\ Io$

Where, Io = peak value of alternating current.

CLASS–12

Physics

Notes

Root mean square value of alternating voltage

Vrms = Vo / √2 = 0.707 Io = 0.707 Vo

Reactance

The opposition offered by an inductor or by a capacitor in the path of flow of alternating current is called reactance.

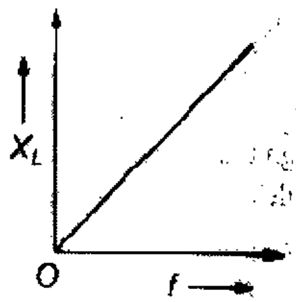
Reactance is of two types

(i) **Inductive Reactance** (XL) Inductive reactance is the resistance offered by an inductor.

Inductive reactance (XL) = Lω = L2πf = L2π / T

Its unit is ohm. XL □ f

For direct current, XL = 0 (f = 0)



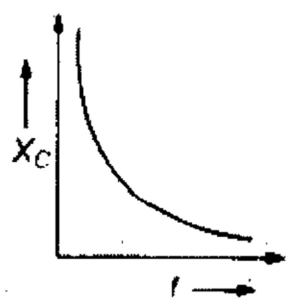
(ii) **Capacitive Reactance** (Xc) Capacitive reactance is the resistance offered by an inductor

Capacitive reactance,

Xc = 1 / Cω = 1 / C2πf = T / C 2π

Its unit is ohm Xc □ 1 / f

For direct current, Xc = ∞ (f = 0)



Impedance

The opposition offered by an AC circuit containing more than one out of three components L, C and R, is called impedance (Z) of the circuit.

Impedance of an AC circuit, Z = √R2 + (XL – XC)2

Its SI unit is ohm.

Power in an AC Circuit

The power is defined as the rate at which work is being in the circuit.

The average power in an AC circuit,

Pav = Vrms irms cos θ

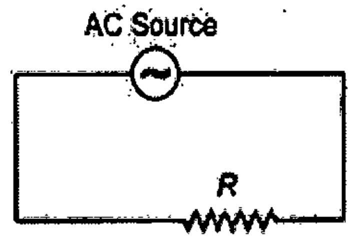
= V / √2 i / √2 cos θ = Vi / √2 cos θ

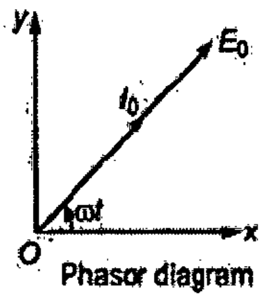
where, cos θ = Resistance(R) / Impedance (Z) is called the power factor 0f AC circuit.

Current and Potential Relations

Here, we will discuss current and potential relations for different AC circuits.

(i) **Pure Resistive Circuit** (**R** circuit)





(a) Alternating emf, E = Eo sin ωt

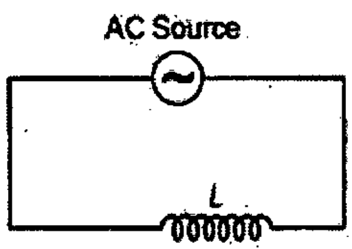
(b) Alternating current, I = Io sin ωt

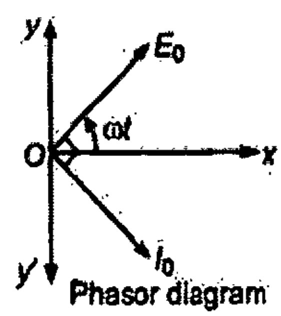
(c) Alternating emf and alternating current both are in the same phase.

(d) Average power decay, (P) = Ev . Iv

(e) Power factor, cos θ = 1

(ii) **Pure Inductive Circuit** (L Circuit)





(a) Alternating emf, E = Eo sin ωt

(b) Alternating current, I = Io sin (ωt – π / 2)

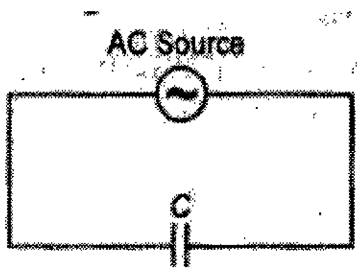
(c) Alternating current lags behind alternating emf by π / 2.

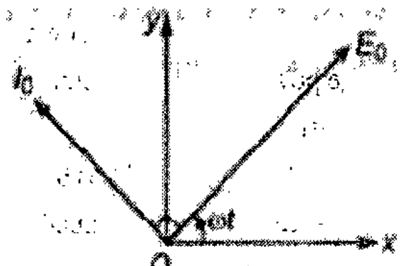
(d) Inductive reactance, XL = Lω = L2πf

(e) Average power decay, (P) = 0

(f) Power factor, cos θ = cos 90° = 0

(iii) **Pure Capacitive Circuit**





Phasor diagram

(a) Alternating emf, E = Eo sin ωt

(b) Alternating current, I = Io sin (ωt + π / 2)

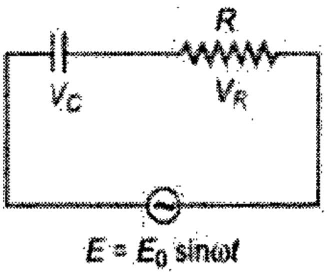
(c) Alternating current lags behind alternating emf by π / 2.

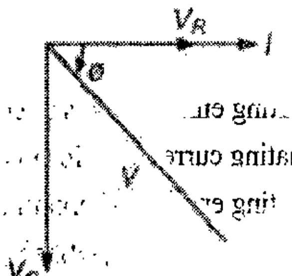
(d) Inductive reactance, XL = Cω = C2πf

(e) Average power decay, (P) = 0

(f) Power factor, cos θ = cos 90° = 0

(iv) **R – C Circuit**





Phasor diagram

E = Eo sin ωt

I = Eo / 2 sin (ωt – φ)

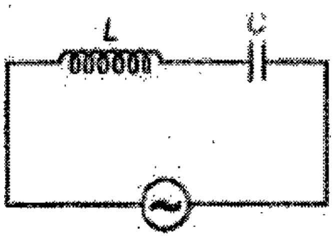
Z = √R2 + (1 / ωC)2

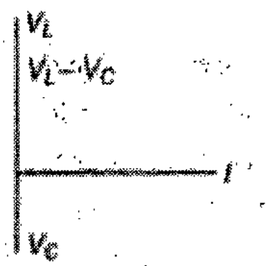
tan φ = – 1 / ωC / R

Current leading the voltage by φ

V2 = V2R = V2C

(v) **L – C Circuit**





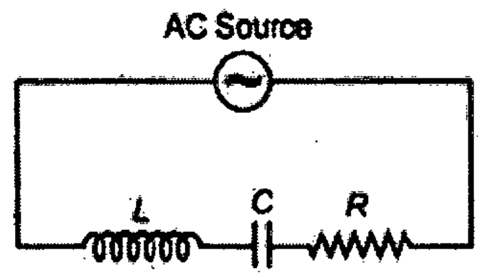
Phasor diagram

$$E = E_0 \sin \omega t,\ I = \frac{E}{2} \sin(\omega t - \phi)$$

$$Z = X_L - X_C \text{ and } \tan\phi = \frac{X_L - X_C}{0}$$

- For $X_L > X_C, \phi = \frac{\pi}{2}$ and for $X_L < X_C, \phi = -\frac{\pi}{2}$
- If $X_L = X_C$ at $\omega = \frac{1}{\sqrt{LC}}, Z = 0$

(vi) L – C – R Circuit



(a) Alternating emf, E = Eo sin Ωt

(b) Alternating current, I = Io sin (Ωt ± θ)

(c) Alternating current lags leads behind alternating emf by ω.

(d) Resultant voltage, V = √V2R + (VL – VC)2

(e) Impedance, Z = √R2 + (XL – XC)2

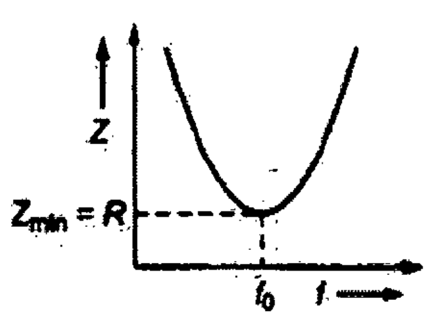
(f) Power factor, cos θ = R / Z = R / √√R2 + (XL – XC)2

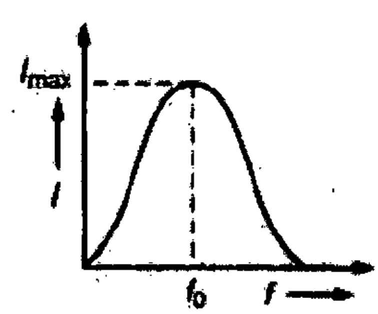
(g) Average power decay, (P)= EVIV cos θ

Resonance in AC Circuit

The condition in which current is maximum or impedance is minimum in an AC circuit, is called resonance.

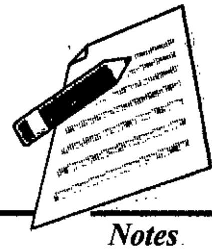
(i) Series Resonance Circuit





In this circuit components L, C and R are connected in series.

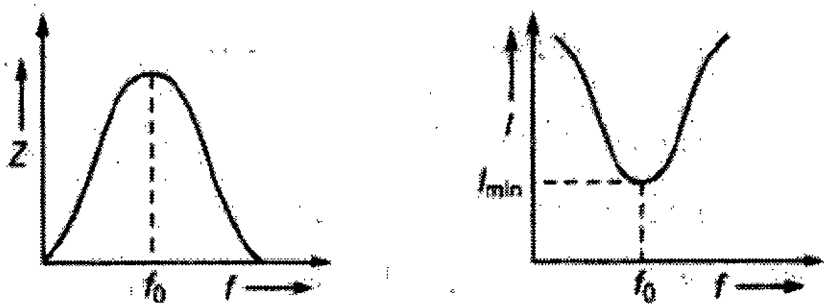
At resonance = XL = XC



Resonance frequency $f = 1 / 2\pi\sqrt{LC}$

A series resonance circuit is also known as acception circuit.

(ii) **Parallel Resonance Circuit**



In this circuit L and C are connected in parallel with each other.

At resonance, XL = XC

Impedance (Z) of the circuit is maximum.

Current in the circuit is minimum.

Wattless Current

Average power is given by

Pav = Erms = Irms cos θ

Here the Irms cos φ contributes for power dissipation. Therefore, it is called wattless current.

AC Generator or Dynamo

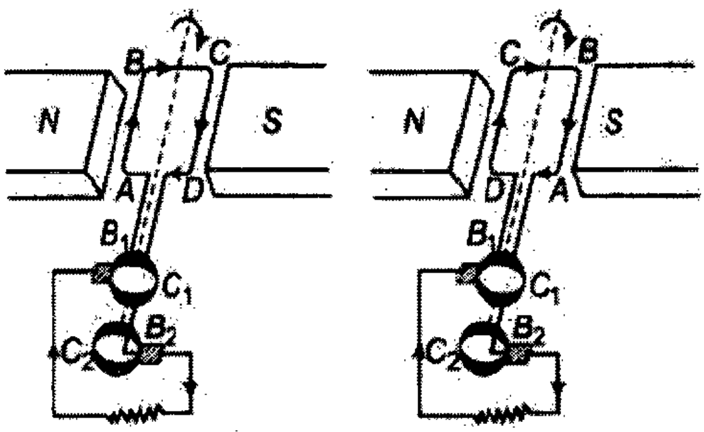
It is a device which converts mechanical energy into alternating current energy.

Its working is based on electromagnetic induction.

The induced emf produced by the AC generator is given by

e = NBAω sin ωt = eo = sin ωt

There are four main parts of an AC generator



Working of AC dynamo

(i) **Armature** It is rectangular coil of insulated copper wire having a large number of turns.

(ii) **Field Magnets** These are two pole pieces of a strong electromagnet.

(iii) **Slip Rings** These are two hollow metallic rings.

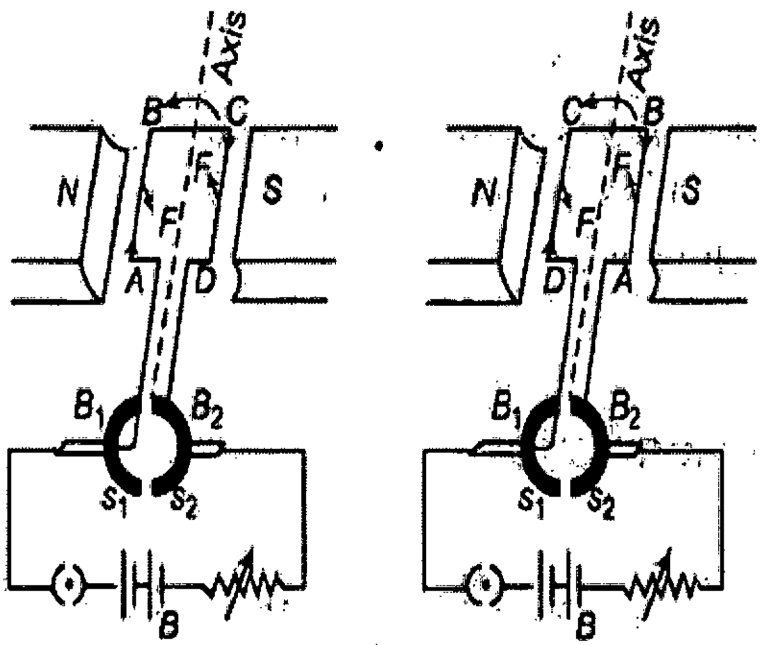
(iv) **Brushes** These are two flexible metals or carbon rods, which remains slightly in contact with slip rings.

Note an DC generator or dynamo contains split rings or commutator in spite of slip rings.

DC Motor

It is a device which converts electrical energy into mechanical energy.

Its working is based on the fact that when a current carrying coil is placed in uniform magnetic field a torque act on it.



Torque acting on a current carrying coil placed in uniform magnetic field

$\tau = NBIA \sin \theta$

When armature coil rotates a back emf is produced in the coil.

Efficiency of a motor,

η = Back emf / Applied emf = E / V

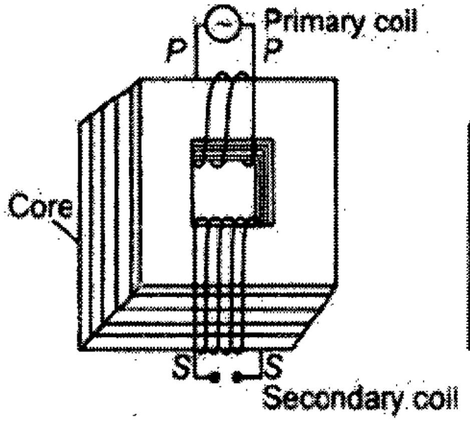
Transformer

It is a device which can change a low voltage of high current into a high voltage of low current and vice-versa.

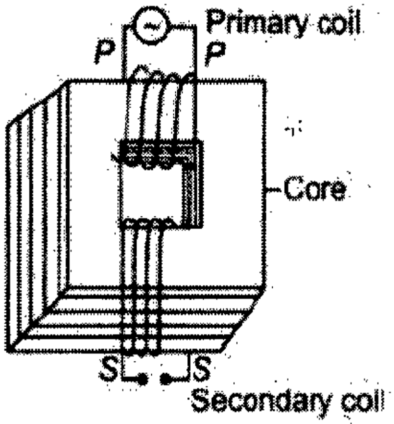
Its working is based on mutual induction.

There are two types of transformers.

(i) **Step-up Transformers** It converts a low voltage of high current into a high voltage of low current.



(b) Step-up transformer



(b) Step-down transformer

In this transformer,

Ns > NP, Es > EP

and IP > IS

(ii) Step-down Transformer It converts a high voltage of low current into a low voltage of high current.

In this transformer,

NP > NS, EP > ES and IP < IS

Transformation Ratio

Transformation ratio,

K = NS / NP = ES / EP = IP / IS

For step-up transformer, K > 1

For step-down transformer, K < 1

Energy Losses in a Transformer

The main energy losses in a transformer are given below

1. Iron loss
2. Copper loss
3. Flux loss
4. Hysteresis loss
5. Humming loss

Important Points

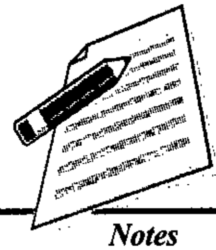
- Transformer does not operate on direct current. It operates only on alternating voltages at input as well as at output.
- Transformer does not amplify power as vacuum tube.

Notes

- Transformer, a device based on mutual induction converts magnetic energy into electrical energy.
- Efficiency, η = Output power / Input power
  Generally, efficiency ranges from 70% to 90%.
- A choke coil is a pure inductor. Average power consumed per cycle is zero in a choke coil.
- A DC motor connects DC energy from a battery into mechanical energy of rotation.
- An AC dynamo/generator produces are energy from mechanical energy of rotation of a coil.
- An induction coil generates high voltages of the order of 1OS V from a battery. It is based on the phenomenon of mutual induction.

Summary of the unit

- Alternating current is defined as the current that varies like a sine function with time.
- The value of current will oscillate between a maximum value and a minimum value.
- In case of AC the current is changing its magnitude at every instant of time.
- The direction of current will be clockwise and anticlockwise and it will keep on repeating.
- Frequency of the alternating current is defined as how fast the electrons are changing their directions. For example: If frequency is 20Hz this means electrons are moving back and forth 20 times in a second.



Multiple choice Question

1. Alternating voltage (V) is represented by the equation

   (a) V(t) = Vm eωt

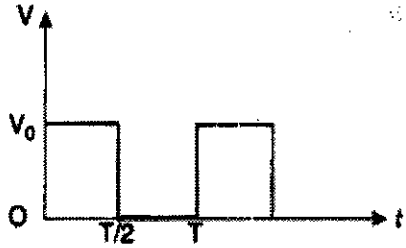
   (b) V(t) = Vm sin ωt

   (c) V(t) = Vm cot ωt

   (d) V(t) = Vm tan ωt

   Answer: b

2. The rms value of potential difference V shown in the figure is

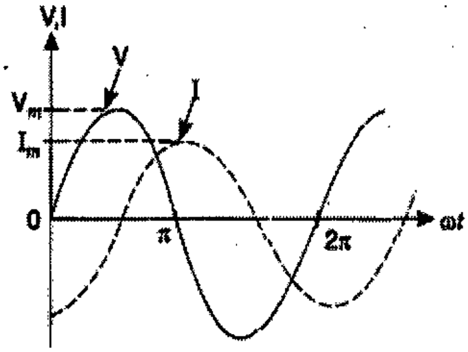


   (a) $\frac{V_0}{\sqrt{3}}$ (b) V_0 (c) $\frac{V_0}{\sqrt{2}}$ (d) $\frac{V_0}{2}$

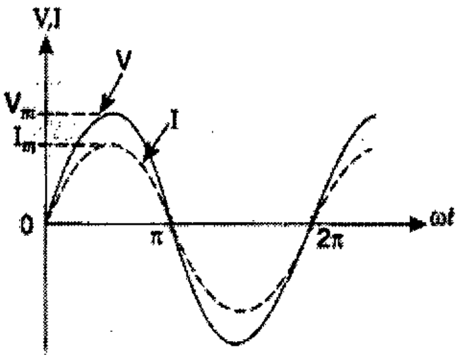
   Answer: c

3. The phase relationship between current and voltage in a pure resistive circuit is best represented by

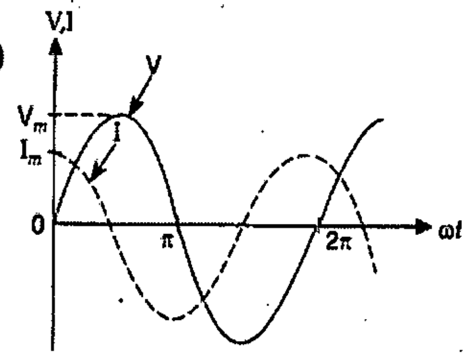
   (a)



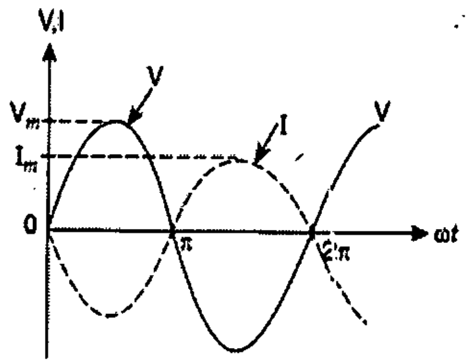
   (b)



(c)



(d)

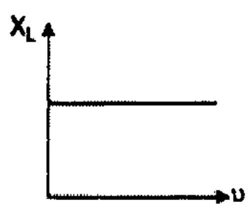


Answer: b

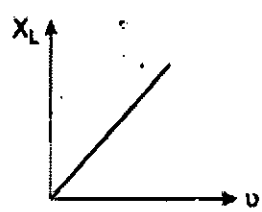
4. In the case of an inductor
   (a) voltage lags the current by π2
   (b) voltage leads the current by π2
   (c) voltage leads the current by π3
   (d) voltage leads the current by π4
   Answer: b

5. Which of the following graphs represents the correct variation of inductive reactance XL with frequency u?

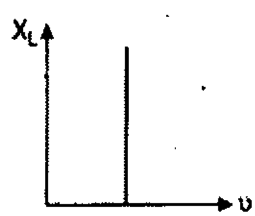
(a)



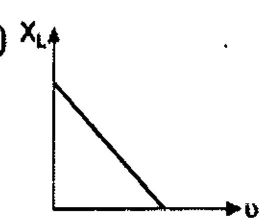
(b)



(c)



(d)



Answer: b

6. In a pure capacitive circuit if the frequency of ac source is doubled, then its capacitive reactance will be

   (a) remains same

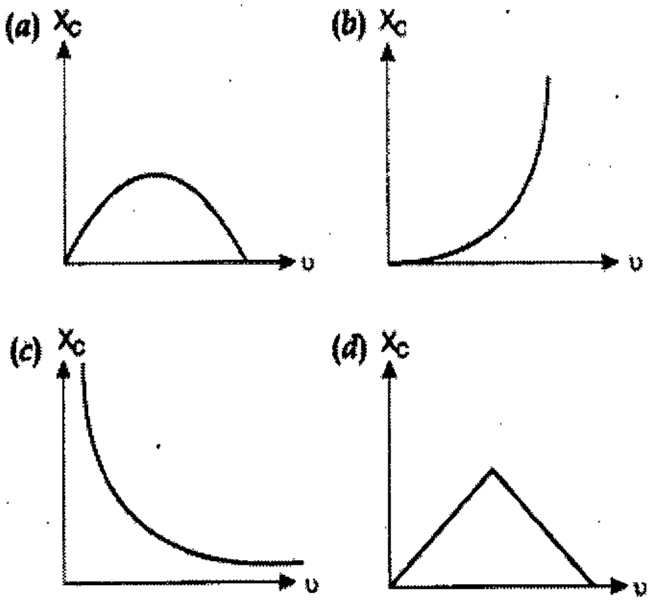
   (b) doubled

   (c) halved

   (d) zero

   Answer: c

7. Which of the following graphs represents the correct variation of capacitive reactance Xc with frequency v u?



   Answer: c

8. In an alternating current circuit consisting of elements in series, the current increases on increasing the frequency of supply. Which of the following elements are likely to constitute the circuit?

   (a) Only resistor

   (b) Resistor and inductor

   (c) Resistor and capacitor

   (d) Only inductor

   Answer: c

9. In which of the following circuits the maximum power dissipation is observed?

   (a) Pure capacitive circuit

   (b) Pure inductive circuit

   (c) Pure resistive circuit

   (d) None of these

   Answer: c

10. In series LCR circuit, the phase angle between supply voltage and current is

(*a*) $\tan \phi = \frac{X_L - X_C}{R}$ (*b*) $\tan \phi = \frac{R}{X_L - X_C}$

(*c*) $\tan \phi = \frac{R}{X_L + X_C}$ (*d*) $\tan \phi = \frac{X_L + X_C}{R}$

Answer: a

Review Questions

1. Show that in the free oscillations of an LC circuit, the sum of energies stored in the capacitor and the inductor is constant in time.
2. What is the principle of transformer? . Explain how laminating the core of a transformer helps to reduce eddy current losses in it. Why the primary and secondary coils of a transformer are preferably wound on the same core
3. A lamp is connected in series with a capacitor. Predict your observations for dc and ac connections. What happens in each case if the capacitance of the capacitor is reduced?
4. Prove that an ideal capacitor in an A.C circuit does not dissipate power?
5. (i) Explain briefly with the help if labelled diagram, the basic principle of the working of an AC generator

   (ii) In an A.C generator, coil of N turns and Area A is rotated at 'v' revolutions per sec in a uniform magnetic field B. Write the expression for the EMF produced
6. (i) Derive the expression for the average power consumed in a series LCR circuit connected to AC source where phase difference between voltage and current is φ

   (ii) Define the quality factor in an AC circuit?
7. Why is choke coil need in the use of fluorescent tubes with AC mains?

Numerical Questions

1. A 100 μF capacitor in series with a 40 &Omega resistance is connected to 100 V, 60Hz supply

   Calculate the following

   a. Reactance
   b. Impedance
   c. Maximum Current in the circuit
   d. rms voltage across the resistor and capacitor. Is the algebraic sum of these voltages more than the source voltage? if Yes resolve the paradox
2. An A.C voltage given by V=70sin100πtV=70sin□100πt is connected across a pure resistor of 25 Ω. Find the following

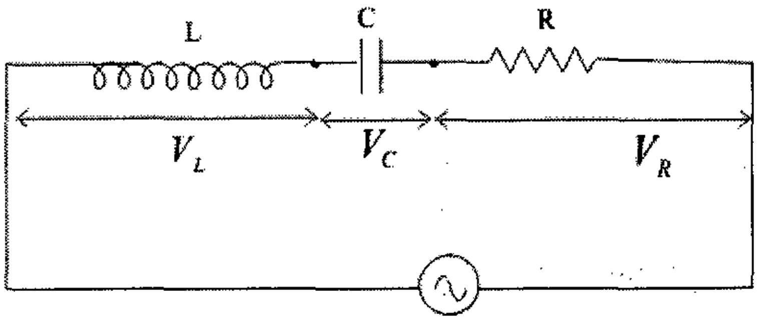
   a. Frequency of the source
   b. rms current through the resistor

3. An inductor L of inductance XLXL is connected in series with a bulb B and an ac source.

   How would brightness of the bulb change when (i) number of turns in the inductor is reduced, (ii) an iron rod is inserted in the inductor and (iii) a capacitor of reactance

   XC=XLXC=XL *is inserted in series in the circuit. Justify your answer in each* case.

4. The given circuit diagram shows a series LCR circuit connected to a variable frequency 230 V source. Here L=5.0 H, C=80 μ F, R=40 Ω .



   (a) Determine the source frequency, which drives the circuit in resonance.

   (b) Obtain the impedance of the circuit and the amplitude of current at the resonating frequency.

   (c) Determine the rms potential drops across the three elements of the circuit.

   (d) How do you explain the observation that the algebraic sum of the voltage of the three elements obtained in (c) is greater than the supplied voltage?

5. A pure inductor of 25.0 mH is connected to a source of 220 V. Find the inductive reactance and rms current in the circuit if the frequency of the source is 50 Hz.

