

1 ELECTRIC CHARGE

Positive and negative charges were named by Benjamin Franklin.

Charging can be done by

1. Friction
2. Induction
3. Conduction

Charging by friction

When glass rod is rubbed with silk, the rod acquires one type of charge and silk acquires other type of charge.

2 PROPERTIES OF CHARGES

- Two types of charges exist.
- Like charges repel unlike attract.
- A body is charged by loss or gain of electrons.
- In an isolated systems, total charge remains conserved.
- Charge exists in discrete nature. $q = \pm n \times e$
- Moving charge has magnetic effects along with electric effects.

3 CONDUCTORS AND INSULATORS

- Some substances which readily allow passage of electricity through them are called conductors
- Metals, human body and earth are conductors.
- Materials which opposes flow of charge through them are insulators.
- Glass, porcelain, plastic, nylon, wood etc are insulators.

Earthing

A process of sharing charges with earth is called grounding or earthing

- Accelerating charges emit radiations.
- Gold leaf electroscope detects charge on a body.
- Charge is scalar and additive in nature.

4 CHARGES INTERACTION

Coulomb's law is quantitative statement about force between two point charges.

- Force varies inversely as square of distance between the charges and directly proportional to product of magnitude to two charges and acts along the line joining two charges
- Two charges q_1 and q_2 separated by distance r in vacuum, the magnitude of force (F) between them

$$F = K \frac{|q_1 q_2|}{r^2}$$

K depends on system of units and medium. In SI unit in vacuum $K = 9 \times 10^9$. Unit of charge is coulomb(C)

$$F = \frac{1}{4\pi\epsilon_0} \frac{(q_1 q_2)}{r^2}, \epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2 \text{N}^{-1} \text{m}^{-2}$$

5 FORCE BETWEEN MULTIPLE CHARGES

Force on any charge due to number of other charges is the vector sum of all the forces on that charge due to the other charges, taken one at a time, the individual forces are unaffected by presence of other charges. This is termed as superposition principle of electrostatics. Vector sum of forces is obtained by parallelogram law of addition of vectors. Force on first charge due to other

$$\vec{F}_1 = \frac{q_1}{4\pi\epsilon_0} \sum_{i=2}^n \frac{q_i}{r_{1i}^2} \hat{r}_{1i}$$

6 ELECTRIC FIELD OF GHARGES

- A charge placed at a point produces an electric field everywhere in the surrounding. When another charge is brought in field, field there acts on it and produces a force. Faraday introduced field concept.
- Electric field intensity produced by a charge Q at a point distance r is given by
- SI unit of electric field is N/C. Field intensity at a point due to charge Q in space is defined as the force that a unit positive charge would experience if placed at that point.

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

$$\vec{E} = \lim_{q \rightarrow 0} \left(\frac{\vec{F}}{q} \right)$$

- Field vary from point to point and is a vector quantity. Field can transport energy.

Field Due to System of Charges

Electric field at a point P in space due to system of charges is defined as force experienced by a unit test charge placed at that point

$$\vec{E}(r) = \frac{1}{4\pi\epsilon_0} \sum_{i=1}^n \frac{q_i}{r_{ip}^2} \hat{r}_{ip}$$

7 ELECTRIC DIPOLE

- An electric dipole is an arrangement of pair of equal and opposite point charges separated by a distance.
- Direction from $-q$ to $+q$ is direction of dipole moment.

Electric fields due to dipole

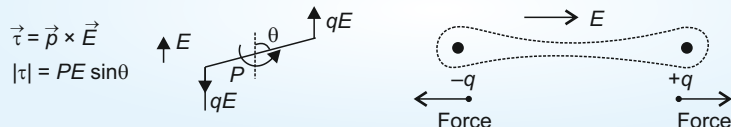
On Axis of Dipole

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{2\vec{p}r}{(r^2 - a^2)^2} \approx \frac{1}{4\pi\epsilon_0} \frac{2\vec{p}}{r^3} \text{ (if } r \gg a)$$

On Equatorial Plane

$$\vec{E} = \frac{-1}{4\pi\epsilon_0} \frac{\vec{p}}{(r^2 + a^2)^{3/2}} \approx \frac{-1}{4\pi\epsilon_0} \frac{\vec{p}}{(r^3)} \text{ (if } r \gg a)$$

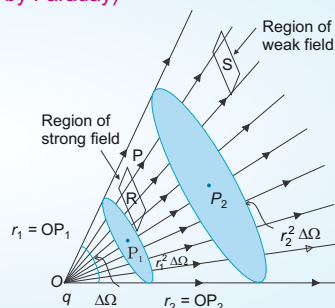
- Polar molecule : H_2O have permanent electric dipole moment even in absence of electric field.
- Non polar molecule : CH_4 , CO_2 . The Dipole moment is zero.
- A dipole in external uniform electric field experience torque but no net force.



8 ELECTRIC FIELD LINES

(Lines of force by Faraday)

Field lines carry information about direction of electric field at different points in space. Relative density of field lines at different points indicates relative strength of electric fields at these points. Faraday introduced non mathematical way of visualizing electric field around charge configuration.



9 ELECTRIC FIELD LINES PROPERTIES

- It is a way of pictorially mapping the electric field around a configuration of charges.
- A line is a curve drawn in such a way that tangent to it at each point is in the direction of net field at that point.
- A field line is a space curve (A curve in three dimension)
- Field lines of a single positive charge are radially outward.
- Field lines start from positive charges and end at negative charges.
- From a single charge, line can start from or end at infinity.
- In a charge free region, electric field lines can be taken to be continuous curves without any breaks.
- Two field lines can never cross each other.
- Electrostatic field lines don't form any closed loop. This follows from their conservative nature.

10 ELECTRIC FLUX

- Similar to fluid flow an analogous quantity exists in electrostatic called electric flux. There is no flow of observable quantity.
- The number of (field) lines crossing a unit area placed normal to field at a point is measure of strength of electric field at that point.
- Number of field lines crossing ΔS area is proportional to $E\Delta S\cos\theta$. This is called electric flux through area element ΔS .

$$\Delta\phi = \vec{E} \cdot \vec{\Delta S} = E\Delta S \cos\theta$$

θ = angle between \vec{E} and outward drawn normal to area element $\vec{\Delta S}$.

- Units : $NC^{-1}m^2$
- Total flux $\phi \approx \sum \vec{E} \cdot \vec{\Delta S}$
Approximate sign is because electric field is taken uniform over area element.
If $\Delta S \rightarrow 0$ then, $\phi = \int \vec{E} \cdot d\vec{s}$

11 GAUSS'S LAW

- Total electric flux through closed surface $s = \frac{q}{\epsilon_0}$, where q = Total charge enclosed by s
- Total flux is zero if closed surface encloses no charge.
- Gauss law is true for any surface, no matter what its shape or size is.
- q is total charge enclosed by surface, located anywhere inside.
- Gaussian surface should not pass through discrete charges.
- Any violation of Gauss's law will indicate departure of inverse square law.

Application of Gauss's law

- Electric field due to infinitely long wire
 $E = \frac{\lambda}{2\pi\epsilon_0 r}$, at distance r from linearly charged rod.
- Field of Uniformly Charged Shell
- Electric field due to infinite plane sheet
 $\vec{E} = \frac{\sigma}{2\epsilon_0} \hat{n}$ is independent of distance from sheet.
Directed out for $q > 0$, directed inwards for $q < 0$
 $E = 0$ ($r < R$) field is zero inside shell.

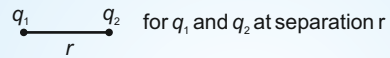
1 ELECTROSTATIC POTENTIAL ENERGY

- Work done by external force in moving a charge against electrostatic repulsive force gets stored in it as potential energy.
- Electric potential energy difference between two points is work required to be done by an external force in slowly moving charge from one point to another against electric field of any charge configuration.
- Potential energy of a charge at a point in electric field due to any charge configuration, is the work done by external force in slowly bringing the charge from infinity to that point.

$$U = \int_{\infty}^r \vec{F}_{\text{ext}} \cdot d\vec{r} = - \int_{\infty}^r \vec{F}_E \cdot d\vec{r}$$

2 POTENTIAL ENERGY OF A SYSTEM OF CHARGES

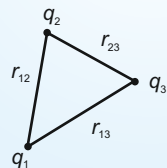
- For assembly of two charges



$$U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r} \quad (\text{Depends on charge nature})$$

- For assembly of three charges

$$U = \frac{1}{4\pi\epsilon_0} \left(\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} \right)$$



3 ELECTRIC POTENTIAL

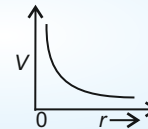
Work done by an external force in bringing a unit positive charge from infinity to that point without acceleration is equal to electrostatic potential at that point.

Its SI unit is volt.

4 ELECTROSTATIC POTENTIAL DUE TO A POINT CHARGE

$$V(r) = \frac{Q}{4\pi\epsilon_0 r}$$

For $Q > 0$, $V > 0$
For $Q < 0$, $V < 0$



5 POTENTIAL DUE TO A SYSTEM OF CHARGES (SUPERPOSITION LAW)

- Potential at a point due to total charge configuration is the algebraic sum of the potentials due to individual charges

$$V = V_1 + V_2 + V_3 + \dots = \frac{1}{4\pi\epsilon_0} \sum \frac{q_i}{r_i}$$

6 POTENTIAL DUE TO AN ELECTRIC DIPOLE

$$V = \frac{p \cos \theta}{4\pi\epsilon_0 r^2}$$

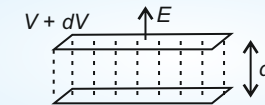
($r \gg$ dipole length at general point)

- Potential on axis of dipole

$$V = \pm \frac{1}{4\pi\epsilon_0} \frac{p}{r^2} \quad \begin{cases} + \text{ For } \theta = 0 \\ - \text{ For } \theta = \pi \end{cases}$$

- Potential in the equatorial plane of dipole is zero

7 RELATION BETWEEN FIELD AND POTENTIAL



$$E = -dV/dl$$

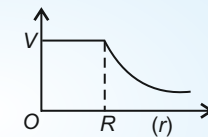
8 POTENTIAL DUE TO UNIFORMLY CHARGED SPHERICAL CONDUCTING SHELL

$$V = \frac{1}{4\pi\epsilon_0} \frac{q}{r} \quad (r \geq R)$$

q is charge on shell and R is its radius.