8 ELECTROMAGNETIC WAVES

- Basic idea of displacement current, Electromagnetic waves, their characteristics, their transverse nature (qualitative ideas only).
- Electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays) including elementary facts about their uses.

Objective of the chapter

The main objective of this chapter is to make student understand about the concepts **Electromagnetic Waves,** their characteristics, their transverse nature. Electromagnetic spectrum has also been explained in this chapter.

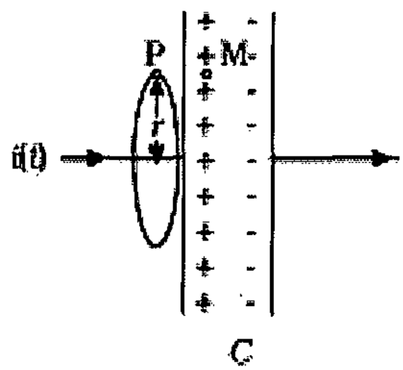
Introduction

Displacement Current

We know that an electric current produces a magnetic field around it. J.C. Maxwell showed that for logical consistency, a changing electric field must also produce a magnetic field. Further, since magnetic fields have always been associated with currents, Maxwell postulated that this current was proportional to the rate of change of the electric field and called it displacement current. In this article, we will look at displacement current in detail.

How a changing electric field produces a magnetic field?

To determine this, let's look at the process of charging a capacitor. Further, we will apply Ampere's circuital law to find a magnetic point outside the capacitor.



The figure above shows a parallel plate capacitor connected in a circuit through which a time-dependent current i(t) flows. We will try to find the magnetic field at a point P, in the region outside the capacitor.

Consider a plane circular loop of radius r centred symmetrically with the wire. Also, the plane of the loop is perpendicular to the direction of the current carrying wire. Due to the symmetry, the magnetic field is directed along the circumference of the loop and has similar magnitude at all points on the loop.

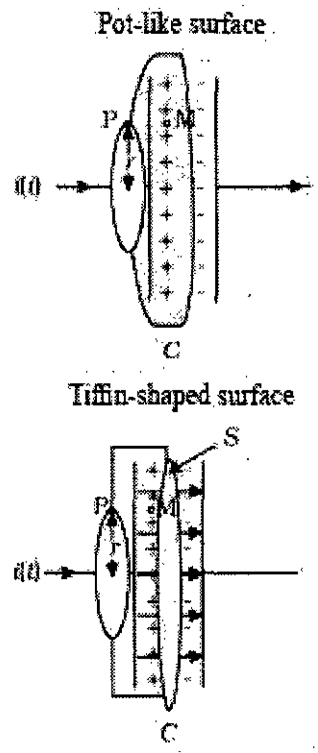


Figure 2

However, as shown in the Figure (2) above, when the surface is replaced by a pot-like surface where it doesn't touch the current but has its bottom between the capacitor plates or a tiffin-shaped surface (without the lid) and Ampere's circuital law is applied, certain contradictions arise.

These contradictions arise since no current passes through the surface and Ampere's law does not take that scenario into consideration. This leads us to understand that there is something missing in the Ampere's circuital law. Also, the missing term is such which enables us to get the same magnetic field at point P regardless of the surface used.

Maxwell's Displacement Current

If we look at the last figure again, we can observe that the common thing that passes through the surface and between the capacitor plates is an electric field. This field is perpendicular to the surface, has the same magnitude over the area of the capacitor plats and vanishes outside it.

Hence, the electric flux through the surface is Q/ε0 (using Gauss's law). Further, since the charge on the capacitor plates changes with time, for consistency we can calculate the current as follows:

$i = \varepsilon_0 (dQ/dt)$

This is the missing term in Ampere's circuital law. In simple words, when we add a term which is ε0 times the rate of change of electric flux to the total current carried by the conductors, through the same surface, then the total has the same value of current 'i' for all surfaces. Therefore, no contradiction is observed if we use the Generalized Ampere's Law.

Hence, the magnitude of B at a point P outside the plates is the same at a point just inside. Now, the current carried by conductors due to the flow of charge is called 'Conduction current'. The new term added is the current that flows due to the changing electric field and is called 'Displacement current' or Maxwell's Displacement current'.

Displacement Current Explained

By now we understand that there are two sources of a magnetic field:

1. Conduction electric current due to the flow of charges
2. Displacement current due to the rate of change of the electric field

Hence, the total current (i) is calculated as follows: (where ic – conduction current and id – displacement current)

$i = i_c + i_d$

$= i_c + \varepsilon_0 (dQ/dt)$

This means that –

- Outside the capacitor plates: $i_c = i$ and $i_d = 0$
- Inside the capacitor plates: $i_c = 0$ and $i_d = i$

So, the generalized Ampere's law states:

The total current passing through any surface of which the closed loop is the perimeter is the sum of the conduction current and the displacement current.

This is also known as – **Ampere-Maxwell Law**. It is important to remember that the displacement and conduction currents have the same physical effects. Here are some points to remember:

- In cases where the electric field does not change with time, like steady electric fields in a conducting wire, the displacement current may be zero.
- In cases like the one explained above, both currents are present in different regions of the space.
- Since a perfectly conducting or insulating medium does not exist, in most cases both the currents can be present in the same region.
- In cases where there is no conduction current but a time-varying electric field, only displacement current is present. In such a scenario we have a magnetic field even when there is no conduction current source nearby.

Faraday's Law of Induction and Ampere-Maxwell Law

According to Faraday's law of induction, there is an induced emf which is equal to the rate of change of magnetic flux. Since emf between two points is the work done per unit charge to take it from one point to the other, its existence simply implies the existence of an electric field. Rephrasing Faraday's law:

A magnetic field that changes with time gives rise to an electric field.

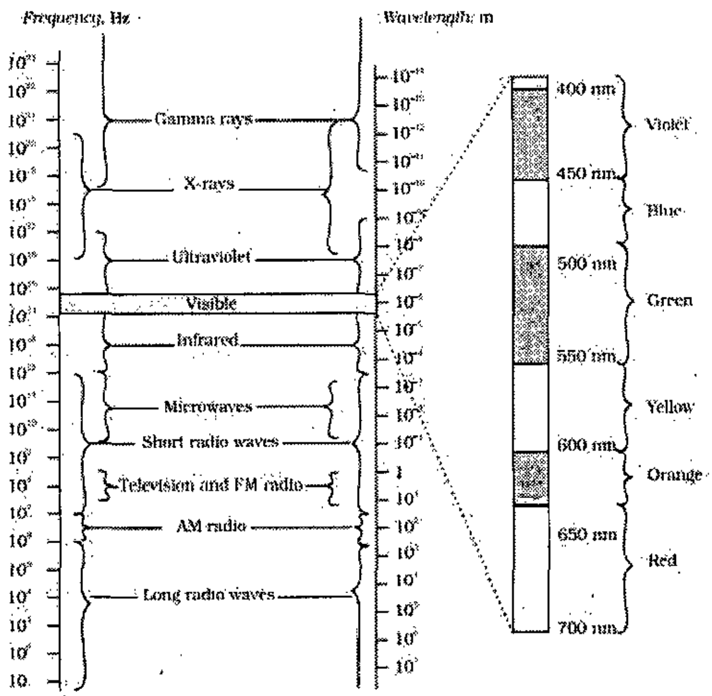
Hence, an electric field changing with time gives rise to a magnetic field. This is a consequence of the displacement current being the source of the magnetic field. Hence, it is fair to say that time-dependent magnetic and electric fields give rise to each other.

Electromagnetic Spectrum

When Maxwell predicted the existence of electromagnetic waves, the visible light waves were the only ones familiar to us. People barely knew about ultraviolet and infrared rays. However, by the end of the nineteenth century, X-rays and gamma-rays were also discovered. Today, we know that electromagnetic waves include different types of waves. Electromagnetic Spectrum is the classification of these waves according to their frequency.

Electromagnetic Spectrum

Here is a quick look at the electromagnetic spectrum with common names for various regions.



CLASS–12

Physics

Notes

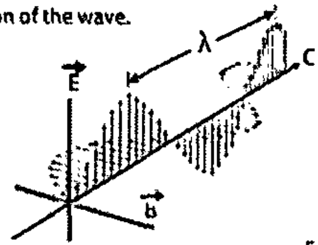
Let's look at each of these electromagnetic waves in the order of decreasing wavelengths.

Electromagnetic Wave

toppr

Electromagnetic Wave

An electromagnetic wave is radiated by an accelerated charge - as coupled electric and magnetic field oscillating perpendicular to each other and also to the direction of propagation of the wave.



Magnitude of E and B are related as $\frac{E_0}{B_0} = c$

Speed of an electromagnetic wave in free space is given by

$$\boxed{c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}}$$

Properties

- Do not carry any charge
- Do not deflect by electric and magnetic field
- Travel with speed of light in vacuum
- Frequency does not change when it goes from one medium to another, but its wavelength changes
- Transverse in nature
- Do not require any material medium for propagation

Electromagnetic Spectrum

The orderly distribution of electromagnetic waves in accordance with their wavelength or frequency

Modified Ampere's Law

$$\boxed{\oint B.dl = \mu_0 (I_C + I_D)}$$

Displacement Current

It is the current which is produced when electric field and hence electric flux changes with time.

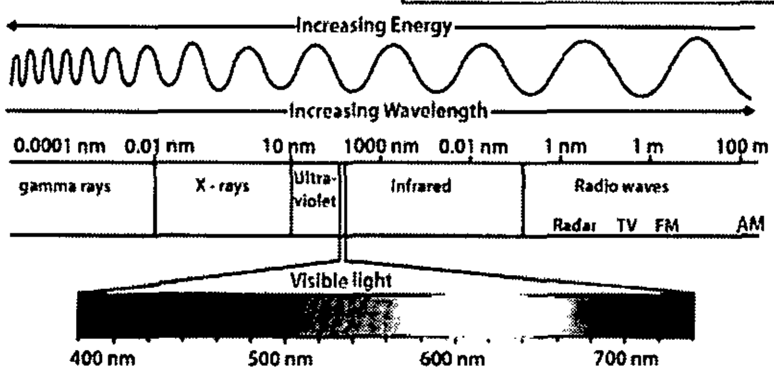
$$\boxed{I_D = \varepsilon_0 \frac{d\phi_E}{dt}}$$

Maxwell's Equations

- $\oint_S \vec{E}.d\vec{s} = \frac{q}{\varepsilon_0}$
- $\oint_S \vec{B}.d\vec{s} = 0$
- $\oint_S \vec{E}.d\vec{l} = -\frac{d\phi_B}{dt} = -\frac{d}{dt}\oint_S \vec{B}.d\vec{s}$
- $\oint \vec{B}.d\vec{l} = \mu_0 (I_C + I_D)$

$$= \mu_0\left(I_C + \varepsilon_0 \frac{d\phi_E}{dt}\right)$$

$$= \mu_0\left(I_C + \varepsilon_0 \frac{d}{dt}\oint_S \vec{E}.d\vec{s}\right)$$



Radiowaves: Used in radio communication

Infrared: Useful for elucidating molecular structure.

Visible light: Detected by stimulating nerve endings of human retina.

Ultraviolet: Can cause many chemical reactions, *e.g.*, the tanning of the human skin.

X - rays: • Penetrate matter
• Ionize gases (*e.g.*, Radiography)

Gamma rays: In the treatment of cancer and tumours

Waves in the Electromagnetic Spectrum

Waves in the electromagnetic spectrum are broadly classified as follows:

1. Radio waves
2. Microwaves
3. Infrared rays
4. Visible rays
5. Ultraviolet rays
6. X-rays
7. Gamma rays

Radio Waves

- Radio waves are usually in the frequency range from 500 kHz to 1000 MHz.
- Also, the range of the AM (amplitude modulated) band is between 530 kHz and 1710 kHz.
- Further, shortwave bands use higher frequencies of up to 54 MHz.
- TV waves range from 54 MHz to 890 MHz.
- The FM (frequency modulated) radio band is from 88 MHz to 108 MHz.
- Cellular phones also use radio waves to transmit voice communication in an ultra-high frequency (UHF) band.

Generation of Radio Waves

The accelerated motion of charges in conducting wires generates Radio waves. Radio and television communication systems widely use these waves.

Microwaves

- Microwaves are short-wavelength radio waves with frequencies in the Gigahertz (GHz) range
- Best suited for the radar systems in aircraft navigation
- Another use of Radars is as speed-guns. These speed guns help time fastballs, tennis serves and automobiles.
- These waves form the basis of microwave ovens. In microwave ovens, the frequency of the microwaves is selected to match the resonant frequency of water molecules. This results in a direct transfer of energy from the waves to the kinetic energy of the water molecules raising the temperature of any food containing water.

Generation of Microwaves

Special vacuum tubes called klystrons, magnetrons and Gunn diodes generate microwaves.

Infrared Rays

- 'Heat Waves' is another name for Infrared rays.
- Water molecules present in most materials readily absorb these rays.
- After absorption, their thermal motion increases which increases their heat and that of their surroundings.
- Many physical therapy treatments use Infrared lamps.
- These rays also play an important role in maintaining the earth's average temperature through the greenhouse effect.
    - *Greenhouse effect: The earth's surface absorbs the incoming visible light. Then, it re-radiates it as infrared radiations. The greenhouse gases like carbon dioxide and water vapour trap these radiations.*
- Earth Satellites deploy Infrared detectors for military purposes and to observe the growth of crops.
- Remote switches of household appliances like TV, video recorders, etc. use infrared rays.

Generation of Infrared Rays

Hot bodies and molecules generate Infrared rays. Also, the band lies next to the low-frequency or long-wavelength end of the electromagnetic spectrum.

Visible Rays

- Visible rays are the most familiar form of electromagnetic waves.
- Most importantly, it is that part of the electromagnetic spectrum that is detected by the human eye.
- Frequency range is between 4 x 1014 Hz and 7 x 1014
- Wavelength range is from 700-400 nm.

Ultraviolet Rays

- Ultraviolet rays have wavelengths ranging from 4 x 10-7 m (400 nm) to 6 x 10-10 m (0.6 nm).
- These rays can have harmful effects on humans if exposed to in large quantities.
- Ordinary glass absorbs UV rays. In other words, sit behind a glass window and avoid suntans and sunburns.
- Welding arcs produce a large number of UV rays. Hence, welders wear special goggles or masks with glass to protect their eyes.
- Now, UV rays have shorter wavelengths. Hence, they are focused into very narrow beams and used in high-precision applications like LASIK eye surgery.
- Many water purifiers use UV lamps to kill germs in water.

Generation of Ultraviolet Rays

Special lamps and very hot bodies generate Ultraviolet rays. Also, the sun is an important source of ultraviolet rays.

X-rays

- In the electromagnetic spectrum, X-rays lie beyond the ultraviolet region.
- X-rays have wavelengths ranging from about 10-8 m or 10 nm to 10-13 m or 10-4
- X-rays are particularly well known due to their use as a diagnostic tool in medicine.
- Also, the treatment for certain types of cancer involves the use of X-rays.
- X-rays can damage or destroy living tissues. Hence, you must take care and avoid unnecessary over-exposure to these rays.

Generation of X-rays

X-rays are commonly generated by bombarding a metal target with high energy electrons.

Gamma Rays

- Gamma rays lie in the upper-frequency region of the electromagnetic spectrum
- The wavelengths of these waves range from about 10-10 m to less than 10-14.
- An important application of Gamma rays is their extensive use in medicine to destroy cancer cells

Generation of Gamma Rays

Gamma rays are produced in nuclear reactions. Some radioactive nuclei also emit gamma rays.

Summary of the chapter

Electromagnetic waves or EM waves are waves that are created as a result of vibrations between an electric field and a magnetic field. In other words, EM waves are composed of oscillating magnetic and electric fields.

Description: Electromagnetic waves are formed when an electric field comes in contact with a magnetic field. They are hence known as 'electromagnetic' waves. The electric field and magnetic field of an electromagnetic wave are perpendicular (at right angles) to each other. They are also perpendicular to the direction of the EM wave.

EM waves travel with a constant velocity of 3.00 x 108 ms-1 in vacuum. They are deflected neither by the electric field, nor by the magnetic field. However, they are capable of showing interference or diffraction. An electromagnetic wave can travel through anything - be it air, a solid material or vacuum. It does not need a medium to propagate or travel from one place to another. Mechanical waves

Notes

(like sound waves or water waves), on the other hand, need a medium to travel. EM waves are 'transverse' waves. This means that they are measured by their amplitude (height) and wavelength (distance between the highest/lowest points of two consecutive waves).

The highest point of a wave is known as 'crest', whereas the lowest point is known as 'trough'. Electromagnetic waves can be split into a range of frequencies. This is known as the electromagnetic spectrum. Examples of EM waves are radio waves, microwaves, infrared waves, X-rays, gamma rays, etc.

Multiple choice Questions

1. All electromagnetic waves travel through a vacuum at
   a. the same speed.
   b. speeds that are proportional to their frequency.
   c. speeds that are inversely proportional to their frequency.
   d. None of the above.
2. Electromagnetic waves are
   a. longitudinal.
   b. transverse.
   c. both longitudinal and transverse.
   d. None of the above.
3. The **E** and **B** fields in electromagnetic waves are oriented
   a. parallel to the wave›s direction of travel, as well as to each other.
   b. parallel to the wave's direction of travel, and perpendicular to each other.
   c. perpendicular to the wave›s direction of travel, and parallel to each other.
   d. perpendicular to the wave›s direction of travel, and also to each other.
4. An electromagnetic wave is radiated by a straight wire antenna that is oriented vertically.
   What should be the orientation of a straight wire receiving antenna? It should be placed
   a. vertically.
   b. horizontally and in a direction parallel to the wave›s direction of motion.
   c. horizontally and in a direction perpendicular to the wave›s direction of motion.
   d. None of the above.
5. An electromagnetic wave is traveling to the east. At one instant at a given point its **E** vector points straight up. What is the direction of its **B** vector?
   a. north
   b. down
   c. east
   d. south
6. Which of the following correctly lists electromagnetic waves in order from longest to shortest wavelength?
   a. gamma rays, ultraviolet, infrared, microwaves
   b. microwaves, ultraviolet, visible light, gamma rays
   c. radio waves, infrared, gamma rays, ultraviolet
   d. television, infrared, visible light, X-rays

7. What is the wavelength of light waves if their frequency is 5.0X1014 Hz?
   a. 0.60 m
   b. 6.0 mm
   c. 0.060 mm
   d. 0.60 micro-m
8. How long does it take light to travel 1.0 m?
   a. 3.3 ns
   b. 3.3 micro-s
   c. 3.3 ms
   d. 3.3 s
9. What is the wavelength of a 92.9 MHz radio wave?
   a. 32 mm
   b. 32 cm
   c. 3.2 m
   d. 32 m
10. What frequency are 20 mm microwaves?
   a. 100 MHz
   b. 400 MHz
   c. 15 GHz
   d. 73 GHz

Answers

1.	a	2.	B	3.	D	4.	A
5.	D	6.	D	7.	D	8.	A
9.	C	10.	c				

Review Questions

1. Why is the orientation of the portable radio with respect to broadcasting station important?
2. Why does microwave oven heats up a food item containing water molecules most efficiently?
3. The charge on a parallel plate capacitor varies as $q = q0 \cos 2\pi vt$. The plates are very large and close together (area = A, separation = d). Neglecting the edge effects, find the displacement current through the capacitor?
4. A variable frequency a.c source is connected to a capacitor. How will the displacement current change with decrease in frequency?
5. The magnetic field of a beam emerging from a filter facing a floodlight is given by

6. B0 = 12 × 10-8 sin (1.20 × 107 z – 3.60 × 1015 t) T.
7. What is the average intensity of the beam?
8. Poynting vectors S is defined as a vector whose magnitude is equal to the wave intensity and whose direction is along the direction of wave propagation. Mathematically, it is given by S = (i/μ0) E X B. Show the nature of S vs t graph.
9. Professor C.V Raman surprised his students by suspending freely a tiny light ball in a transparent vacuum chamber by shining a laser beam on it. Which property of EM waves was he exhibiting? Give one more example of this property.

Short Answer Type Questions

1. Show that the magnetic field B at a point in between the plates of a parallel-plate capacitor during charging is $\frac{\varepsilon_0 \mu_r}{2}\frac{dE}{dt}$ (symbols having usual meaning).
2. Electromagnetic waves with wavelength

   (i) λ1 is used in satellite communication

   (ii) λ2 is used to kill germs in water purifies.

   (iii) λ3 is used to detect leakage of oil in underground pipelines.

   (iv) λ4 is used to improve visibility in runways during fog and mist conditions.

   - (a) Identify and name the part of electromagnetic spectrum to which these radiations belong.
   - (b) Arrange these wavelengths in ascending order of their magnitude.
   - (c) Write one more application of each.
3. Show that average value of radiant flux density 'S' over a single period 'T' is given by $S = \frac{1}{2c\mu_0}E_0^2$.
4. You are given a 2μF parallel plate capacitor. How would you establish an instantaneous displacement current of 1mA in the space between its plates?
5. Show that the radiation pressure exerted by an EM wave of intensity I on a surface kept in vacuum is I/c.
6. What happens to the intensity of light from a bulb if the distance from the bulb is doubled? As a laser beam travels across the length of a room, its intensity essentially remains constant. What geometrical characteristic of LASER beam is responsible for the constant intensity which is missing in the case of light from the bulb?
7. Even though an electric field E exerts a force qE on a charged particle yet the electric field of an EM wave does not contribute to the radiation pressure (but transfers energy). Explain.

CLASS–12

Physics

Notes

Long Answer Type Questions

1. An infinitely long thin wire carrying a uniform linear static charge density λ is placed along the z-axis (Fig. 8.1). The wire is set into motion along its length with a uniform velocity $\mathbf{v} = v\hat{\mathbf{k}}_z$. Calculate the poynting vector S = (i/μ0) (E X B).

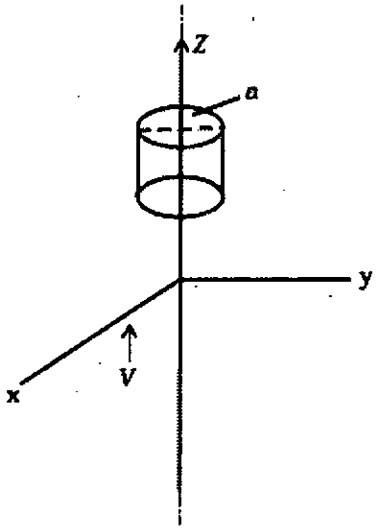


Fig. 8.1

2. Sea water at frequency ν = 4 × 108 Hz has permittivity ε ≈ 80 εo, permeability μ ≈ μo and resistivity ρ = 0.25 Ω–m. Imagine a parallel plate capacitor immersed in sea water and driven by an alternating voltage source V(t) = Vo sin (2π νt). What fraction of the conduction current density is the displacement current density?

9 RAY OPTICS AND OPTICAL INSTRUMENTS

- Ray Optics –
  - Reflection of light
  - Spherical mirrors
  - Mirror formula
  - Refraction of light
  - Total internal reflection and its applications
  - Optical fibres
  - Refraction at spherical surfaces
  - Lenses
  - Thin lens formula
  - Lensmaker's formula
- Magnification, power of a lens, combination of thin lenses in contact combination of a lens and a mirror
- Refraction and dispersion of light through a prism.
- Scattering of light - blue colour of sky and reddish appearance of the sun at sunrise and sunset
- Optical instruments: Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers

Objective of the chapter

The main objective of this chapter is to make student understand about the concepts of Ray Optics. Magnification, power of a lens, Refraction and dispersion of light and various Optical instruments has also been explained in this chapter.

Introduction

Light

Light is a form of energy eyes. which produces the Sources of light are of three types- thermal sources and luminescent sources.

Photometry is a branch measurement of light energy.

Characteristics of Light

Light waves are electromagnetic waves, whose nature is transverse. The speed of light in vacuum is 3 x 108 mls but it is different in different media.

The speed and wavelength of light change when it travels from one medium to another but its frequency remains unchanged.

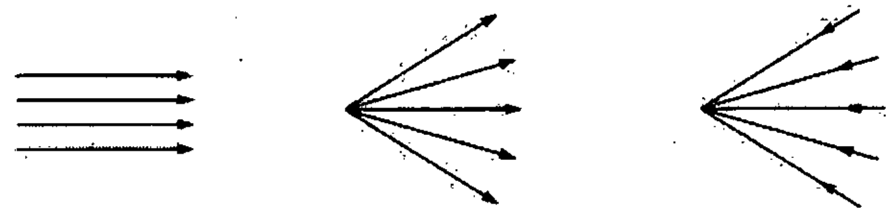
Important Terms

(i) **Luminous Objects** The objects which emits its own light, are called luminous objects, e.g., sun, other stars, an oil lamp etc.

(ii) **Non-Luminous Objects** The objects which do not emit its own light but become visible due to the reflection of light falling on them, are called non-luminous objects, e.g., moon, table, chair. trees etc.

(iii) **Ray of Light** A straight line drawn in the direction of propagation of light is called a ray of light.

(iv) **Beam of Light** A bundle of the adjacent light rays is called a beam of light.



Parallel beam of light   Divergent beam of light   Convergent beam of light

(v) **Image** If light ray coming from an object meets or appear to meet at a point after reflection or refraction, then this point is called image of the object.

(vi) **Real Image** The image obtained by the real meeting of light rays, is called a real image.

Real image can be obtained on a screen. Real image is inverted.

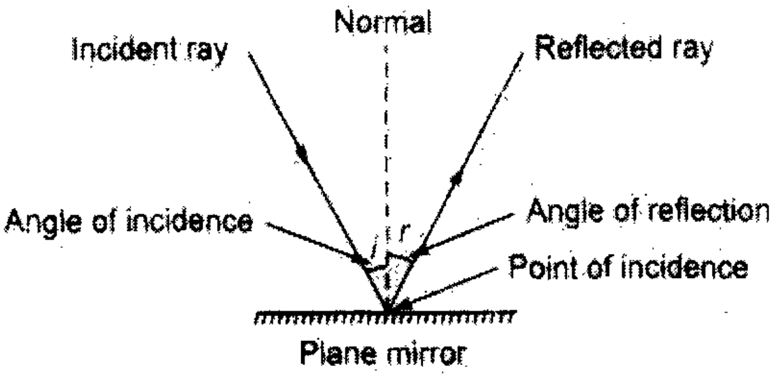
(vii) **Virtual Image** The image obtained when light rays are not really meeting but appears to meet only, is called a virtual image.

Reflection of Light

The rebouncing back of light rays into the same medium on striking a highly polished surface such as a mirror, is called reflection of light.

Laws of Reflection

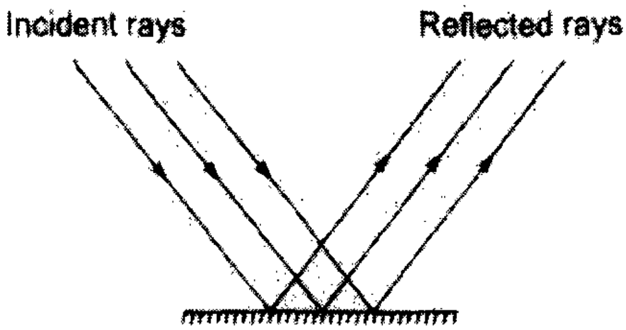
There are two laws of reflection.



(i) The incident ray, the reflected ray and the normal at the point of incidence all three lie in the same plane.

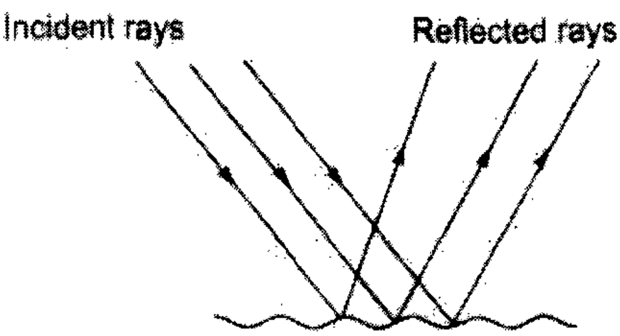
(ii) The angle of incidence (i) is always equal to the angle of reflection (r).

Types of Reflection



(i) **Regular Reflection** When a parallel beam of reflected light rays is obtained for a parallel beam of incident light rays after reflection from a plane reflecting reflection is called regular reflection.

(ii) **Irregular or Diffused Reflection** When a non-parallel beam of reflected light rays is obtained for a parallel beam of incident light rays after reflection from a surface, then such type of reflection is called irregular or diffused reflection.



Mirror

A smooth and highly polished reflecting surface is called a mirror.

(i) **Plane Mirror** A highly polished plane surface is called a plane mirror.

Different properties of image formed by plane mirror

Size of image = Size of object

Magnification == Unity

Distance of image == Distance of object

A plane mirror may form a virtual as well as real image.

A man may see his full image in a mirror of half height of man.

When two plane mirror are held at an angle θ, the number of images of an object placed between them is given as below

(a) $n = [(360° / \theta) - 1]$, where $360° / \theta$ is an integer.

(b) n = integral part of $360° / \theta$, when 360° is not an integer.

[A plane mirror may form a real image, when the pencil of light incident on the mirror is convergent. Children, during their play form an image of sun as wall by a strip of plane mirror.]

Kaleidoscope and periscope employ the principle of image formation by plane mirror.

If keeping an object fixed a plane mirror is rotated in its plane by an angle θ, then the reflected ray rotates in the same direction by an angle 2 θ.

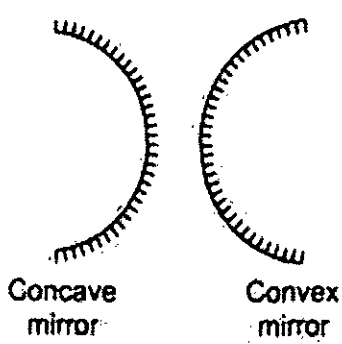
Focal length as well as radius of curvature of a plane mirror is infinity. Power of a plane mirror is zero.

An image formed by a plane mirror is virtual, erect, laterally inverted, of same size as that of object and at the same distance as the object from the mirror.

(ii) **Spherical Mirror** A highly polished curved surface whose reflecting surface is a cut part of a hollows at glass sphere is called a spherical mirror. Spherical mirrors are of two types

(a) **Concave Mirror** A spherical mirror whose bent in surface is reflecting surface, is called a concave mirror.

(b) **Convex Mirror** A spherical mirror whose bulging out surface is reflecting surface, is called a convex mirror.



Some Terms Related to Spherical Mirrors are Given Below

(i) **Centre of Curvature** It is the centre of the sphere of which the mirror or lens is a part.

(ii) **Radius of Curvature (R)** The radius of the hollow sphere of which the mirror is a part, is called radius of curvature.

(iii) **Pole** The central point of the spherical mirror is called its pole (P).

(iv) **Focus** When a parallel beam of light rays is incident on a spherical mirror, then after reflection it meets or appears to meet at a point on principal axis, which is called focus of the spherical mirror.

(v) **Focal Length** The distance between the pole and focus is called focal length (f).

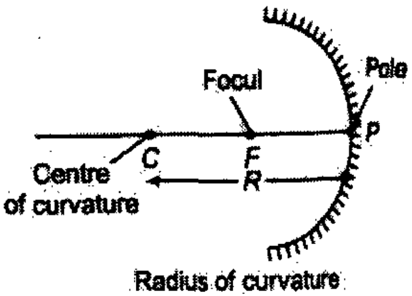
Relation between focal length and radius of curvature is given by

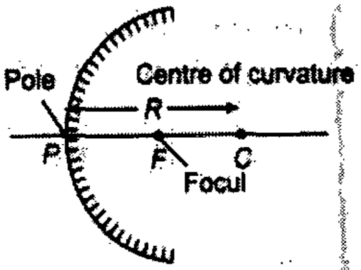
f=R/2

The power of a mirror is given as P = 1/f (metre)

(vi) **Mirror formula** 1/f = 1/v + 1/u

where, f = focal length of the mirror, u = distance of the object and v = distance of the image.





Newton's formula for a concave mirror

$$f = \sqrt{x_1 x_2}$$

$$\Rightarrow \qquad f^2 = x_1 x_2$$

where x_1 and x_2 are the distances of object and image from the focus.

Linear Magnification

The ratio of height of image (1) formed by a mirror to the height of the object (O) is called linear magnification (m).

Lin ear magnification (m) = I/O = -v/u

Areal and Axial Magnification

The ratio of area of image to the area of object is called areal magnification.

$$\text{Areal magnification} = m^2 = \frac{\text{Area of image}}{\text{Area of object}} = \frac{v^2}{u^2}$$

When a small sized object is placed linearly along the principle axis, then its longitudinal or axial magnification is given by

$$\text{Axial magnification} = -\frac{dv}{du} = \left(\frac{v}{u}\right)^2 = \left(\frac{f}{f-u}\right)^2 = \left(\frac{f-v}{f}\right)^2$$

Sign Convention for Spherical Mirrors

1. All distances are measured from the pole of the mirror.
2. Distances measured in the direction of incident light rays are taken as positive.
3. Distances measured in opposite direction to the incident light rays are taken as negative.
4. Distances measured above the principal axis are positive.
5. Distances measured below the principal axis are negative.

Lateral inversion

In the image formed by a plane mirror the right side of the object appears as left side and vice-versa. This phenomenon is called lateral inversion.

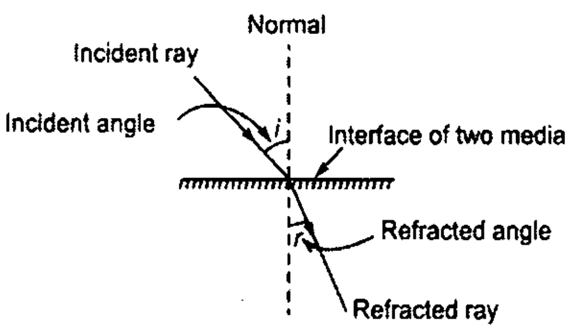
When object is placed between pole and focus of a concave mirror, then its virtual, erect and magnified image is formed.

A convex mirror forms a virtual, erect and diminished image for all conditions of object.

The focal length of concave mirror is taken negative and for a convex mirror taken as positive.

Refraction of Light

The deviation of light rays from its path when it travels from one transparent medium to another transparent medium is called refraction of light.



Cause of Refraction

The speed of light is different in different media.

Laws of Refraction

(i) The incident ray, the refracted ray and the normal at the point of incidence, all three lies in the same plane.

(ii) The ratio of sine of angle of incidence to the sine of angle of refraction is constant for a pair of two media,

$$i.e., \qquad \frac{\sin i}{\sin r} = \text{constant } ({}_1\mu_2)$$

where 1&mu2 is called refractive index of second medium with respect to first medium.

This law is also called Snell's law.

Refractive Index

The ratio of speed of light in vacuum (c) to the speed of light in any medium (u) is *called refractive index of the medium.*

Refractive index of a medium,

$\mu = c/v$

Refractive index of water =4/3 = 1.33; Refractive index of glass = 3/2 = 1.50

When light is reflected by a denser medium, phase difference of π radian or path difference of $\lambda/2$ or time difference T/2 is produced.

This is known as Stoke's law. Distance x travelled by light in a medium of refractive index μ is equal to distance (&mux) travelled in vacuum.

Time taken by light to traverse a thickness x of time $=\mu x/c$, where c = velocity of light in vacuum.

Relative Refractive Index

$${}_1\mu_2 = \frac{v_1}{v_2} = \frac{\text{height of object}}{\text{height of image}}$$

$$\textbf{Refractive index of a medium } \mu = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}$$

where, λ = wavelength of light

$$\therefore \qquad \textbf{Refractive index } \mu \propto \frac{1}{\lambda^2}$$

The refractive index of second medium with respect to first medium

Cauchy's Formula

Critical Angle

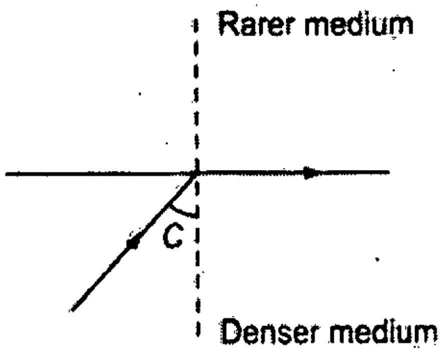
The angle of incidence in a denser medium for which the angle of refraction in rarer medium becomes 90°. is called critical angle (C).

Critical angle for diamond = 24°

Critical angle for glass = 42°:

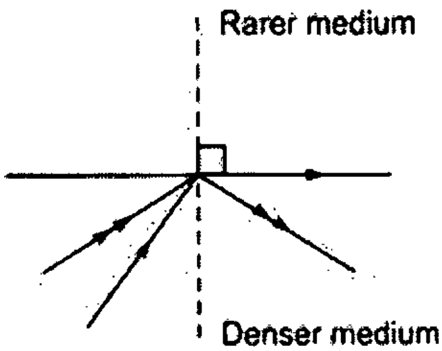
Critical angle for water = 48°:

Refractive index of denser medium $\mu = 1/\sin C$



Total Internal Reflection (TIR)

When a light ray travelling from a denser medium towards a rarer medium is incident at the interface at an angle of incidence greater than critical angle, then light rays reflected back in to the denser medium. This phenomenon is called TIR.



Critical angle increases with temperature.

The refractive index is maximum for violet colour of light and minimum for red colour of light. i.e., $\mu v > \mu R$ therefore critical angle is maximum for red colour of light and minimum for violet colour of light, i.e., $Cv < CR$

Total internal reflection occurs if angle of incidence in denser medium exceeds critical angle.

Mirage is an optical illusion observed in deserts and roads on a hot day when the air near the ground is holler and hence rarer than the air above.

Optical Fibres

are also based on the phenomenon of total internal reflection. Optical fibres consist of several thousands of very long fine quality fibres of glass or quartz. The diameter of each fibre is of the order of 10-4 cm with refractive index of material being of the order of 1.5. Optical fibres are used in transmission and reception of electrical signals by converting them first into light signals.

For Refraction at a Convex or Concave Spherical Surface

$$\frac{\mu}{v} - \frac{1}{u} = \frac{(\mu - 1)}{R}$$

where, μ= refractive index, u = distance of object, v = distance of image and R = radius of curvature of the spherical surface

Lens

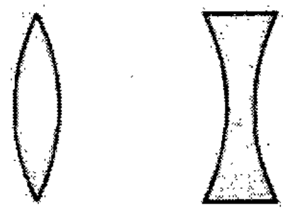
A lens is a uniform transparent medium bounded between two spherical or one spherical and one plane surface.

Convex Lens

A lens which is thinner at edges and thicker at middle is called a convex or converging lens.

Concave Lens

A lens which is thicker at edges and thinner at middle, is called a concave or diverging lens.



Convex Lens   Concave Lens

Lens Formula

1/f = 1/v – 1/u

where, f = focal length of the lens, U = distance of object, U = distance of image.

Lens Maker's formula

1/f=(μ – 1) (1/R1 – 1/R2)

where, μ = refractive index of the material of the lens and R1 and R2 are radii of curvature of the lens.

CLASS–12

Physics

Notes

Power of a Lens

The reciprocal of the focal length of a lens, when it is measured in metre, is called power of a lens.

Power of a lens, $(P) = 1/f(\text{metre})$

Its unit is diopter (D).

The power of a convex (converging) lens is positive and for a concave (diverging) lens it is negative.

Focal Length of a Lens Combination

(i) When lenses are in contact $1/F - 1/f_1 + 1/f_2$

Power of the combination $P = P_1 + P_2$

(ii) When lenses are separated by a distance d

$1/F = 1/f_1 + 1/f_2 - d/f_1 f_1$

Power of the combination

$P = P_1 + P_2 - dP_1P_2$

Linear Magnification

$m = I/O = v/u$

For a small sized object placed linearly along the principal axis, its axial (longitudinal) magnification is given by

Axial magnification $= - dv/du = (v/u)^2$

$= (f/f+u)^2 = (f-v/f)^2$

Focal Length of a Convex Lens by Displacement Method

Focal length of the convex lens $f = (a^2 - d^2) / 4a$

where, a = distance between the image pin and object pin and

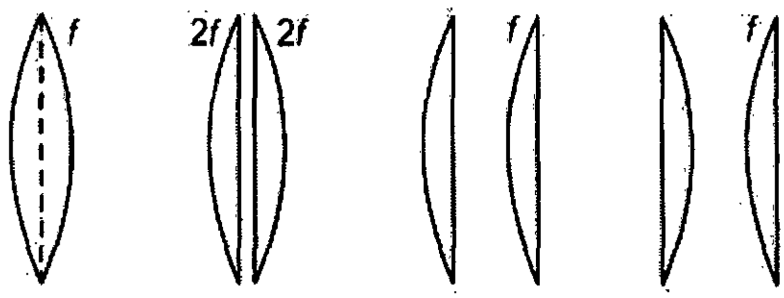
d = distance between two positions of lens.

The distance between the two pins should be greater than four times the focal length of the convex lens, i.e., $a > 4f$.

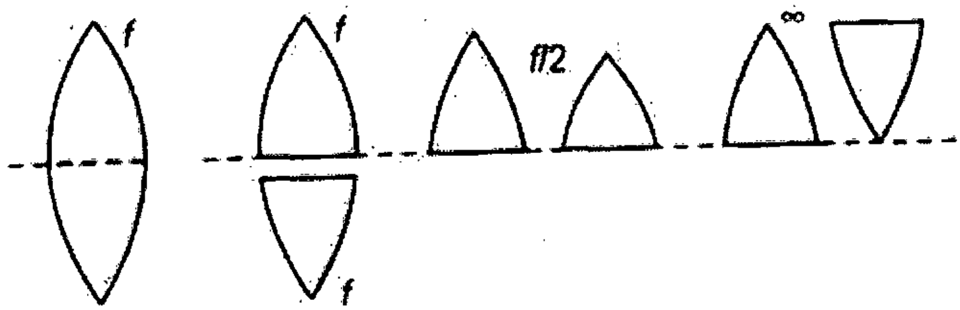
Height of the object $O = \sqrt{I_1 I_2}$

Cutting of a Lens

(i) If a symmetrical convex lens of focal length f is cut into two parts along its optic axis, then focal length of each part (a plano convex lens) is 2f. However, if the two parts are joined as shown in figure, the focal length of combination is again f.

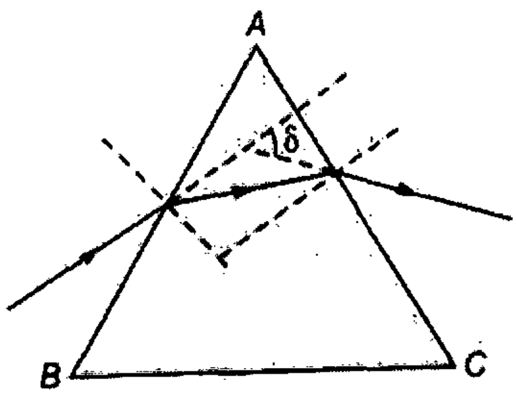


(ii) If a symmetrical convex lens of focal length f is cut into two parts along the principal axis, then focal length of each part remains unchanged as f. If these two parts are joined with curved ends an one side, focal length of the combination is f/2. But on joining two 2 parts in opposite sense the net focal length becomes



Prism

Prism is uniform transparent medium bounded between two refracting surfaces, inclined at an angle.



Angle of Deviation

The angle sub tended between the direction of incident light ray and emergent light fay from a prism is called angle of deviation (δ).

Prism Formula

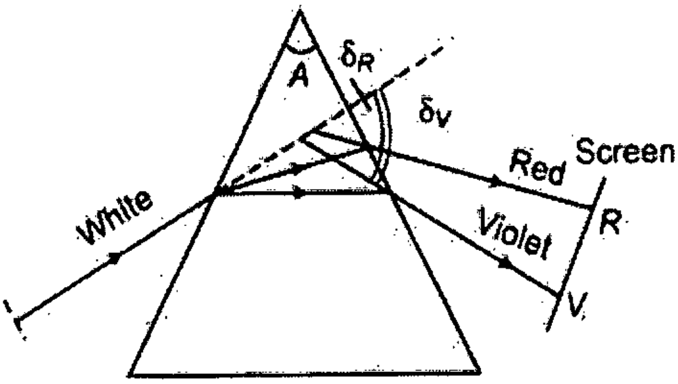
The refractive index of material of prism

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

Dispersion of Light

The splitting of white light into its constituent colours in the sequence of VIBGYOR, on passing through a prism. is called dispersion of light.

The refractive index $\mu v > \mu R$ therefore violet colour deviates most and red colour deviates least. i.e., $\delta v > \delta R$.



Angular Dispersion

The angle subtended between the direction of emergent violet and red rays of light from a prism is called angular dispersion.

Angular dispersion

$(\theta)\ \delta v - \delta R = (\mu v - \mu R\ A$

where δv and δR are angle of deviation.

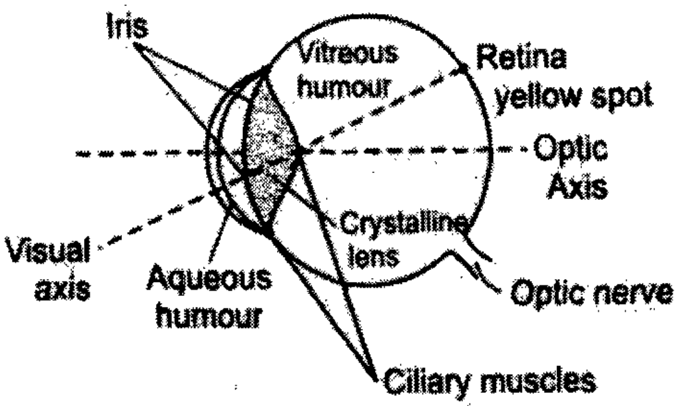
Dispersive Power

$W = \theta/\delta Y = (\mu v - \mu R) / (\mu Y - 1)$

where $\mu Y = (\mu v + \mu R) / 2$, is mean refractive index.

Human Eye

Human eye is an optical instrument which forms real image of the objects on retina. Retina colours contains lakhs of cone and rod cells which of light and intensities of light respectively.



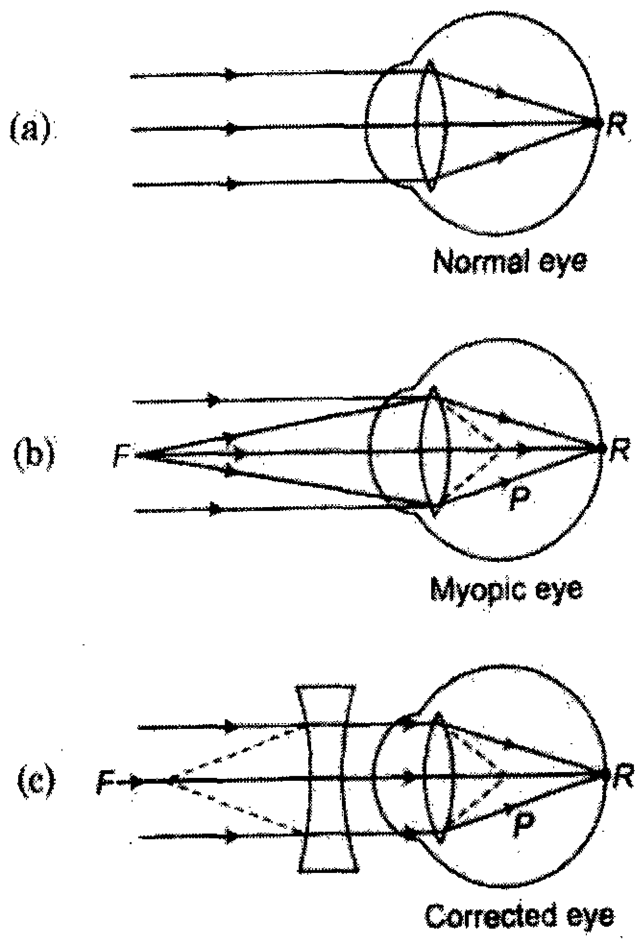
Ciliary muscles change the focal length of eye lens. This power of eye is called power of accommodation of eye.

Different defects of vision of human eye are described below

(i) **Myopia or Short-Sightedness** It is a defect of eye due to which a person can see nearby objects clearly but cannot see far away objects clearly.

In this defect, the far point of eye shifts from infinity to a nearer distance.

This defect can be removed by using a concave lens of appropriate power.

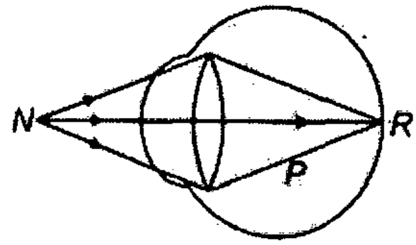


(ii) **Hypermetropia or Long-Sightedness** In this defect, a person can see far away objects clearly but cannot see nearby objects clearly.

In this defect the near point of eye shifts away from the eye.

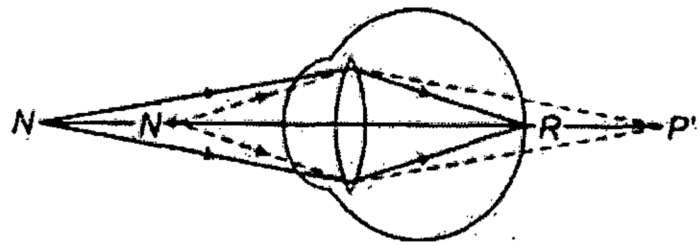
This defect can be removed by using a convex lens of appropriate power.

(a)



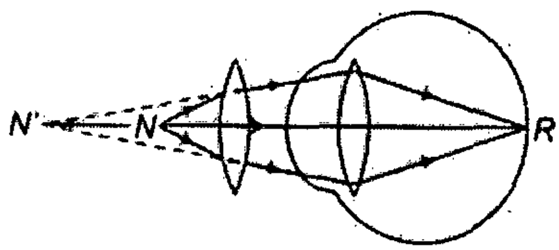
Normal eye

(b)

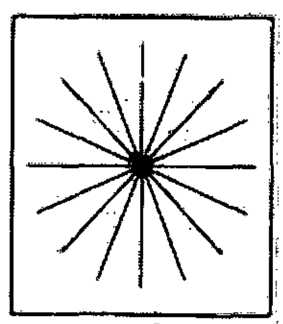


Hypermetropic eye

(c)



Corrected eye



(iii) **Astigmatism** In this defect, a person cannot focus on horizontal and vertical lines at the same distance at the same time.

This defect can be removed by using suitable cylindrical lenses.

(iv) **Colour Blindness** In this defect, distinguish between few colours. a person is unable to The reason of this defect is the absence few colours. of cone cells sensitive for This defect cannot be removed.

(v) Cataract In this defect. an opaque white membrane is developed on cornea due to which person lost power of vision partially or completely.

This defect can be removed by removing this membrane through surgery.

Camera

A photograph camera consists of a light proof box, at one end of which a converging lens system is fitted. A light sensitive film is fixed at the other end of the box, opposite to the lens system. A real inverted image of the object is formed on the film by the lens system.

f-Number for a Camera: The f-number represents the size of the aperture.

f-number =Focal length of the lens (F) / Diameter of the lens(d)

Generally, 2, 2.8, 4, 5.6, 8, 11, 22, 32 are f-numbers.

The amount of light (L) entering the camera is directly proportional to the area (A) of the aperture, i.e.,

L □A□ d2

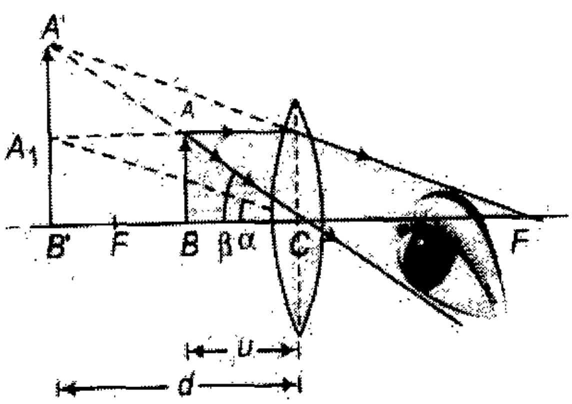
Brightness of Image □ (d2/f2)

where, d = dia meter of the lens and F = focal length of the lens.

Exposure time is the time for which light is incident of photographic film.

Simple Microscope

It is used for observing magnified images of objects. It is consisting of a converging lens of small focal length.



Magnifying Power

(i) When final image is formed at least distance of distinct vision (D), then M=1+d/f

where, f= focal length of the lens.

(ii) When final image is formed at infinity, then M = D/f

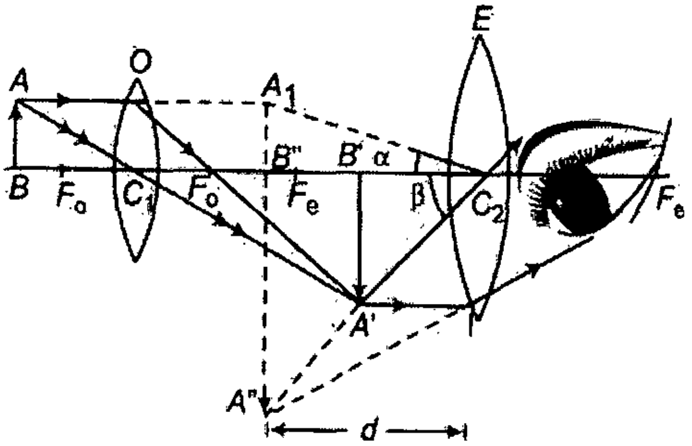
CLASS–12

Physics

Notes

Compound Microscope

It is a combination of two convex lenses called objective lens and eye piece separated by a distance. Both lenses are of small focal lengths but $f_o < f_e$, where f_o and f_e are focal lengths of objective lens and eye piece respectively



Magnifying Power

$M = v_o / u_o \{1 + (D/f_o)$

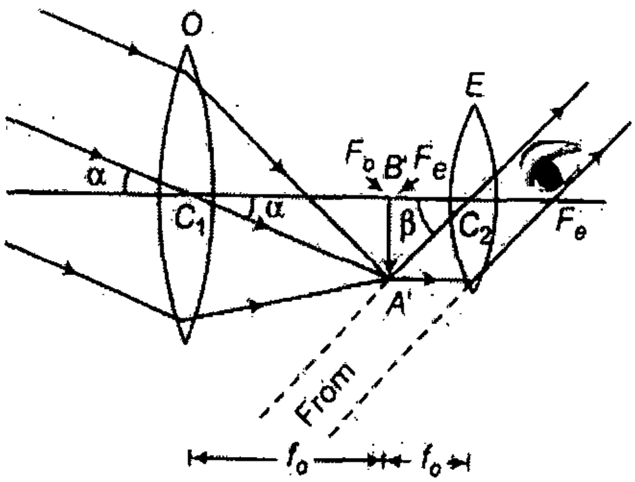
Where v_o= distance of image, formed by objective lens and

u_o = distance of object from the objective

(ii) When final image is formed at infinity, then

$M = v_o/u_o \cdot D/f_e$

Astronomical Telescope



It is also a combination of two lenses, called objective lens and eye piece, separated by a distance. It is used for observing distinct images of heavenly bodies like stars, planets etc.