- Potential is constant inside shell and is equal to potential at surface.

$$V = \frac{1}{4\pi\epsilon_0} \frac{q}{R}$$

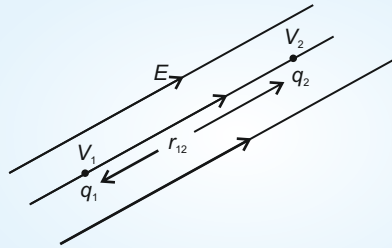


9 EQUIPOTENTIAL SURFACES

- It is a surface with a constant value of potential at all points on its surface.
- Equipotential surfaces of a single point charge are concentric spherical shells centered at the charge.
- For any charge configuration, an equipotential surface is normal to electric field at that point
- No two equipotential surfaces cut each other.

For dipole: Equipotential surfaces:

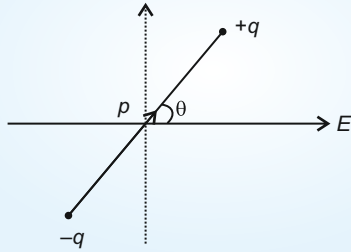


10 POTENTIAL ENERGY IN EXTERNAL FIELD

$$U = q_1 V_1 + q_2 V_2 + \frac{q_1 q_2}{4\pi\epsilon_0 r_{12}}$$

11 POTENTIAL ENERGY OF A DIPOLE

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

**12 ELECTROSTATICS OF A CONDUCTOR**

- Inside conductor, electrostatic field is zero, either is neutral or charged.
- Electrostatic potential is constant throughout volume of the conductor & same value as on surface.
- If a cavity is created inside conductor and a charge is kept outside cavity. Any electric field outside conductor does not enter into the cavity. So cavity of conductor remains shielded.
- No work done is done in moving a charge on a conducting surface.
- When a conductor placed in external electric field, field lines are always normal to conducting surface.

13 DIELECTRICS

- Dielectrics are non conducting substances having no charge carriers.
- Polar dielectric : Polar dielectric has permanent dipole moment. Ex. HCl, H₂O.
- Non polar dielectric : Non polar dielectric has no dipole moment. Ex. O₂, H₂.
- A dielectric with polar/non polar molecules develops a net dipole moment in an external electric field. The dielectric is polarized. Dipole moment developed per unit volume called polarization P.
 $P = \epsilon_0 \chi_e E$, χ_e = electric susceptibility of dielectric medium.
 $\chi_e = (K - 1)$

14 DIELECTRIC STRENGTH

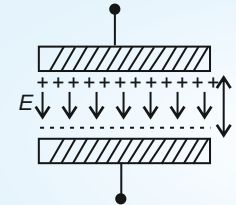
- Maximum value of electric field that a dielectric medium can withstand without breakdown (of its insulating property) is called its dielectric strength.
- For air dielectric strength is $E = 3 \times 10^6$ V/m
- For any capacitor, the electric field do not exceed the break down limits. There is limit to charge amount that can be stored on a given capacitor without significance leakage.

15 CAPACITANCE OF CAPACITORS

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

C is independent of Q and V but depends on shape, size and separation of system of two conductors & also on dielectric, separating two conductors. Every capacitor has limited electric capacity.

SI unit : F (farad)

16 PARALLEL PLATE CAPACITOR

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

Plate area : A (For each)

Plate separation : d

Dielectric inserted occupying full intervened region

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

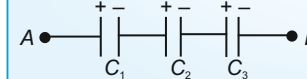
K = dielectric constant of the substance

17 COMBINATION OF CAPACITORS**Series Combination of Capacitors**

Charges on plates $\pm Q$ are same on each capacitor.

$$V = V_1 + V_2 + V_3$$

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



- Equivalent capacity decreases.

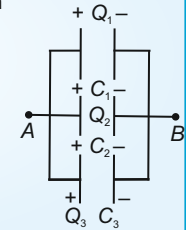
Parallel Combination of Capacitors

Same potential difference is applied across each capacitor.

Plate charges not necessarily same.
Equivalent capacity
 $C = C_1 + C_2 + C_3$

$$Q = Q_1 + Q_2 + Q_3$$

- Equivalent capacity increases in parallel

**18 ENERGY STORED IN A CAPACITOR**

$$U = \frac{QV}{2} = \frac{1}{2} CV^2 = \frac{Q^2}{2C}$$

$$U/V = u = \frac{1}{2} \epsilon_0 E^2$$

(Energy density)

19 CHARGE SHARING IN CAPACITORS

- When two capacitors of different potential are joined with positive plates together and negative together, common potential is

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

- Final energy is less than initial and is lost as heat and electromagnetic radiation

$$\Delta U = \frac{1}{2} \frac{C_1 C_2}{C_1 + C_2} (V_1 - V_2)^2$$

1 ELECTRIC CURRENT

Current through a given area is net charge passing per unit time through the area.