Magnifying Power

(i) When final image is formed at least distance of distinct vision (D), then M = fo/fe {1+ (D/fe)} where fo and fe are focal lengths of objective and eyepiece respectively.

Length of the telescope (L) = (fo + ue)

where, ue = distance of object from the eyepiece.

(ii) When final image is formed at infinity, then M = fo/fe

Length of the telescope (L) = fo + fe

For large magnifying power of a telescope fo should be large and fe should be small.

For large magnifying power of a microscope; fo < fe should be small.

Resolving Power

The ability of an optical instrument to produce separate and clear images of two nearby objects, is called its resolving power.

Limit of Resolution

The minimum distance between two nearby objects which can be just resolved by the instrument, is called its limit of resolution (d).

Resolving power of a microscope = $1/d = 2\ \mu \sin\theta / \lambda$

where, d = limit of resolution, λ = wavelength of light used.

μ = refractive index of the medium between the objects and objective lens and θ = half of the cone angle.

Resolving power of a telescope = $1/d\theta = d/1.22\ \lambda$

where, $d\theta$ = limit of resolution, A = wavelength of light used and

d = diameter of aperture of objective

Aberration of Lenses

The image formed by the lens suffer from following two main drawbacks

(i) **Spherical Aberration** Aberration of the lens due to which the rays pass through the lens are not focussed at a single and the image of a point object placed on the axis is blurred. called spherical aberration.

It can be reduced by using

- lens of large focal lengths
- plano-convex lenses
- crossed lenses
- combining convex and concave lens

(ii) **Chromatic Aberration** Image of a white object formed by lens is usually coloured and blurred. This defect of the image produced by lens is called chromatic aberration.

Scattering of Light

When light passes through a medium in which particles are suspended whose size is of the order of wavelength of light, then light on striking these particles, deviated in different directions. These phenomena is called scattering of light.

According to the Lord Rayleigh, the intensity of scattered light

$I \propto 1/\lambda^4$

Therefore, red colour of light is scattered least and violet colour of light is scattered most.

Daily Life Examples of Scattering of Light

1. Blue colour of sky.
2. Red colour of signals of danger. /
3. Black colour of sky in the absence of atmosphere
4. Red colour of the time of sun rise and sun set.
5. The human eye is most sensitive to yellow colour

Summary of the chapter

1. The laws of reflection and refraction are true for all surfaces and pairs of media at the point of the incidence.
2. The real image of an object placed between f and 2f from a convex lens can be seen on a screen placed at the image location. If the screen is removed, is the image still there? This question puzzles many, because it is difficult to reconcile ourselves with an image suspended in air without a screen. But the image does exist. Rays from a given point on the object are converging to an image point in space and diverging away. The screen simply diffuses these rays, some of which reach our eye and we see the image. This can be seen by the images formed in air during a laser show.
3. Image formation needs regular reflection/refraction. In principle, all rays from a given point should reach the same image point. This is why you do not see your image by an irregular reflecting object, say the page of a book.
4. Thick lenses give coloured images due to dispersion. The variety in colour of objects we see around us is due to the constituent colours of the light incident on them. A monochromatic light may produce an entirely different perception about the colours on an object as seen in white light.
5. For a simple microscope, the angular size of the object equals the angular size of the image. Yet it offers magnification because we can keep the small object much closer to the eye than 25 cm and hence have it subtended a large angle. The image is at 25 cm which we can see. Without the microscope, you would need to keep the small object at 25 cm which would subtend a very small angle.

Multiple choice Questions

1. Which of the following is not a property of light?

   (a) It can travel through vacuum

   (b) It has a finite speed

   (c) It requires a material medium for its propagation

   (d) It involve transportation energy

   Answer: (c) It requires a material medium for its propagation

2. Two points P and q are situated at the same distance from a source of light but on opposite sides. The plane difference between the light waves passing through P and q will be:

   (a) n

   (b) 2n

   (c) $\frac{\pi}{2}$

   (d) zero

   Answer: (d) zero

3. The phase difference between the electric and the magnetic field vectors in electromagnetic waves is

   (a) $\frac{\pi}{4}$

   (b) $\frac{\pi}{2}$

   (c) π

   (d) zero

   Answer: (d) zero

4. A ray of light travelling in air is incident of a glass slab. The ray gets partly reflected and partly refracted. The phase difference between the reflected and the refracted waves is :

   (a) $\frac{\pi}{2}$

   (b) $\frac{\pi}{4}$

   (c) π

   (d) zero

   Answer: (c) π

5. Which of the following cannot be polarised?

   (a) radio waves

   (b) transverse waves

   (c) sound waves

   (d) X-rays

   Answer: (c) sound waves

6. Light year is the unit of:
   (a) distance
   (b) time
   (c) intensity of light
   (d) None of these
   Answer: (a) distance
7. If a mirror is approaching you at a speed of 10 ms^1, the speed with which your image approach you is:
   (a) 10 ms-1
   (b) 5 ms-1
   (c) 20 ms-1
   (d) 15 ms-1
   Answer: (c) 20 ms-1
8. The refractive indices (R.I.) of glass and water with respect to air are 3/2 and 4/3 respectively. The R.I. of glass w.r. to water is:
   (a) 8/9
   (b) 9/8
   (c) 7/6
   (d) 2
   Answer: (b) 9/8
9. The angle of minimum deviation for an equilateral glass prism is 30°. Refractive index of the prism is:
   (a) \(\frac{1}{√3}\)
   (b) √2
   (c) 1
   (d) can't be determined
   Answer: (b) √2
10. A beam of light is incident at 60° to a plane surface. The reflected and refracted rays are perpendicular to each other. What is the R.I. of the surface:
   (a) \(\frac{1}{√3}\)
   (b) √3
   (c) \(\frac{1}{3}\)
   (d) 3
   Answer: (b) √3

Review Question'

1, A small candle, 2.5 cm in size is placed at 27 cm in front of a concave mirror of radius of curvature 36 cm. At what distance from the mirror should a screen be placed in order to obtain a sharp image? Describe the nature and size of the image. If the candle is moved closer to the mirror, how would the screen have to be moved?

2. A 4.5 cm needle is placed 12 cm away from a convex mirror of focal length 15 cm. Give the location of the image and the magnification. Describe what happens as the needle is moved farther from the mirror
3. A tank is filled with water to a height of 12.5 cm. The apparent depth of a needle lying at the bottom of the tank is measured by a microscope to be 9.4 cm. What is the refractive index of water? If water is replaced by a liquid of refractive index 1.63 up to the same height, by what distance would the microscope have to be moved to focus on the needle again?
4. A small bulb is placed at the bottom of a tank containing water to a depth of 80cm. What is the area of the surface of water through which light from the bulb can emerge out? Refractive index of water is 1.33. (Consider the bulb to be a point source.)
5. A prism is made of glass of unknown refractive index. A parallel beam of light is incident on a face of the prism. The angle of minimum deviation is measured to be 40°. What is the refractive index of the material of the prism? The refracting angle of the prism is 60°. If the prism is placed in water (refractive index 1.33), predict the new angle of minimum deviation of a parallel beam of light.
6. Double-convex lenses are to be manufactured from a glass of refractive index 1.55, with both faces of the same radius of curvature. What is the radius of curvature required if the focal length is to be 20cm?
7. A beam of light converges at a point P. Now a lens is placed in the path of the convergent beam 12cm from P. At what point does the beam converge if the lens is (a) a convex lens of focal length 20cm, and (b) a concave lens of focal length 16cm?
8. An object of size 3.0cm is placed 14cm in front of a concave lens of focal length 21cm. Describe the image produced by the lens. What happens if the object is moved further away from the lens?

10 WAVE OPTICS

- Wave optics: Wave front and Huygen's principle, reflection and refraction of plane wave at a plane surface using wave fronts
- Proof of laws of reflection and refraction using Huygen's principle
- Interference Young's double slit experiment and expression for fringe width, coherent sources and sustained interference of light
- *Diffraction due to a single slit, width of central maximum*
- Resolving power of microscopes and astronomical telescopes
- Polarisation, plane polarised light Brewster's law, uses of plane polarised light and Polaroids

Objective of the chapter

The main objective of this chapter is to make student understand about the concepts of Wave optics. Interference Young's double slit experiment and Resolving power of microscopes and astronomical telescopes and topics like Polarisation has also been explained in this chapter.

Introduction

Wave optics describes the connection between waves and rays of light. According to wave theory of light, the light is a form of energy which travels through a medium in the form of transverse wave motion. The speed of light in a medium depends upon the nature of medium.

Newton's Corpuscular Theory

Light consists of very small invisible elastic particles which travel in vacuum with a speed of 3 x 108 m/s.

The theory could explain reflection and refraction.

The size of corpuscular of different colours of light are different.

It could not explain interference, diffraction, polarisation. photoelectric effect and Compton effect. The theory failed as it could not explain why light travels faster in a rarer medium than in a denser medium.

Wave front

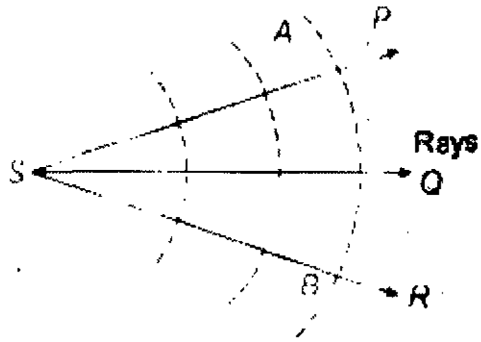
A wave front is defined as the continuous locus of all the particles of a medium, which are vibrating in the same phase.

These are three types

(i) Spherical wave front

(ii) Cylindrical wave front

(iii) Plane wave front



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

Huygen's Wave Theory

Light travel in a medium in the form of wave front.

A wave front is the locus of all the particles vibrating in same phase.

All particles on a wave front behave as a secondary source of light, which emits secondary wavelets.

The envelope of secondary wavelets represents the new position of a wave front.

When source of light is a point source, the wave front is spherical.

Amplitude (A) is inversely proportional to distance (x) i.e., A □ 1 / x .

□ Intensity (I) □ (Amplitude)2

When Source of light is linear, the wave front is cylindrical.

Amplitude (A) □ 1 / √x

□ Intensity □ (Amplitude)2 □ 1 / x

Huygen's Principle

(i) Every point on given wave front (called primary wave front) acts as a fresh source of new disturbance called secondary wavelets.

(ii) The secondary wavelets travel in all the directions with the speed of light in the medium.

(iii) A surface touching these secondary wavelets tangentially in the forward direction at any instant gives the new (secondary) wave front of that instant.

Maxwell's Electromagnetic Wave Theory

(i) Light waves are electromagnetic waves which do not require a material medium for their propagation.

(ii) Due to transverse nature, light wave undergo polarisation.

(iii) The velocity of electromagnetic wave in vacuum is $c = 1 / \sqrt{\mu_o \varepsilon_o}$

(iv) The velocity of electromagnetic waves in medium is less than that of light, $v < c$

$v = 1 / \sqrt{\mu_o \varepsilon_o \varepsilon_r \mu_r} = c / \sqrt{\mu_o \varepsilon_r}$

(v) The velocity of electromagnetic waves in a medium depend upon the electric and magnetic properties of the medium.

where, μ_o = absolute magnetic permeability and

ε_o = absolute electrical permittivity of free space.

(vi) It failed to explain the phenomenon of photoelectric effect, Compton effect and Raman effect.

Max Planck's Quantum Theory

(i) Light emits from a source in the form of packets of energy called quanta or photon.

(ii) The energy of a photon is $E = hv$, where h is Planck's constant and v is the frequency of light.

(iii) Quantum theory could explain photoelectric effect, Compton effect and Raman effect.

(iii) Quantum theory failed to explain interference, diffraction and polarisation of light.

de – Broglie's Dual Theory

Light waves have dual nature, wave nature according to Maxwell's electromagnetic wave theory and particle nature according to Max-Planck's quantum theory.

Two natures of light are like the two faces of a coin. In anyone phenomena only its one nature appears.

Energy of photon $= hv = hc / \lambda$

where, h = Planck's constant 6.6 * 10<sup-34 J / s

de-Broglie wave equation is $\lambda = h / p = h / mv$

where h denotes Planck's constant.

Superposition of Waves

When two similar waves propagate in a medium simultaneously, then at any point the resultant displacement is equal to the vector sum of displacement produced by individual waves.

$y = y_1 + y_2$

Interference of Light

When two light waves of similar frequency having a zero or constant phase difference propagate in a medium simultaneously in the same direction, then due to their superposition maximum intensity is obtained at few points and minimum intensity at other few points.

This phenomena of redistribution of energy due to superposition of waves is called interference of light waves.

The interference taking place at points of maximum intensity is called **constructive interference**.

The interference taking place at points of minimum intensity is **destructive interference**.

Fringe Width

The distance between the centres of two consecutive bright or dark fringes is called the fringe width.

The angular fringe width is given by $\theta = \lambda / d$.

where λ is the wavelength of light d is the distance between two coherent sources.

Conditions for Constructive and Destructive Interference

For Constructive Interference

Phase difference, $\varphi = 2n\pi$

Path difference, $\Delta x = n\lambda$

where, $n = 0, 1, 2, 3, \ldots$

For Destructive Interference

Phase difference, $\varphi = (2n - 1)\pi$

Path difference, $\Delta x = (2n - 1)\pi / 2$.

where, $n = 1, 2, 3, \ldots$

If two waves of exactly same frequency and of amplitude a and b interfere, then amplitude of resultant wave is given by

$R = \sqrt{}a2 + b2 + 2ab \cos \varphi$

where φ is the phase difference between two waves.

$Rmax = (a + b)$

$Rmin = (a - b)$

Intensity of wave

□ $I = a2 + b2 + 2ab \cos \varphi$

$= I1 + I2 + 2 \sqrt{}I1\ I2 \cos \varphi$

where I1 and I2 are intensities of two waves.

□ $I1 / I2 = a2 / b2 = \omega1 / \omega2$

Where $\omega1$ and $\omega2$ are width of slits.

Energy remains conserved during interference.

Interference fringe width

$\beta = D\lambda / d$

where, D = distance of screen from slits, λ = wavelength of light and d = distance between two slits.

Distance of nth bright fringe from central fringe $xn = nD\lambda / d$

Distance of nth dark fringe from central fringe $x'n = (2n - 1) D\lambda / 2d$

Coherent Sources of Light

The sources of light emitting light of same wavelength, same frequency having a zero or constant phase difference are called coherent sources of light.

When a transparent sheet of refractive index μ and of thickness t is introduced in one of the paths of interfering waves, then fringe pattern shifts in that direction by a distance Y

$Y = D / d\,(\mu - 1)\,t = \beta / \lambda\,(\mu - 1)\,t$

where, β = fringe width.

Fresnel's Biprism

It is a combination of two prisms of very small refracting angles placed base to base. It is used to obtain two coherent sources from a single light source.

Lyod's Mirror

The shape of interference fringes is usually hyperbolic.

When screen is held at 900 to the line joining foci of the hyperbola, the fringes are circular.

When distance of screen (D) is very large compare to the distance between the slits (d), the Cringes are straight.

Diffraction

The bending of light waves around the corners of an obstacle or aperture is called diffraction of light.

The phenomenon of diffraction is divided mainly in the following two classes

(a) Fresnel class

(b) Fraunhofer class

S.No	Fresnel Class	Fraunhofer Class
1	The source is at a finite distance	The source is at infinite distance

2	No optical are required.	Optical are in the form of Collimating lens and focusing lens are required.
3	Fringes are not sharp and well defined.	Fringes are sharp and well defined.

Fraunhofer Diffraction at a Single Slit

Linear Width 0f central maximum $2D\lambda / a = 2f\lambda / a$

Angular width of central maximum $= 2\lambda / a$

where, λ = wavelength of light, a = width of single slit, D = distance of screen from the slit and f = focal length of convex lens.

For Secondary Minima

(a) Path difference $= n\lambda$

(b) Linear distance $= nD\lambda / a = nf\lambda / a$

(c) Angular spread $= n\lambda / a$

where, n = 1, 2, 3,.,.

For Secondary Maxima

(a) Path difference = (2n + 1) &lamda; / 2

(b) LInear distance = (2n + 1) D & lamda; / 2a = (2n + 1) f & lamda; / 2a

(c) Angular spread = (2n + 1) &lamda; / 2

Important Points

- A soap bubble or oil film on water appears coloured in white light due to interference of light reflected from upper and lower surfaces of soap bubble or oil film.
- In interference fringe pattern all bright and dark fringes are of same width,
- In diffraction fringe pattern central bright fringe is brightest and widest. and I remaining secondary maxima's are of gradually decreasing intensities.
- The difference between interference and diffraction is that the interference is the superposition between the wavelets coming from two coherent sources while the diffraction is the superposition between the wavelets coming from the single wave front

Polarisation

The phenomena of restructuring of electric vectors of light into a single direction is called **polarisation.**

Ordinary light has electric vectors in all possible directions in a plane perpendicular to the direction of propagation of light.

When ordinary light is passed through a tourmaline, calcite or quartz crystal the transmitted light have electric vectors in a particular direction parallel to the axis of crystal. This light is plane polarised light.

[A plane containing the vibrations of polarised light is called plane of vibration.

A plane perpendicular to the plane of vibration is called **plane of polarisation**.]

Polarisation can take place only in transverse waves.

Nicol Prism

A nicol prism is an optical device which is used for producing plane polarised light and analysing light the same.

The nicol prism consists of two calcite crystal cut at 68° with its principal axis joined by a glue called Canada balsam.

Law of Malus

When a beam of completely plane polarised light is incident on an analyser, the intensity of transmitted light from analyser is directly proportional to the square of the cosine of the angle between plane of transmission of analyser and polariser, i.e.,

$I \propto \cos^2 \theta$

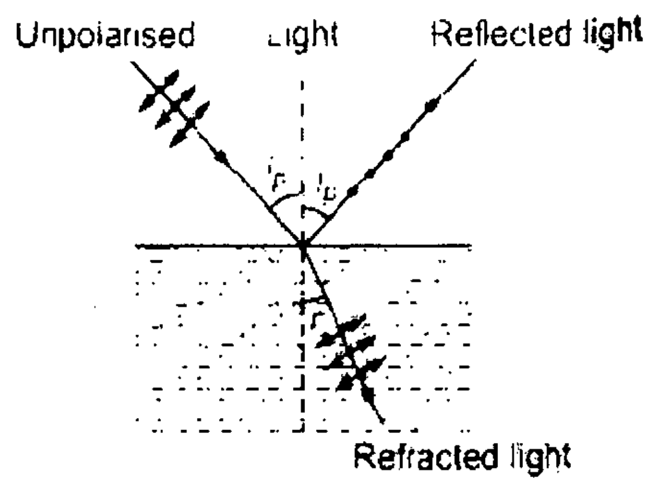
When ordinary light is incident on a polariser the intensity of transmitted light is half of the intensity of incident light.

When a polariser and analyser are perpendicular to each other, then intensity of transmitted light from analyser becomes O.

Brewster's Law

When unpolarised light is incident at an angle of polarisation (ip) on the interface separating air from a medium of refractive index μ, then reflected light becomes fully polarised, provided

$\mu = \tan i_p$



If angle of polarisation is ip and angle of refraction is μ then

ip + r = 90°

Refractive index μ = tan ip = 1 / sin C

where, C = critical angle.

Double Refraction

When unpolarised light is incident on a calcite or quartz crystal it splits up into two refracted rays. one of which follows laws of refraction. called ordinary ray (O-ray) and other do not follow laws of refraction. called extraordinary ray (E-ray). This phenomenon is called double refraction.

Dichroism

Few double refracting crystals have a property of absorbing one of the two refracted rays and allowing the other to emerge out. This property of crystal is called dichroism.

Polaroid

It is a polarising film mounted between two glass plates. It is used to produce polarised light.

A polaroid is used to avoid glare of light in spectacles.

Uses of Polaroid

(i) Polaroids are used in sun glasses. They protect the eyes from glare.

(ii) The polaroids are used in window panes of a train and especially of an aeroplane. They help to control the light entering through the window.

(iii) The pictures taken by a stereoscopic camera. When seen with the help of polarized spectacles, create three-dimensional effect.

(iv) The windshield of an automobile is made of polaroid. Such a mind shield protects the eyes of the driver of the automobile from the dazzling light of the approaching vehicles.

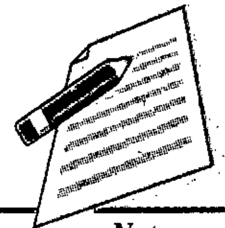
Summary of the chapter

1. Huygens' principle tells us that each point on a wave front is a source of secondary waves, which add up to give the wave front at a later time.
2. Huygens' construction tells us that the new wave front is the forward envelope of the secondary waves. When the speed of light is independent of direction, the secondary waves are spherical. The rays are then perpendicular to both the wave fronts and the time of travel is the same measured along any ray. This principle leads to the well-known laws of reflection and refraction.
3. The principle of superposition of waves applies whenever two or more sources of light illuminate the same point. When we consider the intensity of light due to these sources at the given point, there is an interference term in addition to

Notes

the sum of the individual intensities. But this term is important only if it has a non-zero average, which occurs only if the sources have the same frequency and a stable phase difference.

4. Young's double slit of separation d gives equally spaced fringes of angular separation λ/d. The source, mid-point of the slits, and central bright fringe lie in a straight line. An extended source will destroy the fringes if it subtends angle more than λ/d at the slits.
5. A single slit of width a gives a diffraction pattern with a central maximum. The intensity falls to zero at angles of 2 , , a a λ λ $\pm$ $\pm$ etc., with successively weaker secondary maxima in between. Diffraction limits the angular resolution of a telescope to λ/D where D is the diameter. Two stars closer than this give strongly overlapping images. Similarly, a microscope objective subtending angle 2β at the focus, in a medium of refractive index n, will just separate two objects spaced at a distance $\lambda/(2n \sin \beta)$, which is the resolution limit of a microscope. Diffraction determines the limitations of the concept of light rays. A beam of width a travel a distance a 2 /λ, called the Fresnel distance, before it starts to spread out due to diffraction.
6. Natural light, e.g., from the sun is unpolarised. This means the electric vector takes all possible directions in the transverse plane, rapidly and randomly, during a measurement. A polaroid transmits only one component (parallel to a special axis). The resulting light is called linearly polarised or plane polarised. When this kind of light is viewed through a second polaroid whose axis turns through 2π, two maxima and minima of intensity are seen. Polarised light can also be produced by reflection at a special angle (called the Brewster angle) and by scattering through $\pi/2$ in the earth's atmosphere.



Multiple choice Questions

1. Polarisation phenomenon explains which nature of light?
   a. Transverse
   b. longitudinal
   c. Both transverse and longitudinal
   d. geometrical

   Answer: (a) Transverse

2. A narrow slit is taken and a parallel beam of moving electrons is incident normally on it. At a larger distance from the slit, a fluorescent screen is placed. Which of the following statement is true if the size of the slit is further narrowed?
   a. The diffraction pattern cannot be observed on the screen
   b. The angular width of the central maxima of the diffraction pattern will increase
   c. The angular width of the central maxima of the diffraction pattern will decrease
   d. The angular width of the central maxima of the diffraction pattern remains the same

   Answer: (c) The angular width of the central maxima of the diffraction pattern will decrease

3. How does the diffraction band of blue light look in comparison with the red light?
   a. No changes
   b. Diffraction pattern becomes narrower
   c. Diffraction pattern becomes broader
   d. Diffraction pattern disappears

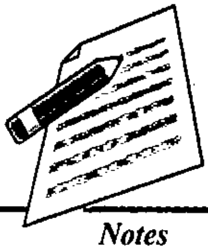
   Answer: (b) Diffraction pattern becomes narrower

4. Two coherent sources of light can be obtained from
   a. Two different lamps
   b. Two different lamps but of the same colour
   c. Two different lamps of the same colour and having the same colour
   d. None of these

   Answer: (d) None of these

5. Which of the following phenomenon is not explained by Huygen's wave theory?
   a. Diffraction
   b. Interference
   c. Polarisation
   d. Photoelectric effect

   Answer: (d) Photoelectric effect



6. What is the value of coherent time if L is the coherent length and c is the velocity of light?
   a. cL
   b. L/c
   c. c/L
   d. 1/Lc

   Answer: (b) L/c
7. The ratio of the amplitude of the two sources producing interference 3 : 5, the ratio of intensities at maxima and minima is
   a. 25:6
   b. 5:3
   c. 16:1
   d. 25:9

   Answer: (c) 16:1
8. The colours on the soap bubble is due to
   a. Interference
   b. Polarisation
   c. Diffraction
   d. Reflection

   Answer: (a) Interference
9. Which of the following statements indicates that light waves are transverse?
   a. Light waves can be polarised
   b. Light waves can show interference
   c. Light waves undergo diffraction
   d. They travel in the vacuum

   Answer: (a) Light waves can be polarised
10. In Young's double-slit experiment, the phase difference between the light waves reaching the third bright fringe from the central fringe will be (λ=6000 Å)
    a. Zero
    b. 2π
    c. 4π
    d. 6π

    Answer: 6π

Review Questions

1. Define the term wave front?
2. Give the relation between path difference and wavelength for constructive interference between two waves.

3. State two conditions to obtain sustained interference of light
4. If the separation between the two slits is decreased in Young›s double-slit experiment keeping the screen position fixed. What will happen to the fringe width?
5. Why are coherent sources necessary to produce a sustained interference pattern?
6. Sunglasses are made of Polaroid and not colored glasses. Why?
7. Why does the intensity of a secondary maximum become less as compared to the central maximum?
8. Will ultrasonic big show any polarization? Give a reason for your
9. Why longitudinal waves cannot be polarized?
10. Is there any difference between the colours emerging from a prism and the colours of a soap film seen in sunlight?

Numerical Type Questions

1. Two identical coherent waves each of intensity II, are producing an interference pattern. Write the value of resultant intensity at a point of (i) constructive interference and (ii) destructive interference.
2. If the angle between the planes of the polarizer and analyzer is 60□60□, by what factor does the intensity of transmitted light change when passing through the analyzer?
3. The ratio of intensity of maxima and minima in an interference pattern is 100:64. Calculate the ratio of intensities of the coherent sources producing the pattern.
4. Draw a diffraction pattern due to single slit illuminated by monochromatic source of light. Light of wavelength 500 nm, falls from a distant source of slit 0.50 mm wide. Find the distance between the two dark bands, on either side of the central bright band of the diffraction pattern observed on a screen placed 2m from the slit.
5. Laser light of wavelength 630 nm incident on a pair of slits produces an interference pattern in which the bright fringes are separated by 8.1 mm. A second light produces an interference pattern in which the fringes are separated by 7.2 mm. Calculate the wavelength of the second light.
6. Find the ratio of intensities of two points PP and QQ on a screen in Young's double slit experiment when waves from sources S1S1 and S2S2 have phase difference of (i) 0000 and (ii) π2π2 respectively.
7. In Young's Double Slit experiment using monochromatic light of wavelength λλ, the intensity of light at a point on screen where path difference is λλ; is KK units. What is the intensity of light at a point where path difference is λ3λ3?