- Current may not always be steady. We define current in general

$$I = \lim_{\Delta t \rightarrow 0} \left(\frac{\Delta Q}{\Delta T} \right)$$

- Its SI unit is ampere (A)
- A cell can maintain a steady current

2 DRIFT VELOCITY

The charge carriers like electrons move with an average velocity which is independent of time, this is phenomenon of drift, and is called drift velocity.

$$\vec{V}_d = \frac{-e\vec{E}}{m} \tau$$

τ = relaxation time.

Although collision of electrons don't occur at regular intervals but average time between successive collision is taken as relaxation time.

4 OHM'S LAW

The current flowing through a conductor is proportional to potential difference across it, provided temperature is constant.

$$V \propto I \text{ or } V = RI$$

R is the resistance of substance. SI unit of is ohm ($1 \Omega = 1 \text{ VA}^{-1}$)

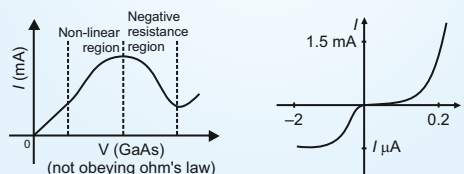
Equivalent form: $\vec{J} = \sigma \vec{E}$ (\vec{J} : Current density vector)

Factors affecting R : $R = \frac{\rho l}{A}$

- Material of conductor
- Area of cross-section of conductor
- Length of conductor,

Limitation of ohm's law

- The relation of V and I is not unique in GaAs.
- V ceases to be proportional to I . Material becomes non-ohmic material.
- For a diode, relation of V and I depends on sign of V . This material is used in electronic devices.



5 RESISTIVITY AND ITS TEMPERATURE DEPENDENCE

- Materials are classified as conductors, semiconductors and insulators according to their resistivity value.
- Metals have resistivity range $10^{-8} \Omega \text{ m}$ to $10^{-6} \Omega \text{ m}$.
- Insulators have resistivity range from 10^5 to $10^{18} \Omega \text{ m}$.
- For metallic conductor over a limited range, resistivity is approximately given by $\rho_T = \rho_0 [1 + \alpha(T - T_0)]$
 ρ_T = resistivity at temp. T
 ρ_0 = resistivity at temp. T_0
 α = temperature coefficient of resistivity

6 TYPES AND COLOUR CODING OF RESISTORS

(a) Wire Bound Resistors

- Made of materials which are relatively insensitive to temperature.
- Winding of wires are of alloys viz., manganin, constantan, nichrome etc.
- Range : fraction of an ohm to few hundred ohms.

(b) Carbon Resistors

- Compact, inexpensive and have higher range.
- Colour coding of carbon resistors

Colour	Number	Multiplier	Tolerance (%)
Black	0	1	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold		10^{-1}	5
Silver		10^{-2}	10
No colour			20

3 CURRENT DENSITY AND MOBILITY

Current through unit cross-sectional area is called current density.

- It is denoted by J and is a vector.
- SI unit is A m^{-2}

$$\vec{J} = \sigma \vec{E} = \left(\frac{ne^2}{m} \tau \right) \vec{E}$$

σ = conductivity

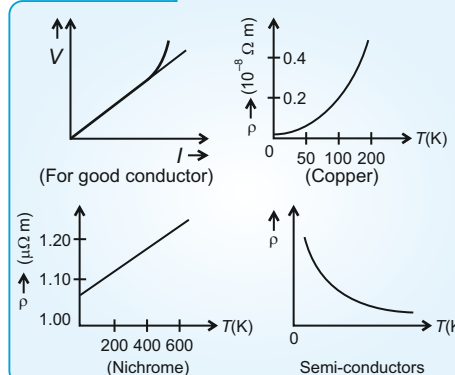
E = electric field inside conductor

The relation is Ohm's law in microscopic form.

- Conductivity is due to mobile carriers.
- In metals, charge carriers are electrons.
- In ionised gas, they are electrons and positive charged ions.
- In electrolytes they are positive and negative ions.
- Mobility is magnitude of drift velocity per unit electric field.

$$m = \frac{|V_d|}{E} = \frac{e\tau}{m}$$

- SI units are $\text{m}^2 \text{ V}^{-1} \text{ s}^{-1}$



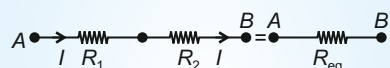
7 CELL AND ITS EMF

- It is a simple device which can maintain a steady current in electric circuit.
- EMF of cell is potential difference between positive and negative electrode when no current is flowing through the cell.
- $V = \epsilon - ir$ (discharging)
 $V = \epsilon + ir$ (charging)
- r is called internal resistance. The actual value of r vary from cell to cell.
- Internal resistance of dry cell is higher than electrolytic cell.