11 DUAL NATURE OF RADIATION AND MATTER

- Dual nature of radiation
- Photoelectric effect
- Hertz and Lenard's observations
- Einstein's photoelectric equation-particle nature of light
- Matter waves-wave nature of particles, de Broglie relation
- Davisson-Germer experiment (experimental details should be omitted; only conclusion should be explained).

Objective of the chapter

The main objective of this chapter is to make student understand about the concepts of **Dual** Nature of Radiation and Matter. Photoelectric effect, Einstein's photoelectric equation and Davisson-Germer experiment and its applications has also been explained in this chapter.

Introduction

Cathode Rays

Cathode rays are the stream of fast-moving electrons. These rays are produced in a discharge tube at a pressure below 0.01 rom of mercury.

Properties of Cathode Rays

(i) Cathode rays are not electromagnetic rays.

(ii) Cathode rays are deflected by electric field and magnetic field.

(iii) Cathode rays produce heat in metals when they fall on them.

(iv) Cathode rays can pass through thin aluminium or gold foils without puncturing them.

(v) Cathode rays can produce physical and chemical change.

(vi) Cathode ray travel in straight line with high velocity momentum and energy and cast shadow of objects placed in their path.

(vii) On striking the target of high atomic weight and high melting point, they produce X-rays.

(viii) Cathode rays produce fluorescence and phosphorescence in certain substance and hence affect photographic plate.

(ix) When any charge particle moves in a field where magnetic and electric fields are present, without any deviation, then

Magnetic force = Electrostatic force

$Bev = Ee$ or $v = E / B$

(x) Specific charge of cathode rays means the ratio of charge and mass.

(xi) Specific charge of electron was determined by J J Thomson using perpendicular magnetic and electric field applied on a beam of electrons, at the same place.

(xii) Specific charge of electron $e / m = E2 / 2VB2$

where, E = electric field, B = magnetic field and V = potential difference applied across ends of tube.

(xii) The value of specific charge of an electron is 1.7589 * 1011 C / kg.

(xiv) Millikan measured the charge of an electron through his popular oil drop experiment.

(xv) The charge of the electron as determined by Millikan was found to be 1.602 * 10-19 C.

Positive Rays

Positive rays were discovered by Goldstein. Positive rays are moving positive ions of gas filled in the discharge tube. The mass of these particles is nearly equal to the mass of the atoms of gas.

(i) These consist of fast moving positively charged particles.

(ii) These rays are deflected in magnetic and electric fields.

(iii) These rays travel in straight line.

(iv) Speed of positive rays is less than that of cathode rays.

(v) These rays can produce fluorescence and phosphorescence.

Electron Emission

It is the phenomenon of emission of electron from the surface of a metal. The electron emission can be obtained from the following process

(i) Thermionic

(ii) Photoelectric emission

(iii) Field emission

(iv) Secondary emission

Photon

Photons are the packets of energy emitted by a source of radiation. The energy of each photon is,

$E = h\nu$

Where h is Planck's constant and ν is frequency of radiation.

The rest mass of a photon is zero.

The momentum of a photon $p = h\nu / c = h / \lambda$

Dynamic or kinetic mass 0f photon $m = h\nu / c2 = h / c\lambda$

where c is speed of light in vacuum and λ is wavelength of radiation. Photons are electrically neutral.

A body can radiate or absorb energy in whose number multiples of a quantum $h\nu$, $2h\nu$, $3h\nu$ .... $nh\nu$, where n is positive integer.

Photoelectric Effect

The phenomena of emission of electrons from a metal surface, when radiations of suitable frequency are incident on it, are called photoelectric effect.

Terms Related to Photoelectric Effect

(i) **Work Function**(φ) The minimum amount of energy required to eject one electron from a metal surface, is called its work function.

(ii) **Threshold Frequency** (νo) The minimum frequency of light which can eject photo electron from a metal surface is called threshold frequency of that metal.

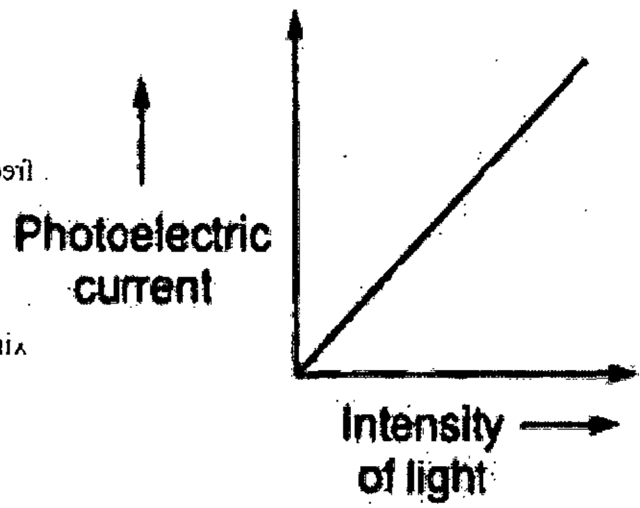
(iii) **Threshold Wavelength** (λmax) The maximum wavelength rJ light which can eject photo electron from a metal surface is called threshold wavelength of that metal.

Relation between work function, threshold frequency and threshold wavelength

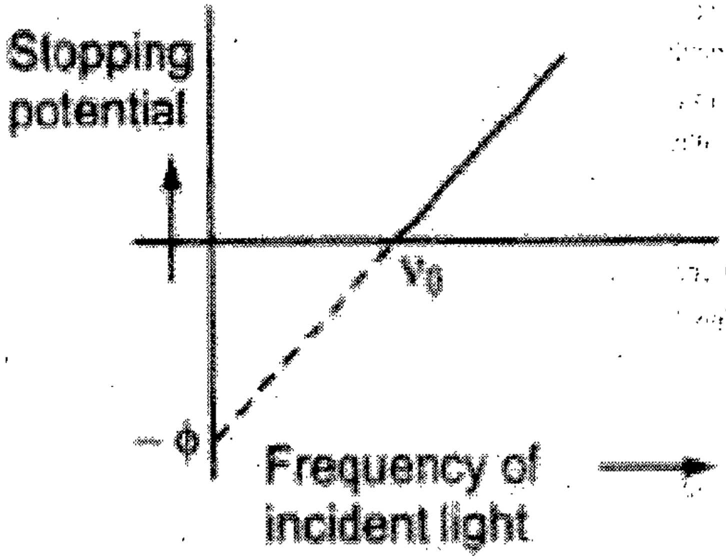
$\varphi = h\nu o = hc / \lambda max$

Laws of Photoelectric Effect

1. For a given metal and frequency of incident light, the photo electric current (the rate of emission of photoelectrons) is directly proportional to the intensity of incident light.



2. For a given metal. there is a certain minimum frequency, called **threshold frequency**, below which there is no emission of photo electrons takes place.
3. Above threshold frequency the maximum kinetic energy of photo electrons depends upon the frequency of incident light.
4. The photoelectric emission is an instantaneous process.



Einstein's Photoelectric Equation

The maximum kinetic energy of photoelectrons

(Ek)max = hv – φ = h(v – vo)

where v is frequency of incident light and vo is threshold frequency.

Stopping Potential

The minimum negative potential given to anode plate at which photoelectric current becomes zero is called stopping potential (Vo).

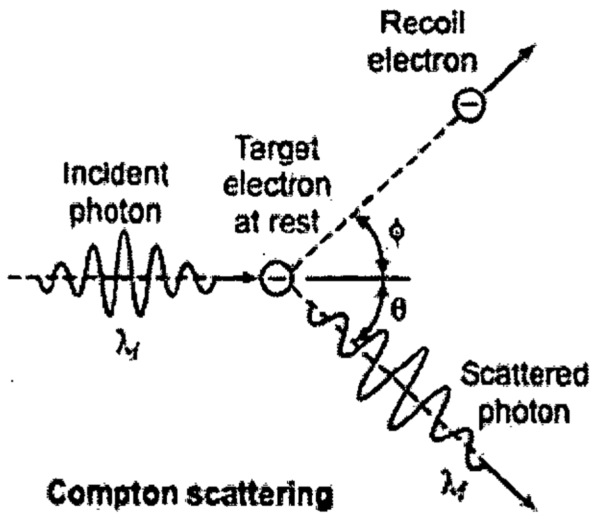
Maximum kinetic energy of photo electrons

(Ek)max = 1 / 2 mv2max = eVo

Compton Effect

When a monochromatic beam of X – falls on a target containing free electrons. it is scattered. As a result, the electrons recoil and scattered radiation has wavelength longer than incident one. This effect is called Compton effect.

(i) λ' – λ = λ = Compton shift Δλ = h / moc (1 – cos φ) where mo is rest mass of an electron and c is the speed of light h / moc Compton shift Δλ is maximum, when φ = 180°



Compton scattering

(ii) Kinetic energy of recoil electron

$E_k = hc / \lambda - hc / \lambda'$

(iii) Direction of recoil electron

$\tan \theta = \lambda \sin \varphi / \lambda' - \lambda \cos \varphi$

(iv) Compton wavelength of electron

$= h / m_0c = 0.024$ A

(v) Maximum Compton shift

$(\Delta\lambda)_{max} = 2h / m_0c$ 0.0048 A

Matter Waves on de-Broglie Waves

A wave is associated with every moving particle, called matter or de-Broglie wave.

de-Broglie Wavelength

If a particle of mass m is moving with velocity v, then wavelength of de-Broglie wave associated with it is given by

$\lambda = h / p = h / mv$

de-Broglie wavelength of an electron is given by

$\lambda = h / mv = h / \sqrt{2meV} = 12.27 / \sqrt{V}$ A.

where, m = mass of electron, e = electronic charge and V = potential difference with which electron is accelerated.

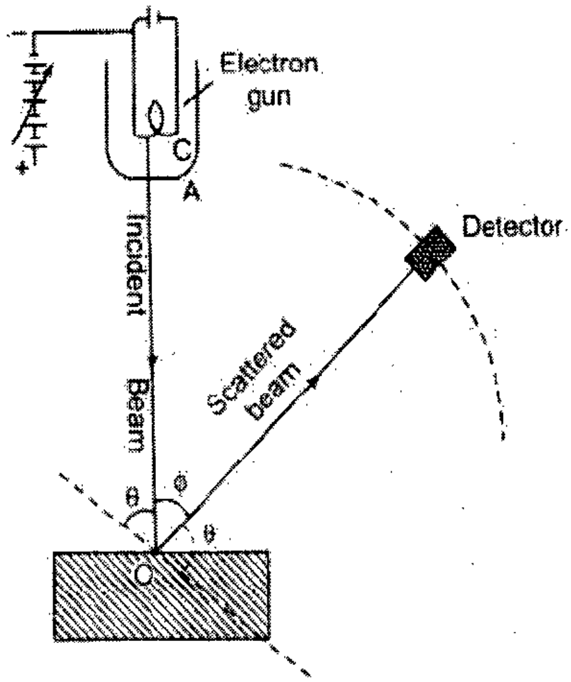
Davisson and Germer proves the existence of de-Broglie waves associated with an electron in motion.

Davisson-Germer Experiment

The wave nature of the material particles as predicted by de-Broglie was confirmed by Davisson and Germer (1927) in united states and by GP Thomson (1928) in Scotland.

This experiment verified the wave nature of electron using Ni crystal.

Davisson and Germer found that the intensity of scattered beam of electrons was not the same but different at different angles of scattering. It is maximum for diffracting angle 50° at 54 V potential difference.



X-rays

When cathode rays strike on a heavy metal of high melting point. then a very small fraction of its energy converts in to a new type of waves, called X-rays.

Properties of X-rays

X-rays were discovered by Roentgen.

(i) X-rays are electromagnetic waves of wavelengths ranging from 0.1 A to 100 A and frequencies ranging from 1016 Hz to 1018 Hz.

(ii) Soft X-rays have greater wavelength and lower frequency.

(iii) Hard X-rays have lower wavelength and higher frequency.

(iv) X-rays are produced by coolidge tube.

(v) Molybdenum and tungsten provide suitable targets. These elements have large atomic number and high melting point for the purpose.

(vi) The intensity of X – rays depend on the heating voltage or filament current.

(vii) The kinetic energy of X-ray photons depends upon the voltage applied across the ends of coolidge tube.

(viii) Energy of X-ray photon is given by $E = h\nu = hc / \lambda$

(ix) If total energy of fast-moving electron transfer to X-ray photon, then its energy, $eV = h\nu = hc / \lambda$

(x) Wavelength of emitted X-rays is given by $\lambda = hc / eV$

where, h = Planck's constant, c = speed of light, e = electronic charge and V = potential difference applied across the ends of the tube.

(xi) Absorption of X-rays

$I = Ioe^{-\mu x}$, where Io = initial intensity of X-rays, I = final intensity of emergent X-rays, x = thickness of material and μ = absorption coefficient.

Diffraction of X-rays

X-rays can be diffracted by crystals following Bragg's law. According to which

$2d \sin \theta = n \lambda$

where, n = 1, 2, 3, …, and d = spacing of crystal planes, θ = angle of diffraction.

X-rays Spectrum

The energy spectrum of X-. rays is a line spectrum, containing following series:

(i) **K – series** When electrons of any higher orbit (n = 2,3,4, …) jump to first orbit (n = 1) then K-series of X-rays are produced.

(ii) **L – series** When electrons of higher orbit (n = 3, 4, 5, …) jump to second orbit (n = 2), then L-series of X-rays are produced.

(iii) **M – series** When electrons of higher orbit (n = 4,5,6, …)jump to third orbit (n = 3), then M-series of X-rays are produced.

First lines of these series are called $K\alpha$, $L\alpha$, $M\alpha$. Second lines of these series are called $K\beta$, $L\beta$, $M\beta$

Moseley's Law

The frequency of X-ray is given by

V = a (Z – b)2

where a and b are constants and Z is atomic number of elements.

Frequency of X-rays

v □ Z2

Summary of the chapter

1. The minimum energy needed by an electron to come out from a metal surface is called the work function of the metal. Energy (greater than the work function (φo) required for electron emission from the metal surface can be supplied by suitably heating or applying strong electric field or irradiating it by light of suitable frequency.
2. Photoelectric effect is the phenomenon of emission of electrons by metals when illuminated by light of suitable frequency. Certain metals respond to ultraviolet light while others are sensitive even to the visible light. Photoelectric effect involves conversion of light energy into electrical energy. It follows the law of conservation of energy. The photoelectric emission is an instantaneous process and possesses certain special features.

3. Photoelectric current depends on (i) the intensity of incident light, (ii) the potential difference applied between the two electrodes, and (iii) the nature of the emitter material.
4. The stopping potential (V_o) depends on (i) the frequency of incident light, and (ii) the nature of the emitter material. For a given frequency of incident light, it is independent of its intensity. The stopping potential is directly related to the maximum kinetic energy of electrons emitted: $e V_0 = (1/2)\, m v^2_{max} = K_{max}$.
5. Below a certain frequency (threshold frequency) v_0, characteristic of the metal, no photoelectric emission takes place, no matter how large the intensity may be.
6. The classical wave theory could not explain the main features of photoelectric effect. Its picture of continuous absorption of energy from radiation could not explain the independence of K_{max} on intensity, the existence of v_o and the instantaneous nature of the process. Einstein explained these features on the basis of photon picture of light. According to this, light is composed of discrete packets of energy called quanta or photons. Each photon carries an energy E (= h v) and momentum p (= h/λ), which depend on the frequency (v) of incident light and not on its intensity. Photoelectric emission from the metal surface occurs due to absorption of a photon by an electron

Multiple choice Questions

1. Light of frequency 1.9 times the threshold frequency is incident on a photosensitive material. If the frequency is halved and intensity is doubled, the photocurrent becomes

   a. doubled

   b. quadrupled

   c. halved

   d. zero

   Answer: (d) zero

2. For a metal having a work function W0, the threshold wavelength is λ. What is the threshold wavelength for the metal having work function 2W0?

   a. λ/4

   b. λ/2

   c. 2λ

   d. 4λ

   Answer: (b) λ/2

3. Radiation of frequency v is incident on a photosensitive metal. When the frequency of the incident radiation is doubled, what is the maximum kinetic energy of the photoelectrons?

   a. 4E

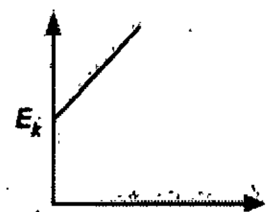
   b. 2E

   c. E + hv

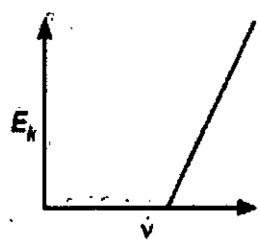
   d. E – hv

   Answer: (c) E + hv

4. How does the maximum kinetic energy of a photoelectron vary with the frequency (v) of the incident radiation?



a.



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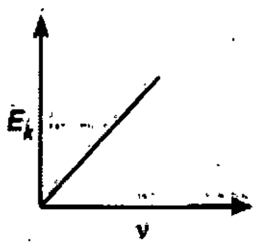
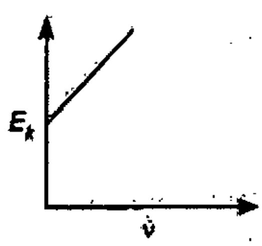
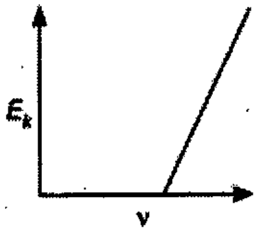


c.

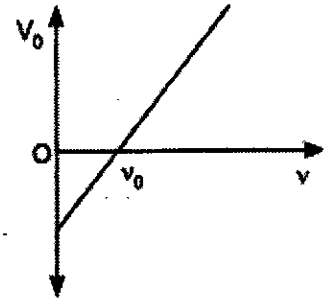


d.

Answer: (b)



5. The stopping potential V0 for photoelectric emission from a metal surface is plotted along with the y-axis and frequency v of incident light along the x-axis. A straight line is obtained as shown. Planck's constant is given by



   a. product of the slope of the line and charge on the electron
   b. intercept along y-axis divided by the charge on the electron
   c. product of the intercept along x-axis and mass of the electron
   d. the slope of the line

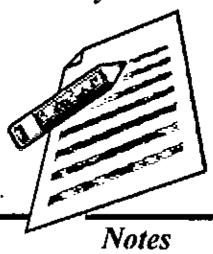
   Answer: (a) product of the slope of the line and charge on the electron

6. Calculate the de Broglie wavelength associated with the electron which has a kinetic energy of 5 eV.
   a. 5.47 Å
   b. 2.7 Å
   c. 5.9 Å
   d. None of the above

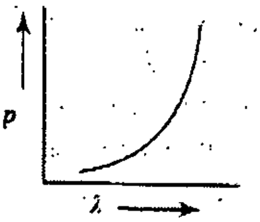
   Answer: (a) 5.47 Å

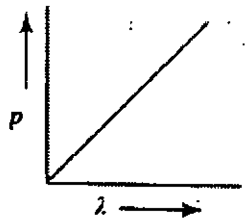
7. What is the ratio of the de Broglie wavelengths proton and an α particle if they are accelerated by the same potential difference?
   a. $2\sqrt{2}$: 1
   b. 3:2
   c. $3\sqrt{2}$: 1
   d. 2: 1

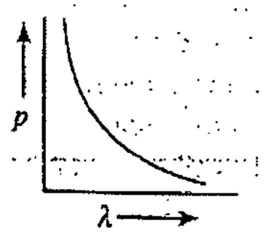
   Answer: (a) $2\sqrt{2}$: 1

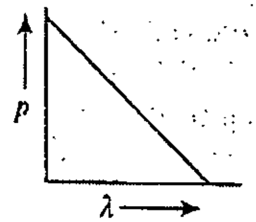


8. Which of the following graphs represent the variation of particle momentum associated with de Broglie wavelength?

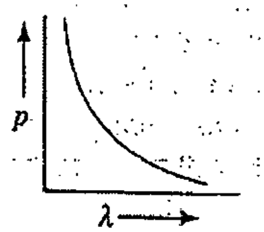
a. 

b. 

c. 

d. 

Answer: (c)



9. By what factor will the de Broglie wavelength change if the K.E if the free electron is doubled?
   a. ½
   b. 12√
   c. 2
   d. 2–√

   Answer: (b) 12√

10. In photoelectric effect what determines the maximum velocity of the electron reacting with the collector?
   a. Frequency of incident radiation alone
   b. The potential difference between the emitter and the collector
   c. The work function of metal
   d. All of these

   Answer: (d) All of these

11. Who among the following established that electric charge is quantised?
   a. R.A. Millikan
   b. Wilhelm Rontgen

c. William Crookes

d. J.J. Thomson

Answer: (a) R.A. Millikan

12. By which of the following physical processes can minimum energy required for the electron emission from the metal surface be supplied to the free electrons?

a. Field emission

b. Thermionic emission

c. Photoelectric emission

d. All of these

Answer: (d) All of these

13. Which of the following statements is true regarding the photoelectric experiment?

a. The stopping potential increases with the increase in the intensity of incident light.

b. The photocurrent increases with the intensity of light.

c. The photocurrent increases with the increase in frequency

d. All of the above

Answer: (b) The photocurrent increases with the intensity of light.

Review Questions

Short Answer type

1. Electrons are emitted from the cathode of a photocell of negligible work function, when photons of wavelength $\lambda\lambda$ are incident on it. derive the expression for the de Broglie wavelength of the electrons emitted in terms of the wavelength of the incident light.

2. Radiations of frequency 10151015 Hz are incident on three photosensitive surfaces A , B and C

Following observations are recorded:

Surface A: No photoemission takes place.

Surface B: Photoemission takes place but photoelectrons have zero energy.

Surface C: Photoemission takes place but photoelectrons have some energy.

Explain the above observations on the basis of Einstein's photoelectric equation.?

3. State how in a photo-cell, the work function of the metal influences the kinetic energy of the emitted electrons.

(a) If the intensity of the incident radiation is doubled, what change occur in (i) the stopping potential and (ii) in photoelectric current?

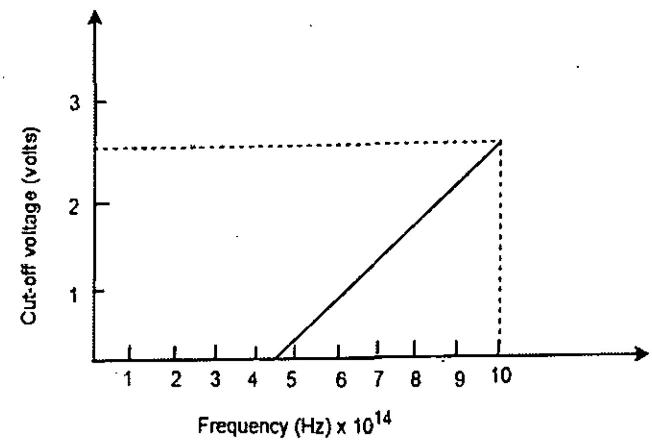
(b) If the frequency of the incident radiation is doubled, what changes occur in the (i) stopping potential and (ii) photoelectric current.

4. An electron and proton have the same de Broglie wavelength. Which one of these has the higher kinetic energy? Which one is moving faster?

5. What is mass of a photon of frequency vv?
6. A particle A with a mass mAmA is moving with a velocity v and hits a particle B (mass mBmB) at rest (one dimensional motion). Find the change in the de Broglie wavelength of the particle A. Treat the collision as elastic

Numerical Questions

1. What is the de Broglie wavelength associated with (i) an electron moving with a speed of 5.4×1065.4×106 m/s and (ii) a ball of mass 1.50 g travelling at 30 m/s
2. For photoelectric effect in sodium, fig. shows the plot of cut-off voltage versus frequency of the incident radiation.

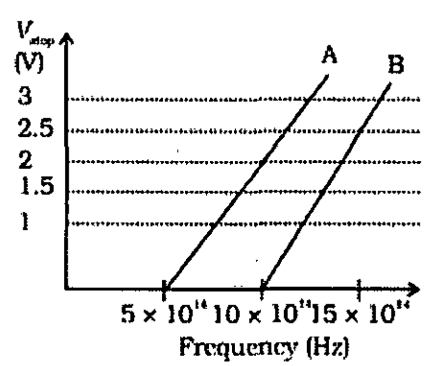


Calculate

i. Threshold frequency

ii. Work function

3. A student performs an experiment on photoelectric effect, using two materials A and B. A plot of V stop vs? is given in below figure



(i) Which material A or B has a higher work function?

(ii) Given the electric charge of an electron = 1.6 \times 10^{-19}

1.6×10−191.6×10−19 C, find the value of h obtained from the experiment for both A and B.

Comment on whether it is consistent with Einstein's theory:

4. Monochromatic light of frequency $6.0\times10146.0\times1014$ Hz is produced by a laser. The power emitted is $2.0\times10-32.0\times10-3$ W.

   (a) What is the energy of a photon in the light beam?

   (b) How many photons per second, on an average, are emitted by the source?

12 ATOMS

- Alpha-particle scattering experiment
- Rutherford's model of atom
- Bohr model
- Energy levels
- Hydrogen spectrum

Objective of the chapter

The main objective of this chapter is to make student understand about the concepts **Atoms** and its related models like Bohr model. Energy levels and Hydrogen spectrum has also been explained in this chapter.

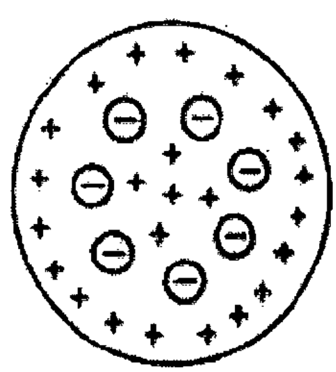
Introduction

Dalton's Atomic Theory

All elements are consisting of very small invisible particles, called atoms. Atoms of same element are exactly same and atoms of different element are different.

Thomson's Atomic Model

Every atom is uniformly positive charged sphere of radius of the order of 10-10 m, in which entire mass is uniformly distributed and negative charged electrons are embedded randomly. The atom as a whole is neutral.



Limitations of Thomson's Atomic Model

1. It could not explain the origin of spectral series of hydrogen and other atoms.
2. It could not explain large angle scattering of α – particles.

Rutherford's Atomic Model

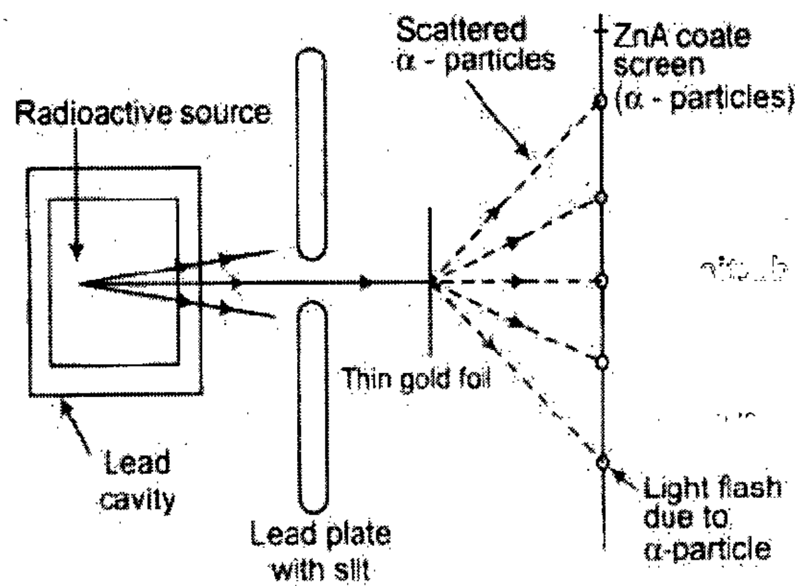
On the basis of this experiment, Rutherford made following observations

(i) The entire positive charge and almost entire mass of the atom is concentrated at its centre in a very tiny region of the order of 10-15 m, called nucleus.