8 COMBINATION OF RESISTORS

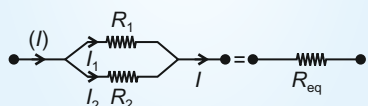
The resistors are sometimes joined together and there are simple rules for calculation of equivalent resistance of such combination.

- Series combination:** If only one of their end point is joined.



$$R_{\text{eq}} = R_1 + R_2$$

- Parallel combination:** If one end of all the resistors are joined together and similarly other ends joined together. (The potential drop across resistors is same).



$$I = I_1 + I_2$$

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

9 Electrical Energy and Power

Under a potential difference in a conductor charges are moving. These charges suffer collisions with ions and atoms during transit. Energy shared by ions and atoms heats up the conductor. Amount of energy dissipated as heat per unit time is called power loss.

$$P = I^2 R = V^2 / R = IV$$

R is resistance when current I is flowing through it.

This energy is supplied by source in circuit.

- For long distance transmission, power loss is minimised by transmitting it at high voltage.

10 KIRCHHOFF'S RULES

- For complicated electric circuits to determine all the currents and potential differences, Kirchhoff formulated two laws:

- Junction rule:** At any junction, sum of currents entering the junction is equal to sum of currents leaving the junction.

- Mesh or loop rule:** The algebraic sum of changes in potential around any closed loop involving resistors and cells in the loop is equal to zero.

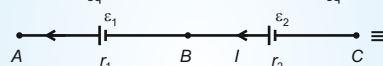
Note: Bending or reorientation of wire does not change the validity of junction law.

11 COMBINATION OF CELLS

- Cell can be grouped in series or parallel depending upon current requirements.

- In series: Two cells of emf ε_1 and ε_2 with internal resistances r_1 and r_2 the combination can be considered as one cell

of emf ε_{eq} and internal resistance r_{eq}



$$(\varepsilon_{\text{eq}} = \varepsilon_1 + \varepsilon_2) \text{ and } (r_{\text{eq}} = r_1 + r_2)$$

- In parallel combination of two cells

$$\varepsilon_{\text{eq}} = \left(\frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2} \right)$$

$$r_{\text{eq}} = \left(\frac{r_1 r_2}{r_1 + r_2} \right)$$

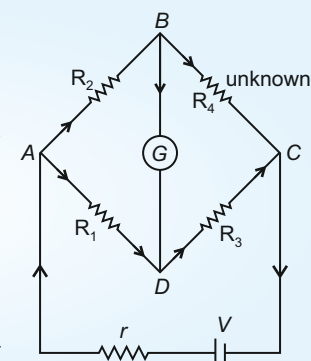
12 WHEATSTONE BRIDGE

- Wheatstone bridge in its balanced condition provide a practical method for determination of internal resistance.

- If R_1 and R_2 are two resistances in first and second arm and R_3 in third arm. R_3 is kept on changing till galvanometer shows no deflection. The bridge is then balanced and from balance condition R_4 is known.

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

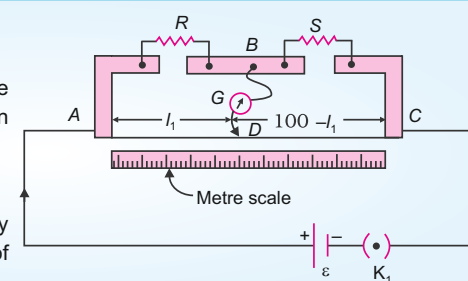
- The value of one resistance is determined knowing other three resistors.

**13 METER-BRIDGE**

- It is based on wheatstone bridge.
- With same principle as of Wheatstone bridge it is used to calculate unknown resistance, R , under balance condition.

$$R = S \times \frac{l_1}{100 - l_1}$$

- Percentage error in R is minimised by adjusting balance point near the middle of bridge.

**14 POTENTIOMETER**

This is a versatile electric instrument used to compare emf(s) and to determine internal resistance of a cell.

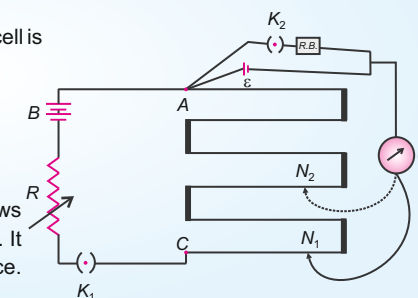
- The method involves condition of no current flow. In this way it can compare emfs of two cells.
- The potentiometer wire has uniform cross-section and homogeneous material so potential drop per unit length of potentiometer wire is constant.
- The formula for internal resistance calculation of cell is

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

l_1 = balancing length without shorting cell

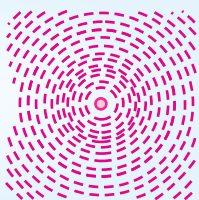
l_2 = balancing length with cell by parallel resistance R

- The potentiometer has the advantage that it draws no current from voltage source being measured. It is not affected by internal resistance of the source. Thus it has high accuracy.



1 MAGNETIC FIELD

- It is space around a current carrying conductor in which its magnetic effects can be felt.
- Oersted concluded that moving charges or currents produced a magnetic field in the surrounding space.