(ii) The negatively charged electrons revolve around the nucleus in different orbits.

(iii) The total positive charge 011 nucleus is equal to the total negative charge on electron. Therefore, atom as an overall is neutral.

(iv) The centripetal force required by electron for revolution is provided by the electrostatic force of attraction between the electrons and the nucleus.



Distance of Closest Approach

ro = 1 / 4π εo . 2Ze2 / Ek

where, Ek = kinetic energy of the cc-particle.

Impact Parameter

The perpendicular distance of the velocity vector of a-particle from the central line of the nucleus, when the particle is far away from the nucleus is called impact parameter.

$$b = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Ze^2 \cot\left(\frac{\theta}{2}\right)}{E_k}$$

Impact parameter

where, Z = atomic number of the nucleus, Ek = kinetic energy of the c-particle and θ = angle of scattering.

Rutherford's Scattering Formula

$$N(\theta)=\frac{N_i\, nt\, Z^2 e^4}{(8\pi\varepsilon_0)^2\, r^2 E^2 \sin^4\left(\frac{\theta}{2}\right)}$$

where, N(θ) =number of c-particles, Ni = total number of α-particles reach the screen. n = number of atoms per unit volume in the foil, Z = atoms number, E = kinetic energy of the alpha particles and t = foil thickness

$$N \propto \frac{1}{\sin^4\left(\frac{\theta}{2}\right)}$$

Limitations of Rutherford Atomic Model

(i) **About the Stability of Atom** According to Maxwell's electromagnetic wave theory electron should emit energy in the form of electromagnetic wave during its orbital motion. Therefore. radius of orbit of electron will decrease gradually and ultimately it will fall in the nucleus.

(ii) **About the Line Spectrum** Rutherford atomic model cannot explain atomic line spectrum.

Bohr's Atomic Model

Electron can revolve in certain non-radiating orbits called stationary or bits for which the angular momentum of electron is an integer multiple of (h / 2π)

mvr = nh / 2π

where n = I, 2. 3,... called principle quantum number.

The radiation of energy occurs only when any electron jumps from one permitted orbit to another permitted orbit.

Energy of emitted photon

hν = E2 – E1

where E1 and E2are energies of electron in orbits.

Radius of orbit of electron is given by

r = n2h2 / 4π2 mK Ze2 □ r □ n2 / Z

where, n = principle quantum number, h = Planck's constant, m = mass of an electron, K = 1 / 4 π ε, Z = atomic number and e = electronic charge.

Velocity of electron in any orbit is given by

v = 2πKZe2 / nh □ v □ Z / n

Frequency of electron in any orbit is given by

v = KZe2 / nhr = 4π2Z2e4mK2 / n3 h3

□ v prop; Z3 / n3

Kinetic energy of electron in any orbit is given by

Ek = 2π2me4Z2K2 / n2 h2 = 13.6 Z2 / n2 eV

Potential energy of electron in any orbit is given by

Ep = – 4π2me4Z2K2 / n2 h2 = 27.2 Z2 / n2 eV

□ Ep = □ Z2 / n2

Total energy of electron in any orbit is given by

E = – 2π2me4Z2K2 / n2 h2 = – 13.6 Z2 / n2 eV

□ Ep = □ Z2 / n2

Wavelength of radiation emitted in the radiation from orbit n2 to n1 is given by

$$\frac{1}{\lambda} = \frac{2\pi^2 mK^2e^4Z^2}{ch^3}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$$\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$$R = \frac{2\pi^2 mK^2e^4Z^2}{ch^3}$$

$$= 1.097 \times 10^7 \text{ m}^{-1}$$

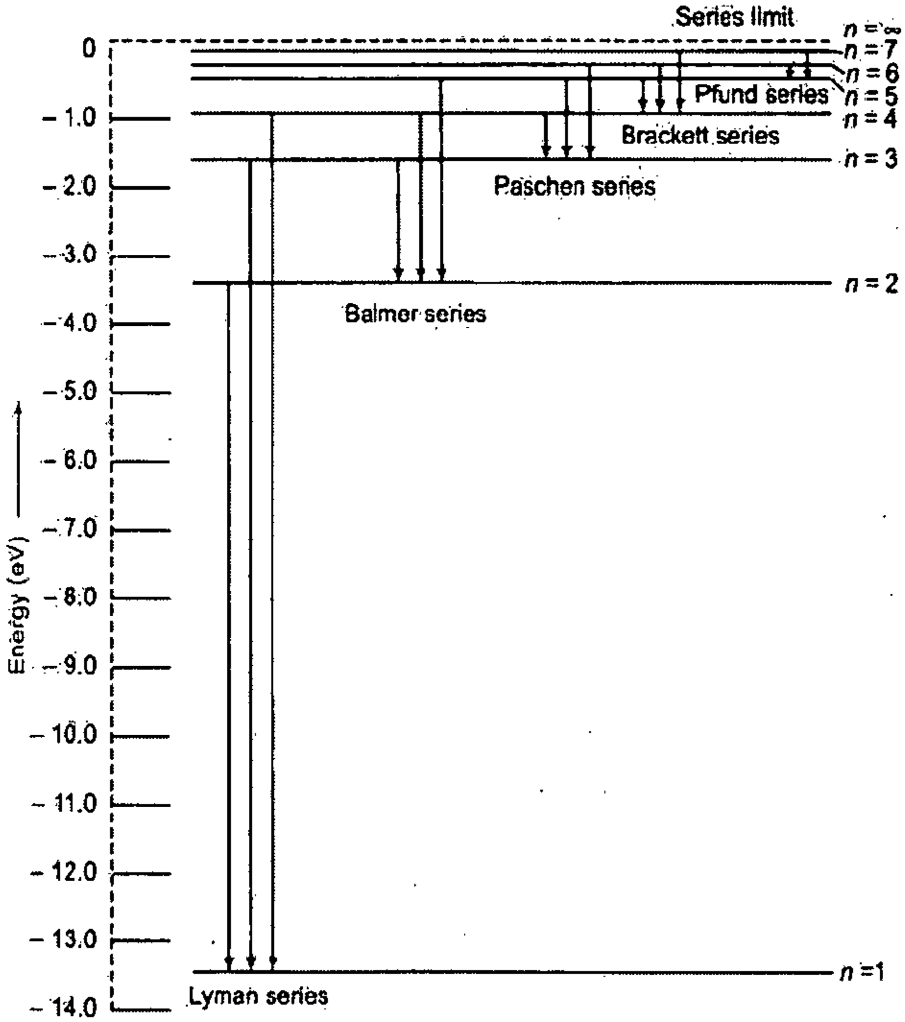
In quantum mechanics, the energies of a system are discrete or quantized. The energy of a particle of mass m is confined to a box of length L can have discrete values of energy given by the relation

En = n2 h2 / 8mL2 ; n < 1, 2, 3,...

Hydrogen Spectrum Series

Each element emits a spectrum of radiation, which is characteristic of the element itself. The spectrum consists of a set of isolated parallel lines and is called the **line spectrum.**

Notes



Hydrogen spectrum contains five series

(i) **Lyman Series** When electron jumps from n = 2, 3,4, …orbit to n = 1 orbit, then a line of Lyman series is obtained.

This series lies in ultra **violet region.**

(ii) **Balmer Series** When electron jumps from n = 3, 4, 5,… orbit to n = 2 orbit, then a line of Balmer series is obtained.

This series lies in **visual region.**

(iii) **Paschen Series** When electron jumps from n = 4, 5, 6,… orbit to n = 3 orbit, then a line of Paschen series is obtained.

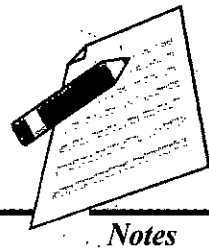
This series lies in **infrared region**

(iv) **Brackett Series** When electron jumps from n = 5,6, 7…. orbit to n = 4 orbit, then a line of Brackett series is obtained.

This series lies in **infrared region.**

(v) **Pfund Series** When electron jumps from n = 6,7,8, … orbit to n = 5 orbit, then a line of Pfund series is obtained.

This series lies in **infrared region.**



Notes

Wave Model

It is based on wave mechanics. Quantum numbers are the numbers required to completely specify the state of the electrons.

In the presence of strong magnetic field, the four-quantum number are

(i) Principle quantum number (n) can have value 1,2, ... ∞

(ii) Orbital angular momentum quantum number l can have value 0,1, 2, ... ,(n – 1).

(iii) Magnetic quantum number (me) which can have values – I to I.

(iv) Magnetic spin angular momentum quantum number (ms) which can have only two value + 1 / 2.

Summary of the unit

1. Both the Thomson's as well as the Rutherford's models constitute an unstable system. Thomson's model is unstable electrostatically, while Rutherford's model is unstable because of electromagnetic radiation of orbiting electrons.
2. What made Bohr quantise angular momentum (second postulate) and not some other quantity? Note, h has dimensions of angular momentum, and for circular orbits, angular momentum is a very relevant quantity. The second postulate is then so natural!
3. The orbital picture in Bohr's model of the hydrogen atom was inconsistent with the uncertainty principle. It was replaced by modern quantum mechanics in which Bohr's orbits are regions where the electron may be found with large probability.
4. Unlike the situation in the solar system, where planet-planet gravitational forces are very small as compared to the gravitational force of the sun on each planet (because the mass of the sun is so much greater than the mass of any of the planets), the electron-electron electric force interaction is comparable in magnitude to the electron nucleus electrical force, because the charges and distances are of the same order of magnitude. This is the reason why the Bohr's model with its planet-like electron is not applicable to many electron atoms.
5. Bohr laid the foundation of the quantum theory by postulating specific orbits in which electrons do not radiate. Bohr's model includes only one quantum number n. The new theory called quantum mechanics supports Bohr's postulate. However, in quantum mechanics (more generally accepted), a given energy level may not correspond to just one quantum state. For example, a state is characterised by four quantum numbers (n, l, m, and s), but for a pure Coulomb potential (as in hydrogen atom) the energy depends only on n.
6. In Bohr model, contrary to ordinary classical expectation, the frequency of revolution of an electron in its orbit is not connected to the frequency of spectral line. The latter is the difference between two orbital energies divided by h. For transitions between large quantum numbers (n to n – 1, n very large), however, the two coincide as expected.

7. Bohr's semi classical model based on some aspects of classical physics and some aspects of modern physics also does not provide a true picture of the simplest hydrogenic atoms. The true picture is quantum mechanical affair which differs from Bohr model in a number of fundamental ways. But then if the Bohr model is not strictly correct, why do we bother about it? The reasons which make Bohr's model still useful are: (i) The model is based on just three postulates but accounts for almost all the general features of the hydrogen spectrum. (ii) The model incorporates many of the concepts we have learnt in classical physics. (iii) The model demonstrates how a theoretical physicist occasionally must quite literally ignore certain problems of approach in hopes of being able to make some predictions. If the predictions of the theory or model agree with experiment, a theoretician then must somehow hope to explain away or rationalise the problems that were ignored along the way.

Multiple choice Questions

1. Balmer series lies in which spectrum?

   (a) visible

   (b) ultraviolet

   (c) infrared

   (d) partially visible, partially infrared

   Answer: (b)

2. In Bohr model of hydrogen atom, let P.E. represents potential energy and T.E. represents the total energy. In going to a higher level.

   (a) P. E. decreases, T.E. increases

   (b) P. E. increases, T.E. decreases

   (c) P. E. decreases, T.E. decreases

   (d) P. E. increases, T.E. increases

   Answer: (d)

3. Which of the following statements is correct in case of Thomson's atomic model?

   (a) It explains the phenomenon of thermionic emission, photoelectric emission and ionisation.

   (b) It could not explain emission of line spectra by elements.

   (c) It could not explain scattering of □-particles

   (d) All of the above

   Answer: (c)

4. Which one did Rutherford consider to be supported by the results of experiments in which α-particles were scattered by gold foil?

   (a) The nucleus of an atom is held together by forces which are much stronger than electrical or gravitational forces.

   (b) The force of repulsion between an atomic nucleus and an α-particle varies with distance according to inverse square law.

   (c) α-particles are nuclei of Helium atoms.

   (d) Atoms can exist with a series of discrete energy levels

   Answer: (b)

5. According to the Rutherford's atomic model, the electrons inside the atom are

   (a) stationary

   (b) not stationary

   (c) centralized

   (d) None of these

   Answer: (b)

6. According to classical theory, the circular path of an electron in Rutherford atom model is
   (a) spiral
   (b) circular
   (c) parabolic
   (d) straight line
   Answer: (a)
7. Rutherford's α-particle experiment showed that the atoms have
   (a) Proton
   (b) Nucleus
   (c) Neutron
   (d) Electrons
   Answer: (b)
8. Electrons in the atom are held to the nucleus by
   (a) coulomb's force
   (b) nuclear force
   (c) Vander Waal's force
   (d) gravitational force
   Answer: (a)
9. The Rutherford α-particle experiment shows that most of the α-particles pass through almost unscattered while some are scattered through large angles. What information does
   (a) Atom is hollow.
   (b) The whole mass of the atom is concentrated in a small centre called nucleus
   (c) Nucleus is positively charged
   (d) All of the above
   Answer: (d)

Review Questions

1. Define ionisation energy. What is its value for a hydrogen atom?
2. Write the expression for Bohr's radius in hydrogen atom.
3. What is the ratio of radii of the orbits corresponding to first excited state and ground state in a hydrogen atom?
4. The radius of innermost electron orbit of a hydrogen atom is 5.3 × 10-11 m. What is the radius of orbit in the second excited state?
5. Find the ratio of energies of photons produced due to transition of an electron of hydrogen atom from its
   (i) second permitted energy level to the first level, and
   (ii) the highest permitted energy level to the first permitted level.

6. The ground state energy of hydrogen atom is -13.6 eV. What are the kinetic and potential energies of electron in this state?
7. Why is the classical (Rutherford) model for an atom—of electron orbiting around the nucleus—not able to explain the atomic structure?
8. When is Ha line of the Balmer series in the emission spectrum of hydrogen atom obtained?
9. What is the maximum number of spectral lines emitted by a hydrogen atom when it is in the third excited state?
10. (i) In hydrogen atom, an electron undergoes transition from 2nd excited state to the first excited state and then to the ground state. Identify the spectral series to which these transitions belong.

    (ii) Find out the ratio of the wavelengths of the emitted radiations in the two cases.

13 NUCLEI

- Composition and size of –
  - Nucleus
  - Atomic masses
  - Isotopes
  - Isobars
  - Isotones
- Radioactivity alpha, beta and gamma particles/rays and their properties
- Radioactive decay law
- Mass-energy relation –
  - Mass defect
  - Binding energy per nucleon and its variation with mass number
  - Nuclear fission
  - Nuclear fusion

Objective of the chapter

The main objective of this chapter is to make student understand about the concepts of **Nuclei** Composition and size. Radioactivity alpha, beta and gamma particles/rays and their properties and Radioactive decay law has also been explained in this chapter.

Introduction

Nucleus

The entire positive charge and nearly the entire mass of atom is concentrated in a very small space called the nucleus of an atom.

The nucleus consists of protons and neutrons. They are called nucleons.

Terms Related to Nucleus

(i) **Atomic Number** The number of protons in the nucleus of an atom of the element is called atomic number (Z) of the element.

(ii) **Mass Number** The total number of protons and neutrons present inside the nucleus of an atom of the element is called mass number (A) of the element.

(iii) **Nuclear Size** The radius of the nucleus R □ A1/3

□ R = Ro A1/3

where, Ro = 1.1 * 10-15 m is an empirical constant.

(iv) **Nuclear Density** Nuclear density is independent of mass number and therefore same for all nuclei.

ρ = mass of nucleus / volume of nucleus □ ρ = 3m / 4π R3o

where, m = average mass of a nucleon.

(v) **Atomic Mass Unit** It is defined as 1 / 12th the mass of carbon nucleus.

It is abbreviated as amu and often denoted by u. Thus

1 amu = 1.992678 * 10-26 / 12 kg

= 1.6 * 10-27 kg = 931 Me V

Isotopes

The atoms of an element having same atomic number but different mass numbers. are called isotopes.

e.g., 1H1, 1H2, 1H3 are isotopes of hydrogen.

Isobars

The atoms of different elements having same mass numbers but different atomic numbers, are called isobars.

e.g., 1H3, 2He3 and 10Na22, 10Ne22 are isobars.

Isotones

The atoms of different elements having different atomic numbers and different mass numbers but having same number of neutrons, are called isotones.

e.g., 1H3, 2He4 and 6C14, 8O16 are isobars.

Isomers

Atoms having the same mass number and the same atomic number but different radioactive properties are called isomers,

Nuclear Force

The force acting inside the nucleus or acting between nucleons is called nuclear force. Nuclear forces are the strongest forces in nature.

- It is a very short-range attractive force.
- It is non-central. non-conservative force.
- It is neither gravitational nor electrostatic force.
- It is independent of charge.
- It is 100 times that of electrostatic force and 1038 times that of gravitational force.

According to the Yukawa, the nuclear force acts between the nucleon due to continuous exchange of meson particles.

Mass Defect

The difference between the sum of masses of all nucleons (M) mass of the nucleus (m) is called mass defect.

Mass Defect $(\Delta m) = M - m = [Zmp + (A - Z)mn - mn]$

Nuclear Binding Energy

The minimum energy required to separate the nucleons up to an infinite distance from the nucleus, is called nuclear binding energy.

Nuclear binding energy per nucleon = Nuclear binding energy / Total number of nucleons

Binding energy, $Eb = [Zmp + (A - Z)\ mn - mN]c2$

Packing Fraction (P)

p = (Exact nuclear mass) – (Mass number) / Mass number

$= M - A / M$

The larger the value of packing friction. greater is the stability of the nucleus.

[The nuclei containing even number of protons and even number of neutrons are **most stable.**

The nuclei containing odd number of protons and odd number of neutrons are **most instable.]**

Radioactivity

The phenomena of disintegration of heavy elements into comparatively lighter elements by the emission of radiations is called radioactivity. This phenomenon was discovered by Henry Becquerel in 1896.

Radiations Emitted by a Radioactive Element

Three types of radiations emitted by radioactive elements

(i) α-rays

(ii) β-rays

(iii) γ – rays

α-rays consists of α-particles, which are doubly ionised helium ion.

β-rays are consisting of fast-moving electrons.

γ – rays are electromagnetic rays.

[When an α – particle is emitted by a nucleus its atomic number decreases by 2 and mass number decreases by 4.

$${}_{Z}X^{A} \xrightarrow{\alpha\text{-particle}} {}_{Z-2}Y^{A-4}$$

When a β -particle is emitted by a nucleus its atomic number is Increases by one and mass number remains unchanged.

$${}_{Z}X^{A} \xrightarrow{\beta\text{-particle}} {}_{Z+1}Y^{A}$$

When a γ – particle is emitted by a nucleus its atomic number and mass number remain unchanged

Radioactive Decay law

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

Rate of disintegration (– dN / dt) □ N

– dN / dt = λ N

where λ is the decay constant.

The number of atoms present undecayed in the sample at any instant N = No e-λt

where, No is number of atoms at time t = 0 and N is number of atoms at time t.

Half-life of a Radioactive Element

The time is which the half number of atoms present initially in any sample decays, is called half-life (T) of that radioactive element.

Relation between half-life and disintegration constant is given by

T = log2e / λ = 0.6931 / λ

Average Life or Mean Life(τ)

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

Relation between average life and decay constant τ = 1 / λ

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

The number of atoms left undecayed after n half-lifes is given by

N = No (1 / 2)n = No (1 / 2) t/T

where, n = t / T, here t = total time.

Activity of a Radioactive Element

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

Activity R = (– dN / dt)

Activity of the sample after time t,

R = Ro e -λt

Its SI unit is Becquerel (Bq).

Its other units are Curie and Rutherford.

1 Curie = 3.7 * 1010 decay/s

1 Rutherford = 106 decay/s

Nuclear Fission

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

When a slow-moving neutron strikes with a uranium nucleus (92U235), it splits into 56Ba141 and 36Kr92 along with three neutrons and a lot of energy.

$${}_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} = 3\,{}_{0}n^{1} + \text{energy}$$

Nuclear Chain Reaction

If the particle starting the nuclear fission reaction is produced as a product and further take part in the nuclear fission reaction, then a chain of fission reaction started, which is called nuclear chain reaction.

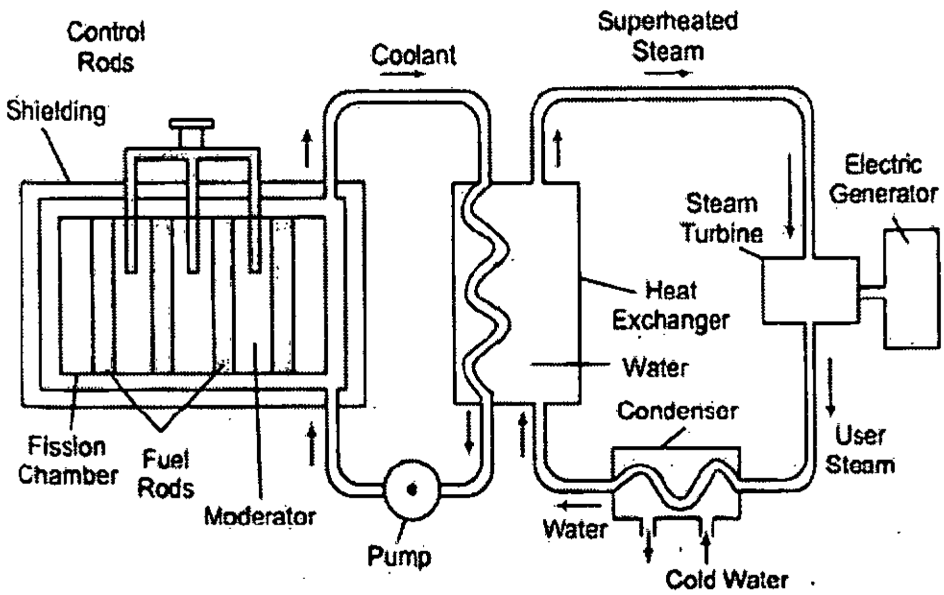
Nuclear chain reactions are of two types

(i) Controlled chain reaction

(ii) Uncontrolled chain reaction

Nuclear Reactor

The main parts of a nuclear reactor are following



(i) **Fuel** Fissionable materials like 92U235, 92U238, 94U239 are used as fuel.

(ii) **Moderator** Heavy water, graphite and beryllium oxide are used to slower down fast-moving neutrons.

(iii) **Coolant** The cold water, liquid oxygen, etc. are used to remove heat generated in the fission process.

(iv) **Control rods** Cadmium or boron rods are good absorber of neutrons and therefore used to control the fission reaction.

Atom bomb working is based on uncontrolled chain reaction.

Nuclear Fusion

The process of combining of two lighter nuclei to form one heavy nucleus, is called nuclear fusion.

Three deuteron nuclei (1H2) fuse, 21.6 MeV is energy released and nucleus of helium (2He4) is formed.

$$ {}_1H^2 + {}_1H^2 + {}_1H^2 \longrightarrow {}_2He^4 + {}_1H^1 + {}_0n^1 + 21.6\ \text{MeV} $$

In this process, a large amount of energy is released.

Nuclear fusion takes place at very high temperature approximately about 107 K and at very high pressure 106 atmosphere.

Hydrogen bomb is based on nuclear fusion.

The source of Sun's energy is the nuclear fusion taking place at sun.

Thermonuclear Energy

The energy released during nuclear fusion is known as thermonuclear energy. Protons are needed for fusion while neutrons are needed for fission process.

Summary of the chapter

1. An atom has a nucleus. The nucleus is positively charged. The radius of the nucleus is smaller than the radius of an atom by a factor of 104. More than 99.9% mass of the atom is concentrated in the nucleus.
2. On the atomic scale, mass is measured in atomic mass units (u). By definition, 1 atomic mass unit (1u) is 1/12th mass of one atom of 12C; 1u = 1.660563 × 10–27 kg.
3. A nucleus contains a neutral particle called neutron. Its mass is almost the same as that of proton
4. The atomic number Z is the number of protons in the atomic nucleus of an element. The mass number A is the total number of protons and neutrons in the atomic nucleus; A = Z+N; Here N denotes the number of neutrons in the nucleus. A nuclear species or a nuclide is represented as X A Z , where X is the chemical

symbol of the species. Nuclides with the same atomic number Z, but different neutron number N are called isotopes. Nuclides with the same A are isobars and those with the same N are isotones. Most elements are mixtures of two or more isotopes. The atomic mass of an element is a weighted average of the masses of its isotopes. The masses are the relative abundances of the isotopes.

5. A nucleus can be considered to be spherical in shape and assigned a radius. Electron scattering experiments allow determination of the nuclear radius; it is found that radii of nuclei fit the formula $R = R_0 A^{1/3}$, where R_0 = a constant = 1.2 fm. This implies that the nuclear density is independent of A. It is of the order of 10^{17} kg/ m^3.

6. Neutrons and protons are bound in a nucleus by the short-range strong nuclear force. The nuclear force does not distinguish between neutron and proton

Multiple choice questions

1. When a β-particle is emitted from a nucleus then its neutron-proton ratio

   (a) increases

   (b) decreases

   (c) remains unchanged.

   (d) may increase or decrease depending upon the nucleus.

   Answer: b

2. The relation between half-life T1/2 of a radioactive sample and its mean life x is

   (*a*) $T_{1/2} = 0.693\,\tau$ (*b*) $\tau = 0.693\,T_{1/2}$

   (*c*) $\tau = T'_{1/2}$ (*d*) $\tau = 2.718\,T_{1/2}$

   Answer: a

3. The quantity which is not conserved in a nuclear reaction is

   (a) momentum.

   (b) charge.

   (c) mass.

   (d) none of these.

   Answer: c

4. The half-life of a radioactive nucleus is 3 hours. In 9 hours, its activity will be reduced to a factor of

   (*a*) $\frac{1}{9}$ (*b*) $\frac{1}{27}$

   (*c*) $\frac{1}{6}$ (*d*) $\frac{1}{8}$

   Answer: d

5. A radioactive element has half-life period 1600 years. After 6400 years what amount will remain?

   (*a*) $\frac{1}{2}$ (*b*) $\frac{1}{16}$

   (*c*) $\frac{1}{8}$ (*d*) $\frac{1}{4}$

   Answer: b

6. Ratio of the radii of the nuclei with mass numbers 8 and 27 would be

   (*a*) $\frac{27}{8}$ (*b*) $\frac{8}{27}$

   (*c*) $\frac{2}{3}$ (*d*) $\frac{3}{2}$

   Answer: c

Review Question's

1. Two nuclei have mass numbers in the ratio 1: 8. What is the ratio of their nuclear radii?
2. A nucleus 23892U92238U undergoes through αα-decay and transforms to thorium. What is
   i. the mass numbers
   ii. atomic number of the daughter nucleus produced?
3. Draw a plot of the binding energy per nucleon as a function of mass number for a large number of nuclei 20 < A < 240. How do you explain the constancy of binding energy per nucleon in the range of 30 < A < 170 using the property that nuclear force is short-ranged?
4. A nucleus with mass number A = 240 and BE/A= 7.6 MeV breaks into two fragments each of A = 120 with BE/ A= 8.5 MeV. Calculate the released energy.
5. How the size of a nucleus is experimentally determined? Write the relation between the radius and mass number of the nucleus. Show that the density of the nucleus is independent of its mass number.
6. Obtain approximately the ratio of the nuclear radii of the gold isotope 19779Au79197Au and the silver isotope 10747Ag47107Ag.