3 VELOCITY SELECTOR

When electric field and magnetic fields are crossed and velocity of particle is perpendicular to both fields then particles with speed $v = \frac{E}{B}$ pass undeflected. This principle is employed in mass spectrometer.

6 BIOT-SAVART'S LAW

- According to this law, the magnetic field at a point due to a current element of length dl carrying current I at distance r from element is

$$|d\vec{B}| = \frac{\mu_0 I dl \sin \theta}{4\pi r^2}$$

θ is angle between \vec{dl} and \vec{r}

2 LORENTZ FORCE

Mechanical force experienced by a moving charge through electric and magnetic field

$$F = q[\vec{E} + (\vec{v} \times \vec{B})] = \vec{F}_{\text{electric}} + \vec{F}_{\text{magnetic}}$$

- Magnetic force depends on magnitude of charge, its nature and its velocity.
- When charge is at rest, it does not experience any magnetic force.
- When charge is moving parallel to magnetic field, it does not experience any mechanical force.

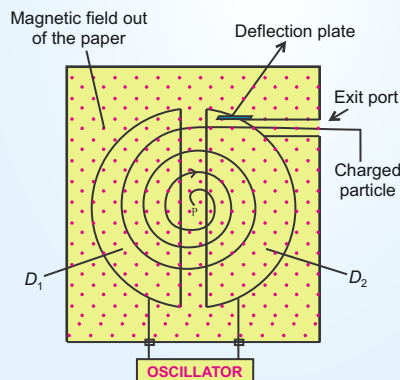
5 CYCLOTRON

A machine to accelerate charged particles or ions to high energies cyclotron; uses both electric and magnetic field in combination to increase kinetic energy of charge particles

- Frequency of revolution of charge particle is independent of its energy.
- $f = \frac{qB}{2\pi m}$. The frequency is called cyclotron frequency.

The frequency of electric field is in resonance with cyclotron frequency. Final KE of ion

$$E_K = \frac{q^2 B^2 R^2}{2m}, \quad R = \text{radius of Dee}$$



7 MAGNETIC FIELD ON AXIS OF CIRCULAR COIL

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

where R = radius of coil

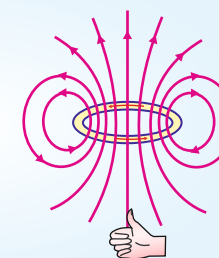
x = distance along axis from

centre of coil plane

- At the centre of loop, $x = 0$

$$B = \frac{\mu_0 I}{2R}$$

Field lines form closed loop around circular wire



4 MOTION IN MAGNETIC FIELD

In uniform magnetic field charge particle can have three types of path.

1. Straight line: when $\vec{B} \parallel \vec{v}$

2. Circular path: $\vec{v} \perp \vec{B}$

Perpendicular force acts as a centripetal force and produces a circular motion perpendicular to magnetic field.

$$\text{Radius of circle } r = \frac{mv}{qB} \text{ and } T = \frac{2\pi m}{qB}$$

3. Helical path: velocity \vec{v} and \vec{B} are inclined at angle $\theta \neq 0, \theta \neq 90^\circ, \theta \neq 180^\circ$

Velocity component along magnetic field remains unchanged, due to other component motion is circular.

The combined path is helical motion.

$$r = \frac{mv_{\perp}}{qB}, \omega = \frac{qB}{m}, p = \frac{2\pi mv_{\parallel}}{qB}$$

8 AMPERE'S CIRCITAL LAW

Law states $\oint_C \vec{B} \cdot d\vec{l} = \mu_0 I$, where I refers to current passing the loop through open surface S . The sign of current is determined from right hand rule.

- If B is directed along tangent to amperian loop of perimeter L and field is constant in magnitude

$$BL = \mu_0 I_e$$

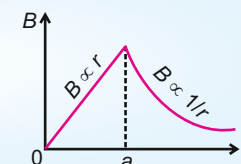
I_e = net current enclosed by closed loop.

9 MAGNETIC FIELD DUE TO SOLID CONDUCTOR

A long straight wire with circular cross-section of radius a

- Magnetic field in region $r < a$, $B = \left(\frac{\mu_0 I}{2\pi a^2}\right)r$

- Magnetic field in region ($r \geq a$), $B = \frac{\mu_0 I}{2\pi r}$



10 MAGNETIC FIELD DUE TO A LINE CURRENT

- Magnetic field at distance R from straight long infinite wire carrying a current I .

$$B = \frac{\mu_0 I}{2\pi R}, \text{ field lines are circles concentric with wire.}$$

11 DIRECTION OF MAGNETIC FIELD

The rule is called right hand rule:

Grasp the wire in your right hand with your extended thumb pointing in the direction of the current, your fingers will curl around in the direction of magnetic field.