14 SEMICONDUCTOR ELECTRONICS: MATERIALS, DEVICES AND SIMPLE CIRCUITS

- Energy bands in conductors, semiconductors and insulators (qualitative ideas only)
- Semiconductor diode - I-V characteristics in forward and reverse bias, diode as a rectifier
- Special purpose p-n junction diodes: LED, photodiode, solar cell and Zener diode and their characteristics, zener diode as a voltage regulator
- Junction transistor, transistor action, characteristics of a transistor and transistor as an amplifier (common emitter configuration), basic idea of analog and digital signals, Logic gates (OR, AND, NOT, NAND and NOR).

Objective of the chapter

The main objective of this chapter is to make student understand about the concepts of Semiconductor Electronics. Special purpose p-n junction diodes and Junction transistor and basic idea of analog and digital signals has also been explained in this chapter.

Introduction

It is the branch of science which deals with the electron flow through a vacuum, gas or semiconductor.

Classification of substances on the basis of conduction of electricity.

Solid

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

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

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

1. Crystalline Solids

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

Their atoms are arranged in a definite geometrical shape.

They have a definite melting point.

They are anisotropic, i.e., their physical properties such as thermal Conductivity refractive index etc., are different in different directions.

They are the real solids.

2. Amorphous Solids

The Solids in which the atoms do not have a definite arrangement are called the amorphous solids. They are also called the glassy solids. For example, glass, rubber, plastic, power, etc. are the amorphous solids.

They do not have a definite arrangement of its atoms, i e., they do not have a characteristic geometrical shape.

They do not have a definite melting point.

They are isotropic. i.e., their physical properties such as conductivity of heat refractive index etc., are same in all the directions.

They are not the real solids.

Monocrystal and Polycrystalline

Monocrystal is a crystal in which the ordered arrangements of the atoms or molecules extends throughout the piece of solid, irrespective of its size.

Polycrystal is a crystalline solid in which each piece of the solid has a number of monocrystals with developed faces joined together.

The polycrystal ceramic made from PbO, ZnO and TiO are used in gas lighters and telephone receivers.

Liquid Crystals

Some organic crystalline solid. when heated acquire fluidity but retain their anisotropic properties. They are called liquid crystals.

Some liquid crystals like cyanobiphenyl can change the plane of polarization of light and such Liquid Crystal Displays (LCD) are used in watches and micro calculators.

Crystal Lattice

A crystal is made up of a three- dimensional array of points such that each point is surrounded by the height bouring Points in an identical way. Such an array of points is known as bravais lattice or space lattice.

Unit cell is the smallest unit of the crystal lattice, repetition of which in three dimensions gives rise to crystal lattice.

The length of three sides of a unit cell are called Primitives or lattice constant represented by a, b, c. The angles between three crystallographic axes are called interfacial angles represented by α, β and γ. The primitives and interfacial angles constitute the lattice parameters of a unit cell.

[The cubic crystal may be of the form, simple cubic (sc) lattice, the body centred cubic (bee) lattice, the face centred Cubic (fcc) lattice.]

The coordination number is defined as the number of nearest neighbours around any lattice point (or atom) in the crystal lattice.

(a) For sc, coordination number is 6.

(b) For bee, coordination number is 8.

(c) For fcc, coordination number is 12.

(d) For sc, atomic radius is a / 2.

(e) For bcc, atomic is a $\sqrt{3}$ / 4.

(f) For fcc. atomic radius is a / 2$\sqrt{2}$.

Classification of solids on the basis of conductivity

(i) **Conductor** Conductors are those substances through which electricity can pass easily, e.g., all metals are conductors.

(ii) **Insulator** Insulators are those substances through which electricity cannot pass, e.g., wood. rubber, mica etc.

(iii) **Semiconductor** Semiconductors are those substances whose conductivity lies between conductors and insulators. e.g., germanium, silicon, carbon etc.

Energy Bands of Solids

1. **Energy Band**

In a crystal due to interatomic interaction valence electrons of one atom are shared by more than one atom in the crystal. Now splitting of energy levels takes place. The collection of these closely spaced energy levels is called an energy band.

2. **Valence Band**

This energy band contains valence electrons. This band may be Partially or completely filled with electrons but never be empty. The electrons in this band are not capable of gaining energy from external electric field to take part in conduction of current.

3. **Conduction Band**

This band contains conduction electrons. This band is either empty or Partially filled with electrons.

Electrons present in this band take part in the conduction of current.

4. **Forbidden Band**

This band is completely empty. The minimum energy required to shift an electron from valence band to conduction band is called band gap (Eg).

Thermionic Emission

Thermionic emission occurs when a metal is heated to a high temperature, the free electrons in the metal gain kinetic energy sufficient to escape through the surface of the metal.

Thermionic Diode

The thermionic diode is a two electrode (cathode and plate) device based on thermionic emission.

A diode allows unidirectional flow of electrons, i.e., only when the plate is positive with respect to cathode. Hence, it is also called a valve.

The triode value consists of three electrodes, e.g., cathode. Plate and grid enclosed in an evacuated glass bulb.

Grid influences the space charge and controls the flow of plate current.

[When the grid is given a negative potential with respect to cathode. It repels the electrons escaping from the cathode and Increases the effect of space charge, at sufficiently negative grid potential is known as cut-off grid bias.

If the grid is given a positive potential with respect to cathode, it attracts the electrons and decreases the effect of space charge. The increasing the plate current. In this case a current flow into the circuit, thus grid modifies the function of valve.]

Grid is always kept at small negative potential with respect to cathode.

Triode can be used as an amplifier, oscillator modulator and demodulator.

An oscillator is an electronic device which generates AC voltage froID DC power. It is basically a positive feedback amplifier with infinite voltage gain.

Types of Semiconductor

(i) **Intrinsic Semiconductor** A semiconductor in its pure state is called intrinsic semiconductor.

(ii) **Extrinsic Semiconductor** A semiconductor doped with suitable impurity to increase its impurity, is called extrinsic semiconductor.

On the basis of doped impurity extrinsic semiconductors are of two types

(i) **n-type Semiconductor** Extrinsic semiconductor doped with pentavalent impurity like As, Sb, Bi, etc. in which negatively charged electrons works as charge carrier, is called n-type semiconductor.

Every pentavalent impurity atom donates one electron in the crystal; therefore, it is called a doner atom

(ii) **p -type Semiconductor** Extrinsic semiconductor doped with trivalent impurity like Al, B, etc., in which positively charged holes works as charge carriers, is called p-type semiconductor.

Every trivalent impurity atom has a tendency to accept one electron, therefore it is called an acceptor atom.

In a doped semiconductor ne nh = n2i where ne and nh are the number density of electrons and holes and ni is number density of intrinsic carriers, i.e., electrons or holes.

In n-type semiconductor, ne > > nh

In p -type semiconductor, nh > > ne

Electrical conductivity of extrinsic semiconductor is given by

$\sigma = 1 / \rho = e$ (ne μe + nh μh)

where ρ is resistivity, μe and μh are mobility of electrons and holes respectively.

Note Energy gap for Ge is 0.72 eV and for Si it is 1.1 eV.

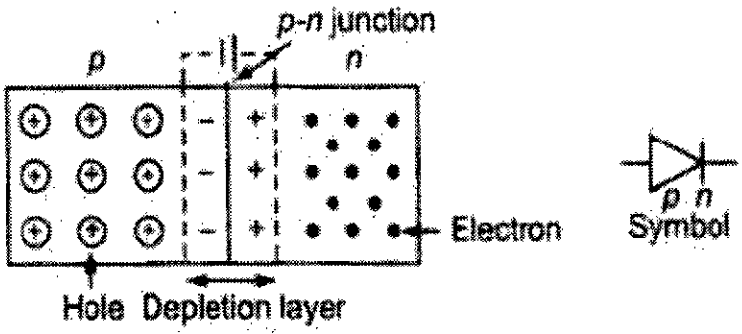
p-n Junction

An arrangement consisting a p -type semiconductor brought into a close contact with n-type semiconductor, is called a p -n junction.

The current in a p-n junction is given by

kB = Io (eeV/k BT – 1)

where Io is reverse saturation current, V is potential difference across the diode, and kB is the Boltzmann constant.



Terms Related to p-n Junction

(i) **Depletion Layer** At p-n. junction a region is created where there are no charge carriers. This region is called depletion layer. The width of this region is of the order of 106 m.

(ii) **Potential Barrier** The potential difference across the depletion layer is called potential barrier.

Barrier potential for Ge is 0.3 V and for Si is 0.7 V.

(iii) **Forward Biasing** In this biasing, the p -side is connected to positive terminal and n-side to negative terminal of a battery.

In this biasing, forward current flows due to majority charge carriers.

The width of depletion layer decreases.

(iv) **Reverse Biasing** In this biasing, the p-side is connected to negative terminal and n-side to positive terminal of a battery.

In this biasing, reverse current flows due to minority charge carriers.

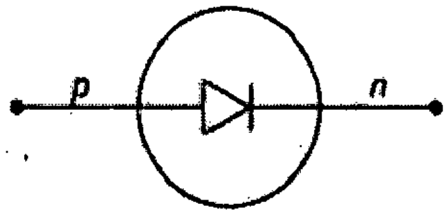
The width of depletion layer increases.

A p-n junction diode can be utilized as a rectifier.

Zener diode, photo-diode, light-emitting diode, etc. are specially designed p-n junction diodes.

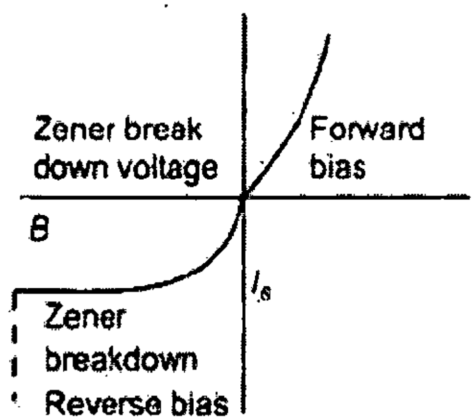
p-n **Junction Diode**

The current through p-n junction flow only from p toward n and not from n toward p.



p-n junction diode

The maximum voltage that a junction diode can bear without break is called zener voltage and the junction diodes possessing this voltage is known as zener diode.



Characteristic curve of *p-n* junction diode

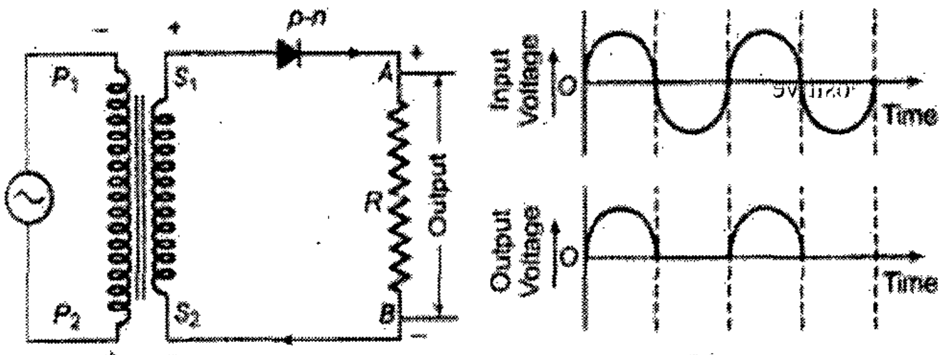
Resistance of diode R = V / I

Rectifier

A device which convert alternating current or voltage into direct current or voltage IS known as rectifier. The process of converting AC into DC IS caned rectification.

Half-Wave Rectifier

A half-wave rectifier converts the half cycle of applied AC signal into DC signal. Ordinary transformer may be used here.

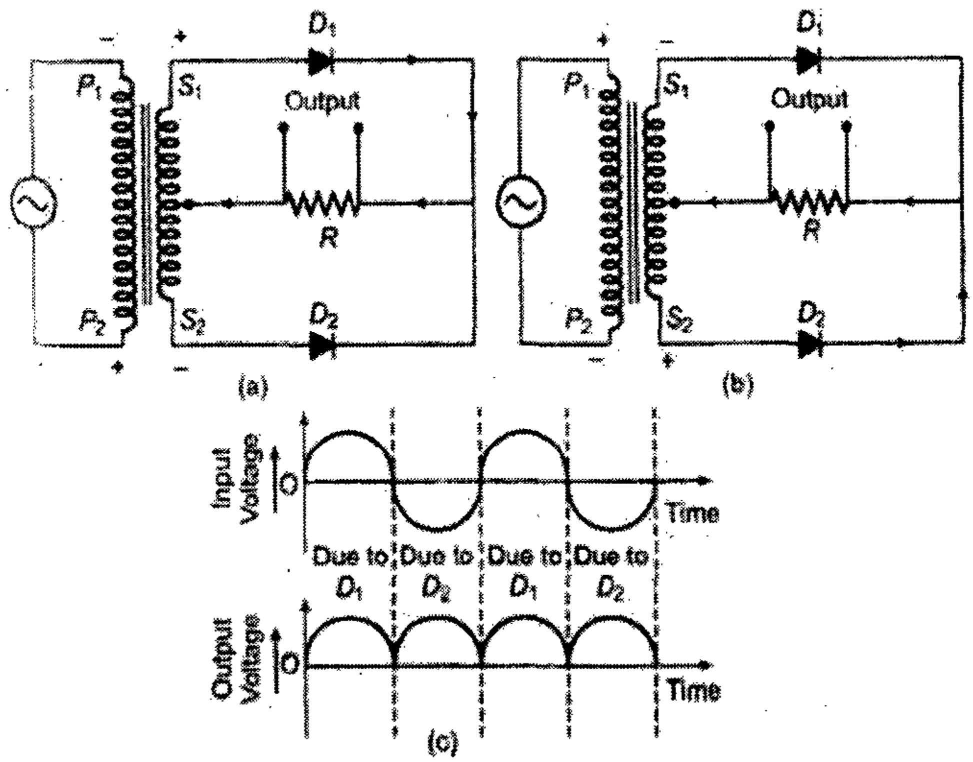


(a) (b)

Full-Wave Rectifier

A full-wave rectifier converts the whole cycle of applied AC signal into DC signal. Centre top, transformer is used here.

[Half-wave rectifier converts only one-half of AC Into DC while full wave rectifier rectifies both halves of AC input.]

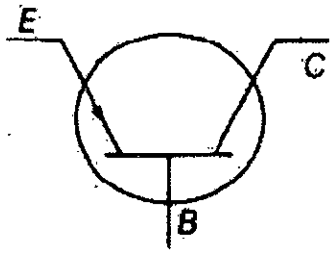


Transistor

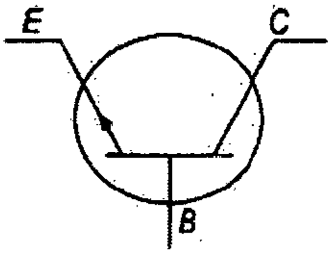
A transistor is an arrangement obtained by growing a thin layer of one type of semiconductor between two thick layers of other similar type semiconductor.

Types of Transistors

(i) *p-n-p* transistor



(ii) *n-p-n* transistor



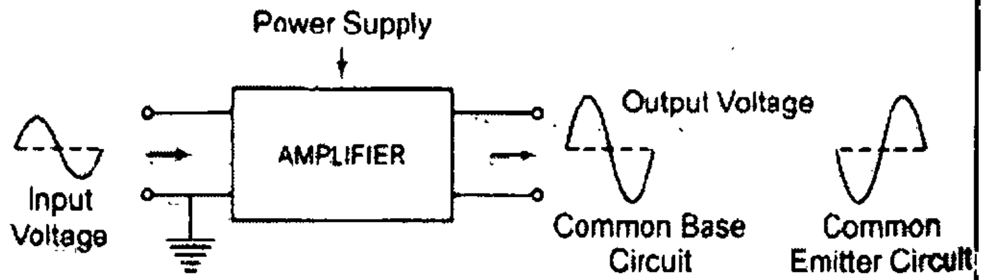
- The left side semiconductor is called emitter, the right side semiconductor is called collector and the thin middle layer is called base.
- Emitter is highly doped and base is feebly doped.
- A transistor can be utilized as an amplifier and oscillator but not a rectifier
- Maximum amplification is obtained in common-emitter configuration.

Transistor as an Amplifier

An amplifier is a device which is used for increasing the amplitude of variation of alternating voltage 01' current or power.

The amplifier thus produces an enlarged version of the input signal.

The general concept of amplification is represented in figure. There are two input terminals for the signal to be amplified and two output terminals for connecting the load; and' a means of supplying power to the amplifier.



1. In Common Base Amplifier,

AC current gain (αAC) = ΔIc / ΔIe

where ΔIc is change in collector current and ΔIe change in emitter current.

AC voltage gain (AV) = Output voltage / Input voltage

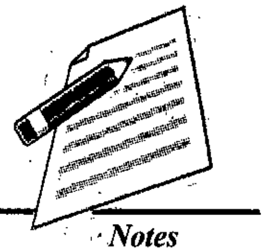
= αAC * Resistance gain = αAC * Ro / Ri

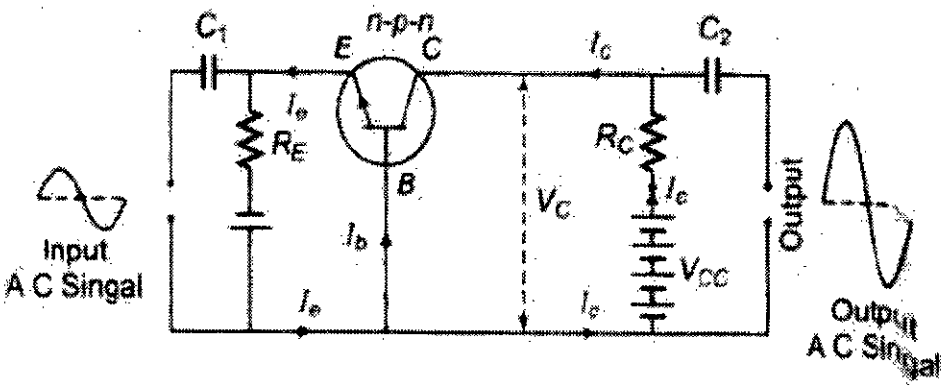
where Ro is output resistance of the circuit and Ri is input resistance of the circuit.

AC power gain = Change in output power / Change in input power

= AC voltage gain * AC current gain

= α2AC * resistance gain





The input and output signals are in the same phase.

There is no amplification in current of a given signal.

There is an amplification in voltage and power of the given signal.

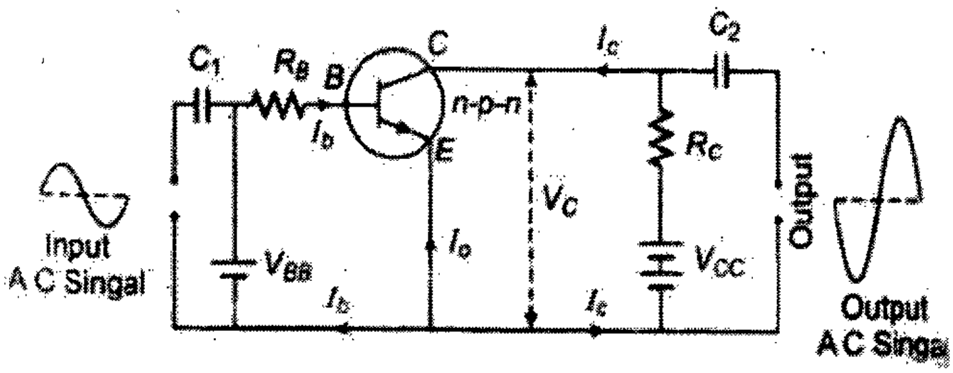
2. In Common Emitter Amplifier

AC current gain (&betaAC) = ΔIc / ΔIe

where ΔIc is change in collector current and ΔIe change in base current.

AC voltage gain (AV) = &betaAC * resistance gain

AC power gain =&beta2AC * Resistance gain



Relation between the current gain of common base and common emitter amplifier.

$\beta = \alpha / 1 - \alpha = Ic / Ie$

The input and output signals are out of phase by π or 180°

There is amplification in current, voltage and power of the given signal.

Light Emitting Diodes (LED)

It is forward biased p-ri junction diode which emits light when recombination of electrons and holes takes place at the junction.

If the semiconducting material of p-ri junction is transparent to light, the light is emitting and the junction becomes a light source, i.e., Light Emitting Diode (LED).

The colour of the light depends upon the types of material used in making the semiconductor diode.

(i) Gallium – Arsenide (Ga-As) – Infrared radiation

(ii) Gallium – phosphide (GaP) – Red or green light

(iii) Gallium – Arsenide – phosphide (GaAsP) – Red or yellow light

Logic Gate

A digital circuit which allows a signal to pass through it, only when few logical relations are satisfied, is called a logic gate.

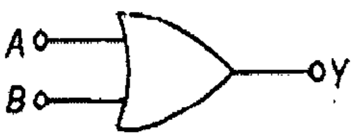
Truth Table

A table which shows all possible input and output combinations is called a truth table.

Basic Logic Gates

(i) OR Gate It is a two input and one output logic gate.

Symbol



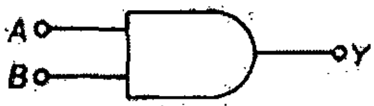
Truth table

A	B	$Y = A + B$
0	0	0
0	1	1
1	0	1
1	1	1

Boolean expression $Y = A + B$ (Y equals A OR B)

(ii) **AND Gate** It is a two input and one output logic gate

Symbol



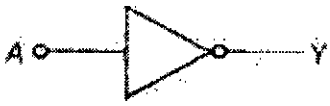
Truth table

A	B	$Y = A \cdot B$
0	0	0
0	1	0
1	0	0
1	1	1

Boolean expression $Y = A \cdot B$ (Y equals A AND B)

(iii) **NOT Gate** It is a one input and one output logic gate.

Symbol



Truth table

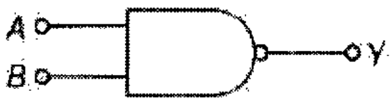
A	$Y=\bar{A}$
0	1
1	0

Boolean expression $Y = \bar{A}$ (Y equals NOT A)

Combination of Gates

(i) **NAND Gate** When output of AND gate is applied as input to a NOT gate, then it is called a NAND gate.

Symbol



Truth table

A	B	$Y=\overline{A \cdot B}$
0	0	1
0	1	1
1	0	1
1	1	0

Boolean expression Y = A * B (Y equals negated of A AND B)

(ii) **NOR Gate** When output of OR gate is applied as input to a NOT gate, then it is called a NOR gate.

Symbol

Truth table

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

Boolean expression Y = A + B (Y equals negated of A OR B)

- The Boolean expression obey commutative law associative law as well as distributive law.
  1. A + B = B+ A
  2. A· B = B· A
  3. A + (B + C) = (A + B) + C
- Demorgan's theorems
  1. A + B = A * B
  2. A * B = A + B

Multiple choice Questions

1. Bonds in a semiconductor:
   (a) trivalent
   (b) covalent
   (c) bivalent
   (d) monovalent
   Answer: (b) covalent
2. Number of electrons in the valence shell of a semiconductor is:
   (a) 1
   (b) 2
   (c) 3
   (d) 4
   Answer: (d) 4
3. Semiconductors of both p-type and n-type are produced by:
   (a) ionic solids
   (b) covalent solids
   (c) metallic solids
   (d) molecular solids
   Answer
   Answer: (b) covalent solids
4. With fall of temperature, the forbidden energy gap of a semiconductor
   (a) increases
   (b) decreases
   (c) sometimes increases and sometimes decreases
   (d) remains unchanged
   Answer: (d) remains unchanged
5. In a p-type semiconductor, current conduction is by:
   (a) atoms
   (b) holes
   (c) electrons
   (d) protons
   Answer: (b) holes
6. The relation between number of free electrons (n) in a semiconductor and temperature (T) is given by:
   (a) n □ T
   (b) n □ T^2
   (c) n □ T1/2
   (d) n □ T3/2
   Answer: (d) n □ T3/2

7. In reverse biasing:
   (a) large amount of current flows
   (b) no current flows
   (c) potential barrier across junction increases
   (d) depletion layer resistance increases
   Answer: (c) potential barrier across junction increases
8. Main function of a transistor is to :
   (a) rectify
   (b) simplify
   (c) amplify
   (d) all the above
   Answer: (c) amplify
9. To obtain p-type silicon semiconductor, we need to dope pure silicon with:
   (a) aluminium
   (b) phosphorus
   (c) oxygen
   (d)germanium
   Answer: (a) aluminium
10. On applying reverse bias to a junction diode, it:
   (a) lowers the potential barrier
   (b) raise the potential barrier
   (c) increases the majority carrier current
   (d) increases the minority carrier current
   Answer: (b) raise the potential barrier

Review Questions

1. State the reason, why GaAs is most commonly used in making of a solar cell.
2. Why should a photodiode be operated at a reverse bias?
3. Give the logic symbol of NOR gate.
4. Give the logic symbol of NAND gate.
5. Give the logic symbol of AND gate.
6. In a transistor, doping level in base is increased slightly. How will it affect
   (i) collector current and
   (ii) base current?
7. What happens to the width of depletion layer of a p-n junction when it is
   (i) forward biased,
   (ii) reverse biased?

15 COMMUNICATION SYSTEMS

- Elements of a communication system (block diagram only)
  - Bandwidth of signals (speech, TV and digital data)
  - Bandwidth of transmission medium
- Propagation of electromagnetic waves in the atmosphere, sky and space wave propagation, satellite communication
- Need for modulation, amplitude modulation and frequency modulation, advantages of frequency modulation over amplitude modulation
- Basic ideas about internet, mobile telephony and global positioning system (GPS).

Objective of the chapter

The main objective of this chapter is to make student understand about the concepts of Elements of a communication system modulation, amplitude modulation and Basic ideas about internet and its applications has also been explained in this chapter.

Introduction

Displacement Current

It is a current which produces in the region in which the electric field and hence the electric flux changes with time.

Displacement current, ID = εo . dφE / dt

where, φE is the electric flux.

Ampere-Maxwell Law

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 (I + I_D)$$

where, μo = Permeability

= 4π * 10-7 V / Am

Maxwell's Equations

(i) $\oint_S \mathbf{E} \cdot d\mathbf{S} = \frac{q}{\varepsilon_0}$

This equation is Gauss's law in electrostatics.

(ii) $\oint_S \mathbf{E} \cdot d\mathbf{S} = 0$

This equation is Gauss's law in magnetostatics.

(iii) $\oint_S \mathbf{E} \cdot d\mathbf{l} = -\frac{d}{dt} \oint_S \mathbf{B} \cdot d\mathbf{S}$

This equation is Faraday's law of electromagnetic induction.

(iv) $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 \left(I + \varepsilon_0 \frac{d\Phi_E}{dt} \right)$

This equation is Ampere-Maxwell law.