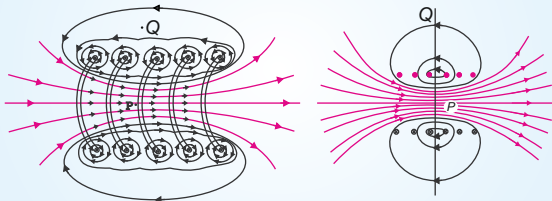
12 LONG SOLENOID

Magnetic field inside long solenoid (B)

When solenoid carries current I is

$$B = \mu_0 n I$$

n = number of turns per unit length



FOR A TOROID

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

N = total number of turns and r = average radius

13 MECHANICAL FORCE ON A CURRENT CARRYING CONDUCTOR

A current carrying conductor of straight length L carrying current I experience force

$$\vec{F} = I(\vec{l} \times \vec{B})$$

But if wire is of arbitrary shape

$$\vec{F} = \sum i(d\vec{l} \times \vec{B})$$

Summation can be converted into integration in most cases

14 FORCE BETWEEN CURRENT CARRYING WIRES

- Two current carrying conductors placed near each other experience magnetic forces. When conductors are parallel

$$F = \frac{\mu_0 I_1 I_2 L}{2\pi d}$$

- Force on one conductor of length L due to current in other at separation d . Parallel currents attract and antiparallel currents repel. The results are in accordance with Newton's third law.

15 TORQUE ON CURRENT LOOPS

- Torque on magnetic dipole
 - $\tau = mB\sin\theta$
 - $\tau = NIAsin\theta$
- Any planar current loop is equivalent to magnetic dipole of dipole moment
 - $m = IA$

16 MAGNETIC MOMENT OF REVOLVING CHARGED PARTICLES

- Magnetic moment associated with revolving electron with speed v in a radius of circle r is

$$\mu = -\frac{evr}{2}$$

$$\text{and } \vec{\mu} = -\frac{e}{2m_e} \vec{J}$$

Where \vec{J} is angular momentum of the electron

- For electron, angular momentum is opposite in direction to magnetic moment.
- In general for any charge q angular momentum and magnetic moment are in same direction.

$$\frac{\mu}{J} = \frac{e}{2m}$$

This is called Gyromagnetic ratio and is constant.

Minimum value of magnetic moment is called Bohr magneton

$$\mu_m = 9.27 \times 10^{-24} \text{ Am}^2$$

17 MOVING COIL GALVANOMETER

- Torque due to radial magnetic field on loop of area A with N number of turns carrying current I is

$$\tau = NIAB$$

- deflection on scale

$$\phi = \left(\frac{NAB}{K} \right) I$$

- Quantity in bracket is constant for galvanometer. This makes linear scale
- Current sensitivity of galvanometer

$$S_i = \frac{\phi}{I} = \frac{NAB}{K}$$

- Current sensitivity can be easily increased by changing N

18 GALVANOMETER CONVERSION AMMETER

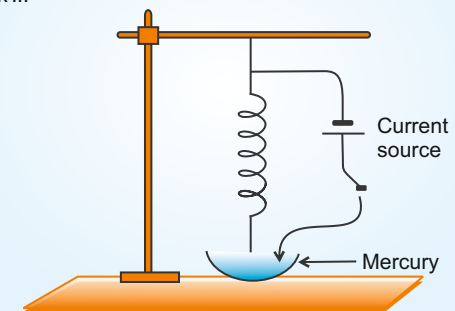
- Modification of galvanometer by connecting a low resistance in parallel.

VOLTMETER

- To measure voltage across any section of circuit. It is connected in parallel. When a large resistance is in series with galvanometer, it becomes a voltmeter.

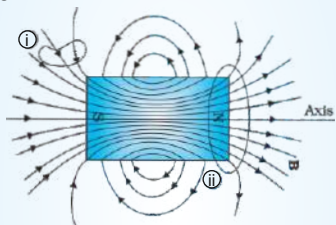
19 ROGET'S SPIRAL

- When current passes through spring the effect is length of parallel current produces attraction, decreasing spring length, oscillations starts and continue with tick - tick - tick ...



1 BAR MAGNET

- It is a magnet in form of a bar
- When freely suspended, it points in N - S direction
- Like poles repel each other, unlike poles attract each other
- Magnetic monopoles do not exist
- Magnetic field lines of magnet form continuous closed loops
- The tangent at a given point represents the direction of net magnetic field \vec{B} at that point
- Magnetic field lines do not intersect each other.



- When magnet cut transverse to length or along its length $M' = M/2$
- Bar magnet as an equivalent solenoid
 $B = \frac{\mu_0 2m}{4\pi r^3}$
- Magnetic moment of solenoid
 $m = nl(2l) \times (\pi a^2)$
- Bar magnetic in uniform magnetic field
 $\vec{\tau} = \vec{m} \times \vec{B}$
 $U_m = -\vec{m} \cdot \vec{B} = -mB \cos \theta$
- $\theta = 0^\circ$ (Most unstable position)
- $\theta = 180^\circ$ (Most unstable position)
- Time period of oscillation of a magnet when freely suspended