Electromagnetic Waves

Electromagnetic waves are those waves in which electric and magnetic field vectors changes sinusoidally and are perpendicular to each other as well as at right angles to the direction of propagation of wave.

The equation of plane progressive electromagnetic wave can be written as E = Eo sin Ω (t – x / c) and B = Bo sin Ω (t – x / c). Where, Ω =2πv

Electromagnetic waves are produced by accelerated charge particles.

Properties of EM Waves

(i) These waves are transverse in nature.

(ii) These waves propagate through space with speed of light, i.e., 3 * 108 m / s.

(iii) The speed of electromagnetic wave,

c = 1 / √μo εo

where, μoo is permittivity of free space,

□ c = Eo / Bo

where Eo and Bo are maximum values of electric and magnetic field vectors.

[According to Maxwell, when a charged particle is accelerated, it produces electromagnetic wave. The total radiant flux at any instant is given by,

p = q2a2 / 6 πεoc2

(iv) The rate of flow of energy in an electromagnetic wave is described by the vector S called the poynting vector, which is ; defined by the expression,

S = 1 / μo E * B

SI unit of Sis watt/m2.

(v) Its magnitude S is related to the rate at which energy is transported by a wave across a unit area at any instant.

(vi) The energy in electromagnetic waves is divided equally between electric field and magnetic field vectors.

(vii) The average electric energy density.

$UE = 1 / 2\ \varepsilon o\ E2 = 1 / 4\ \varepsilon o\ E2o$

(viii) The average magnetic energy density,

$UB = 1 / 2\ B2 / \mu o = 1 / B2o / \mu o$

(ix) The electric vector is responsible for the optical effects of an electromagnetic wave.

(x) Intensity of electromagnetic wave is defined as energy crossing per unit area per unit time perpendicular to the directions of propagation of electromagnetic wave.

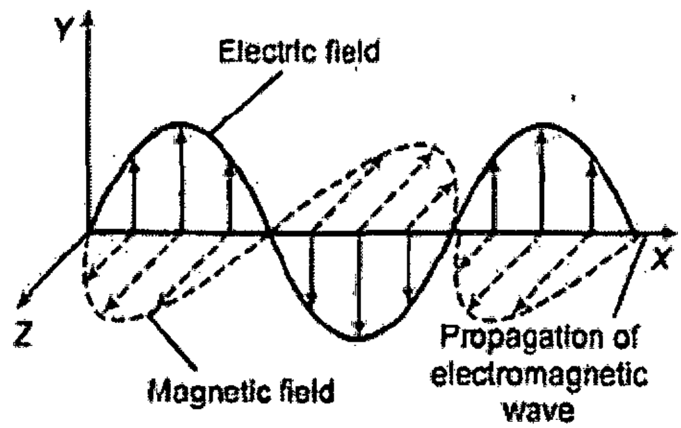
(xi) The intensity I is given by the relation,

$I = < \mu > c = 1 / 2\ \varepsilon o\ E2oc$

(xii) The existence of electromagnetic waves was confirmed by Hertz experimentally in 1888.

Propagation of Electromagnetic Waves

In radio wave communication between two places. the electromagnetic waves are radiated out by the transmitter antenna at one place which travel through the space and reach the receiving antenna at the other place.



Electromagnetic Spectrum

The arranged array of electromagnetic radiations in the sequence of their wavelength or frequency is called electromagnetic spectrum

Radio and microwaves are used in radio and TV communication,

Infrared rays are used to

(i) Treat muscular straw.

(ii) For taking photographs' in fog or smoke.

(iii) In green house to keep plants warm.

(iv) In weather forecasting through infrared photography.

Ultraviolet rays are used

(i) In the study of molecular structure.

(ii) In sterilizing the surgical instruments.

(iii) In the detection of forged documents, £ringer prints.

X-rays are used

(i) In detecting faults, cracks, flaws and holes in metal products.

(ii) In the study of crystal structure.

(iii) For the detection of pearls in oysters.

γ – **rays** are used for the study of nuclear structure.

Earth's Atmosphere

The gaseous envelope surrounding the earth is called earth's atmosphere. It contains the following layers

(i) **Troposphere** This region extends up to a height of 12 km from earth's surface.

(ii) **Stratosphere** This region extends from 12 km to 50 km. In this region, most of the atmospheric ozone is concentrated from 30 to 50 km. This layer is called ozone layer.

(iii) **Mesosphere** The region extends from 50 km to 80 km.

(iv) **Ionosphere** This region extends from 80 km to 400 km.

In ionosphere the electron density is very large in a region beyond 110 km from earth's surface which extends vertically for a few kilometre.

This layer is called **Kennelly Heaviside layer.**

In ionosphere a layer having large electron density is found at height 250 km from earth's surface, called **Appleton layer.**

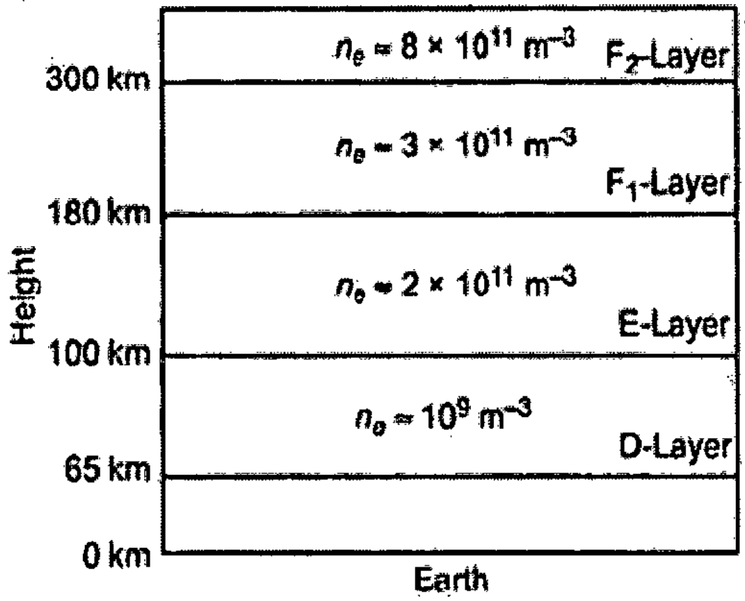
There are four main layers in earth's atmosphere having high density of electrons and positive ions, produced due to ionisation by the high energy particles coming from sun. star or cosmos. These layers play their effective role in space communication. These layers are D, E, F1 and F2.

(i) **D-layer** is at a virtual height of 65 km from surface of earth and having electron density = 109 m-3

(ii) **E-layer** is at a virtual height of 100 km, from the surface of earth, having electron density = 2 * 1011 m-3

(iii) **F1-layer** is at a virtual height of 180 km from the surface of earth, having electron density = 3 * 1011 m-3

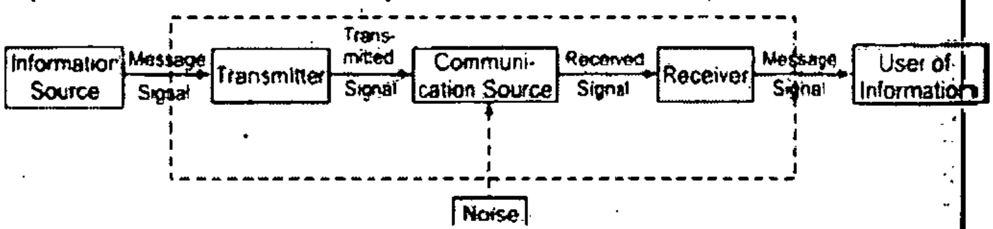
(iv) **F2 – layer** is at a vertical height of about 300 km in night time and about 250 to 400 km in day time. The electron density of this layer is = 8 * 1011 m-3



Communication

Faithful transmission of information from one place to another place is called communication.

Optical fibres are used in optical communication.



Communication System

A communication system contains three main parts

(i) **Transmitter** It process and encode the information and make it suitable for transmission.

The message signal for communication can be analog signals or digital signals.

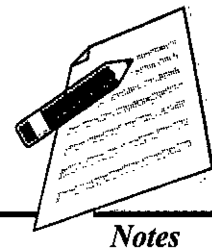
An analog signal can be converted suitably into a digital signal and vice-versa.

[An analog signal is that in which current or voltage value varies continuously with time.

A digital signal is a discontinuous function of time. Such a signal is usually in the form of pulses.]

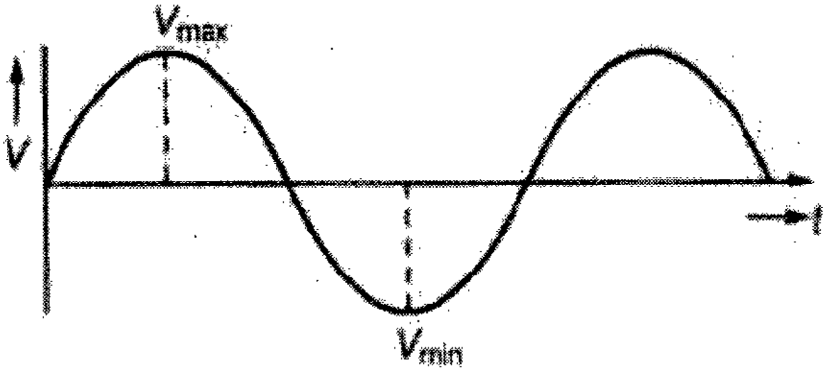
(ii) **Communication Channel** The medium through which information propagate from transmitter to receiver 1S called communication channel.

(iii) **Receiver** It receives and decode the signal.



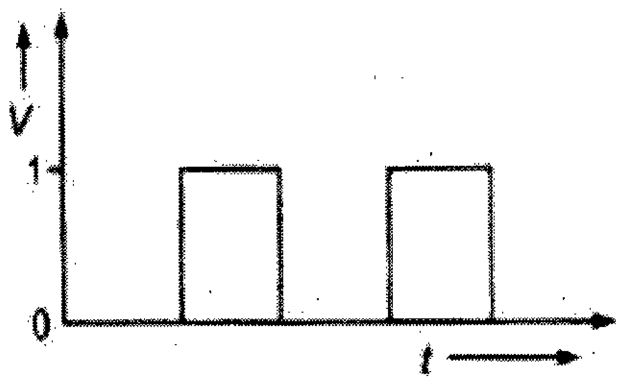
Analog Signal

A signal in which current or voltage changes its magnitude continuously with time, is called an analog signal.



Digital Signal

A signal in which current or voltage have only two values, is called a digital signal.



Note An analog signal can be converted suitable into a digital signal and vice-versa.

Modulation

The process of superimposing the audio signal over a high frequency carrier wave is called modulation.

In the process of modulation anyone characteristic of carrier wave is varied in accordance with the instantaneous value of audio signal (modulating signal).

Need of Modulation

(i) Energy carried by low frequency audio waves (20 Hz to 20000 Hz) is very small.

(ii) For efficient radiation and reception of signal. the transmitting and receiving antennas should be very high approximately 5000 m.

(iii) The frequency range of audio signal is so small that overlapping of signals create a confusion.

Types of Modulation

(i) **Amplitude Modulation** In this type of modulation, the amplitude of high frequency carrier wave is varied in accordance to instantaneous amplitude of modulating signal.

Band width required for amplitude modulation

= twice the frequency of the modulating signal.

(ii) **Frequency Modulation** In this type of modulation, the frequency of high frequency carrier wave is varied in accordance to instantaneous frequency of modulating signal.

(iii) **Pulse Modulation** In this type of modulation, the continuous waveforms are sampled at regular intervals. Information is transmitted only at the sampling times.

Demodulation

The process of separating of audio signal from modulated signal is called demodulation.

Antenna

An antenna converts electrical energy into electromagnetic waves at transmitting end and pick up transmitted signal at receiving end and converts electromagnetic waves into electrical signal.

Modem

The term modem is contraction of the term modulator and demodulator. Modem is a device which can modulate as well as demodulate the signal. It connects one computer to another through ordinary telephone lines.

Fax (Facsimile Telegraphy)

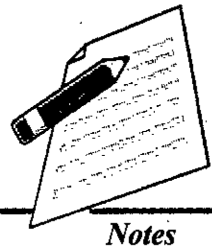
The electronic reproduction of a document at a distant place is called FAX

Radio Waves

The radio waves are the electromagnetic waves of frequency ranging from 500 kHz to about 1000 MHz. These \V8VeS are used In the field of radio communication. With reference to the frequency range and wavelength range, the radio waves have been divided into various categories shown in table.

Frequency Range and Wavelength Range of Radio Waves

S.No.	Frequency band	Frequency range	Wavelength range	Main Use
1.	Very-Low Frequency (VLF)	3 kHz to 30 kHz	10 km to 100 km	Long distance point to point communication
2.	Low Frequency (LF)	30 kHz to 300 kHz	1 km to 10 km	Marine and navigational purposes

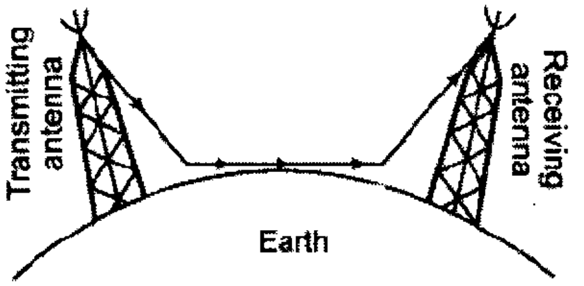


3.	Medium Frequency (MF)	300 kHz to 3 MHz	100 m to 1 km	Marine and broadcasting purposes
4.	High Frequency (HF)	3 MHz to 30 MHz	10 m to 100 m	Communication of all types.
5.	Very-High Frequency (VHF)	30 MHz to 300 MHz	1 m to 10 m	T V Radar and air navigation
6.	Ultra-High Frequency (UHF)	300 MHz to 3000 MHz	10 cm to 1 m	Radar and microwave communication
7.	Super-High-Frequency (SHF)	3 GHz to 30 GHz	1 cm to 10 cm	Radar, Radio relays and navigation purposes
8.	Extremely-High - Frequency (EHF)	30 GHz to 300 GHz	1 mm to 1 cm	Optical fibre communication

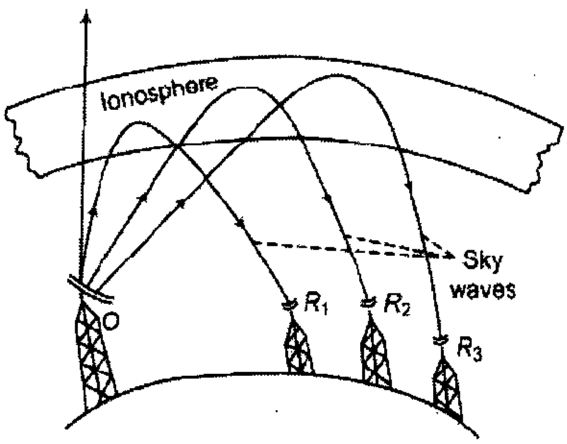
Propagation of Radio Waves

The three modes are discussed below.

(i) **Ground Wave or Surface Wave Propagation** It is suitable for low and medium frequency up to 2 MHz. It is used for local broad casting.



(ii) **Sky Wave Propagation** It is suitable for radio waves of frequency between 2 MHz to 30 MHz. It is used for long distance radio communication.



Critical Frequency The highest frequency of radio wave that can be reflected back by the ionosphere is called critical frequency.

Critical frequency, vc = 9 (Nmax)1 / 2

Where, Nmax = number density of electrons/metre3.

Skip Distance The minimum distance from the transmitter at which a sky wave of a frequency but not more than critical frequency, is sent back to the earth.

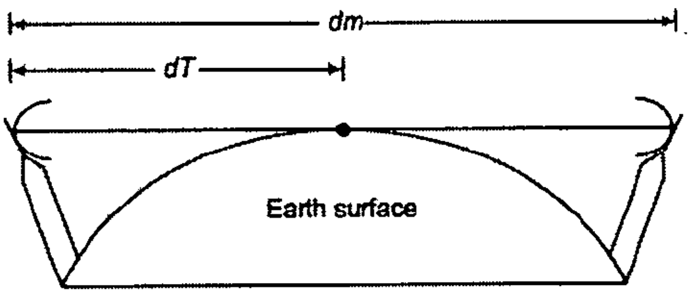
Skip distance (Dskip) = 2h (Vmax / Vc)2 – 1

where h is height of reflecting layer of atmosphere,

Vmax is maximum frequency of electromagnetic waves and Vc is critical frequency.

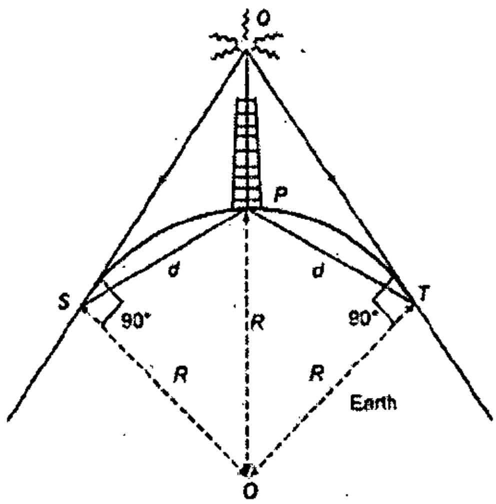
Fading The variation in the strength of a signal at receiver due to interference of waves, is called fading.

(iii) **Space Wave Propagation** It is suitable for 30 MHz to 300 MHz. It is used in television communication and radar communication. It is also called line of sight communication.



- Range is limited due to curvature of earth. If h be the height of the transmitting antenna, then signal can be received upto a maximum distance
  d = √2RH
- If height of transmitting and receiving antennas be hT and hR respectively. The effective range will

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



Microwave Propagation

- Microwaves are electromagnetic wave of frequency 1 to 300 GHz, greater than those of TV signals. The wavelength of microwaves is of the order of a few mm.
- Microwave communication is used in radar to locate the flying objects In space.
- These waves can be transmitted as beam signals in a particular direction, much better than radio wave,
- There is no diffraction of microwave around corners of an obstacle which happens to lie along its passage.

Satellite Communication

It IS carried out between a transmitter and a receiver through a satellite. A geostationary satellite is utilized for this purpose, whose time period is 24 hours.

A communication satellite is a space craft, provided with microwave receiver and transmitter. It is placed in an orbit around the earth. The India remote sensing satellites are

IRS-IA, IRS-IB and IRS-IC

The line-of-sight microwave communication through satellite is possible if the communication satellite is always at a fixed location with respect to the earth, e.g., the satellite which is acting as a repeater must be at rest with respect to the earth. It is so far a satellite known as geo-stationary satellite.

The basic requirements for geostationary satellites are as follows:

1. The time period of revolution of the satellite around the earth is equal to the time period of rotation of earth about its polar axis i.e., 24 h.
2. The sense of revolution of the satellite around the earth is the same as that of the earth about its polar axis i.e., from west to east.
3. The orbital plane of revolution of satellite is concentric and coplanar with the equatorial plane of earth.
4. The height of geostationary satellite above the equator of earth is nearly 36000 km and its orbital velocity is nearly 3.1 km/s.

The orbit in which the gee-satellite above revolves around the earth is known as geo-synchronous orbit. As its angular speed is synchronised with the angular speed of the earth. therefore, the geo-stationary satellite is also known as geo-synchronous satellite.

Merits of Satellites Communication

1. The satellite communication covers wide area for broadcasting a8 compared to other communication systems i.e. it has wide coverage range.
2. The satellite communication is also used effectively in mobile communication.
3. The satellite communication is found to be much economical as compared to other communication systems on earth. In fact. the cost involved in satellite communication is independent of the distance.

4. The satellite communication is most cost effective in remote and hilly areas, such as Ladakh, Himachal Pradesh etc.
5. The satellite communication permits transmission of data at rate.
6. The satellite communication is very accurate and economical search. rescue and navigation purposes.

Demerits of Satellite Communication

1. If a system on the satellite goes out of order due to environmental stresses, it is almost impossible to repair it.
2. In satellite communication, there is a time delay between transmission and reception, due to extremely large communication path length (greater than 2 x 36000 km). This delay causes a time gap during talking, which proves quite annoying.

Remote Sensing

It is a technique of observing or measuring the characteristics of the object at a distance. A polar satellite is utilized for this purpose.

Distance up to which a signal can be obtained from an antenna is given by

$d = \sqrt{2hR}$

where, h is height of antenna and R is radius of earth.

LED and Diode Laser in Communication

Light Emitting. Diode (LED) and diode laser are preferred sources for optical communication links to the following features.

1. Each produces light of suitable power required in optical communication. Diode laser provides light which is monochromatic and coherent. This light is obtained as a parallel beam. It is used in very long-distance transmission.
2. LED provides almost monochromatic light. This suitable for small distance transmission. It is in fact, a low-cost device as compared to diode lasers.

Line Communication

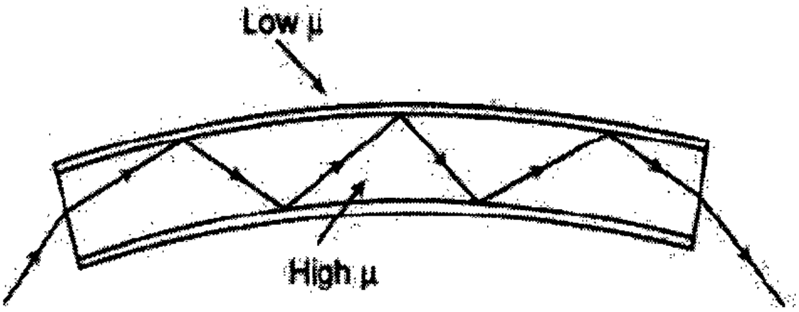
- Transmission lines are used to interconnect points separated from each other. For example, interconnection between a transmitter and a receiver or a transmitter and antenna or an antenna and a receiver are achieved through transmission lines.
- Line communication may be in the form of electrical signal or optical signal.

Optical Fibres

An optical fibre is a long thread consisting of a central core of glass or plastic of uniform refractive index. It is surrounded by a cladding of material of refractive index less than that of the core and a protective Jacket of insulating material.

There are three types of optical fibre configuration

1. Single mode step index fibre
2. Multi-mode step index fibre
3. Multi-mode graded index fibre.



Applications of Optical Fibres

1. A bundle of optical fibres is called light pipe. This pipe can transmit as image. Since the pipe is flexible, it can be twisted in any desired manner. Hence it is used medical and optical examination of even the inaccessible parts of human body, e.g., in endoscopy.
2. Optical fibres are used in transmission and reception of electrical signals by converting them first into light signals.
3. Optical fibres are used in telephone and other transmitting cables. Each fibre can carry up to 2000 telephone messages without much loss of intensity.

Summary of the unit

1. Electronic communication refers to the faithful transfer of information or message (available in the form of electrical voltage and current) from one point to another point.
2. Transmitter, transmission channel and receiver are three basic units of a communication system.
3. Two important forms of communication system are: Analog and Digital. The information to be transmitted is generally in continuous waveform for the former while for the latter it has only discrete or quantised levels.
4. Every message signal occupies a range of frequencies. The bandwidth of a message signal refers to the band of frequencies, which are necessary for satisfactory transmission of the information contained in the signal. Similarly, any practical communication system permits transmission of a range of frequencies only, which is referred to as the bandwidth of the system.
5. Low frequencies cannot be transmitted to long distances. Therefore, they are superimposed on a high frequency carrier signal by a process known as modulation.

6. In modulation, some characteristic of the carrier signal like amplitude, frequency or phase varies in accordance with the modulating or message signal. Correspondingly, they are called Amplitude Modulated (AM), Frequency Modulated (FM) or Phase Modulated (PM) waves.
7. Pulse modulation could be classified as: Pulse Amplitude Modulation (PAM), Pulse Duration Modulation (PDM) or Pulse Width Modulation (PWM) and Pulse Position Modulation (PPM).
8. For transmission over long distances, signals are radiated into space using devices called antennas. The radiated signals propagate as electromagnetic waves and the mode of propagation is influenced by the presence of the earth and its atmosphere. Near the surface of the earth, electromagnetic waves propagate as surface waves. Surface wave propagation is useful up to a few MHz frequencies

Multiple choice Questions

1. Who undertook the first space walk and in which year?

   (a) Leonov 1965

   (b) Neil Armstrong, 1969

   (c) Rakesh Sharma. 1998

   (d) None of these

   Answer: (a) Leonov 1965

2. The term used "to collect the information about an object and a place without physical contact" is called :

   (a) modulation

   (b) communication

   (c) amplification

   (d) remote sensing

   Answer: (d) remote sensing

3. The velocity of electromagnetic wave is:

   (a) 3×105 ms-1

   (b) 3×106 ms-1

   (c) 3×108 ms-1

   (d) 3×1010 ms-1

   Answer: (c) 3×108 ms-1

4. The audio frequencies range from:

   (a) 20 Hz to 20.000 kHz

   (b) 20 Hz to 20 kHz

   (c) 20 kHz to 20.000 kHz

   (d) None of these

   Answer: (b) 20 Hz to 20 kHz

5. The wavelength of a wave of frequency 10 kHz is:

   (a) 30 m

   (b) 300 m

   (c) 30 km

   (d) 300 km

   Answer: (c) 30 km

6. The area served by an antenna of height 100 m is:

   (a) $109 m^2$

   (b) 4×109 m^2

   (c) $6 \times 109 m^2$

   (d) $8 \times 1010 m^2$

   Answer: (b) 4×109 m^2

7. Which of the following is not transducer?
   (a) Loudspeaker
   (b) Amplifier
   (c) Microphone
   (d) All
   Answer: (b) Amplifier
8. The space waves which are affected seriously by atmospheric conditions are:
   (a) MF
   (b) HUF
   (c) VHF
   (d) UHF
   Answer: (d) UHF
9. An antenna is:
   (a) Inductive
   (b) Capacitive
   (c) Resistive
   (d) A transformer
   Answer: (a) Inductive
10. Broadcasting antenna are generally:
   (a) Ommi directional type
   (b) Vertical type
   (c) Horizontal type
   (d) None
   Answer: (b) Vertical type

Review Questions

1. Write the function of a transducer and Repeater in the context of communication systems
2. (i)What is modulation and Write few factors justifying the need of modulation for transmission of a signal?
   (ii)Write two advantage of frequency modulation over amplitude modulation
3. (i)How can a rectangular wave be generated from superimposition of the sinusoidal waves?
   (ii) What is Ionosphere? Explain its importance in Communication
4. Explain and draw the schematic diagram for the following propagation. Give two examples of each of them also
   (i) Ground wave
   (ii) Sky wave
   (iii) Space Wave
   Why is the sky wave mode propagation restricted to frequencies up to 40mHz?

5. Draw a block diagram of a detector for AM signal and show using necessary processes and the waveforms. How the original message signal is detected from the Input AM wave?
6. Draw the block diagram of the generalized communication system. Write the function of the each of the following
   (i)Transmitter
   (ii)Channel
   (iii)Receiver
7. What is pulse modulation? Describe the various type of pulse modulation with the help of suitable diagram
8. Define the terms carrier swing, modulation index, and bandwidth in connection with F.M?
9. Define the terms modulation index for an AM wave. What would be the modulation index for an AM wave for which the maximum amplitude is 'a' and the minimum amplitude is 'b'?

Short Answer type

1. Write the functions of the following in communication systems:
   (i) Transmitter
   (ii) Modulator
2. Why are high frequency carrier waves used for transmission?
3. Distinguish between 'Analog and Digital signals'.
4. Deduce an expression for the distance up to which the T.V signals can directly be received from a T.V tower of height H?

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