$$T = 2\pi \sqrt{\frac{I}{mB}} \text{ and } B = \frac{4\pi^2}{mT^2}$$

2 THE ELECTROSTATIC ANALOGUE

Magnetism	Electrostatics
\vec{B}	\vec{E}
\vec{m}	\vec{P}
μ_0	$\frac{1}{\epsilon_0}$
$\vec{\tau} = \vec{m} \times \vec{B}$	$\vec{\tau} = \vec{P} \times \vec{E}$
$U = -\vec{m} \cdot \vec{B}$	$U = -\vec{P} \cdot \vec{E}$
$\vec{B}_{\text{axial}} = \frac{\mu_0 2m}{4\pi r^3}$	$E_{\text{axial}} = \frac{1}{4\pi\epsilon_0} \frac{2\vec{P}}{r^3}$
$\vec{B}_{\text{eq}} = \frac{-\mu_0 \vec{m}}{4\pi r^3}$	$\vec{E}_{\text{eq}} = \frac{-1}{4\pi\epsilon_0} \frac{\vec{P}}{r^3}$

3 GAUSS'S LAW FOR MAGNETISM

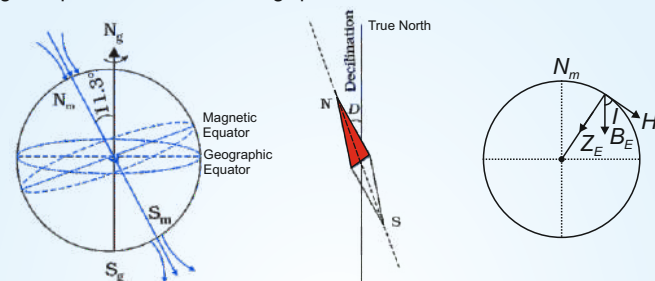
- $\oint \vec{B} \cdot d\vec{A} = 0$
- Isolated magnetic poles do not exist.
- The net magnetic flux is zero for any closed surface.

5 MAGNETISM AND MAGNETIC INTENSITY

- $\vec{M} = \frac{\vec{m}_{\text{net}}}{V} = \frac{\text{Net magnetic moment}}{\text{Volume}}$
- Net field in the interior of a solenoid
 $\vec{B} = \vec{B}_0 + \vec{B}_m$
 \vec{B}_0 : Field in free space
 \vec{B}_m : Field contributed by material core
 $\vec{B}_0 = \mu_0 \vec{H}$ $\vec{B}_m = \mu_0 \vec{M}$
 $\vec{B} = \mu_0 (\vec{H} + \vec{M})$ $\vec{M} = \chi \vec{H}$
 $\vec{B} = \mu_0 (1 + \chi) \vec{H}$ $\mu_r = 1 + \chi$
 $\vec{B} = \mu_0 \mu_r \vec{H}$ $\mu = \mu_0 \mu_r = \mu_0 (1 + \chi)$
 $\vec{B} = \mu \vec{H}$

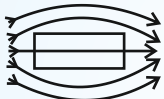

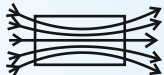
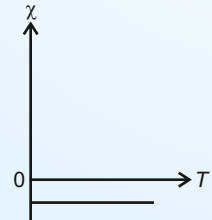
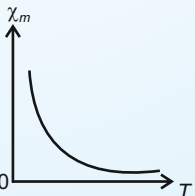
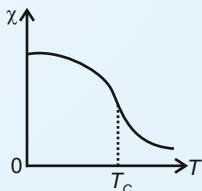
4 EARTH'S MAGNETISM

- Magnetic field of earth is now thought to arise due to electrical current produced by convective motion of metallic fluids in outer core of the earth. This is known as dynamo effect .
- Magnetic poles inside earth change position with times.



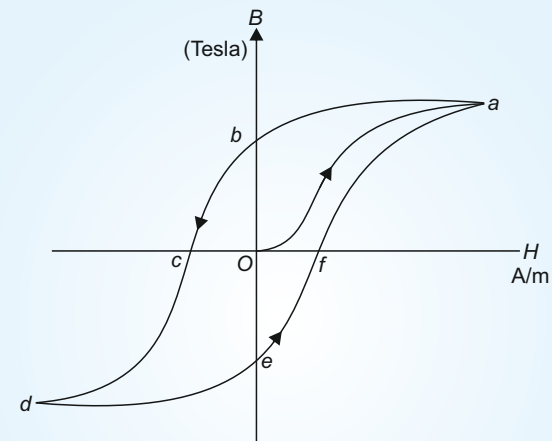
- Earth's magnetic field varies from point to point on earth surface, its value being of order of 10^{-5} T.
- Magnetic field lines of earth resemble that of a hypothetical magnetic dipole located at the centre of earth.
- The vertical plane which passes through the imaginary line joining the magnetic north and the south poles is called magnetic meridian.
- The vertical plane containing longitudinal circle and axis of rotation of earth is called geographic meridian.
- Inclination or magnetic dip(I)**
Angle made by the net magnetic field of earth with the horizontal
 $I_{\text{equator}} = 0$
 $I_{\text{pole}} = 90^\circ$
- Horizontal component (H_E)**
Horizontal Component of net magnetic field of earth
- Magnetic declination(D)**
Angle between magnetic meridian and geographic meridian
- Declination in India is small. It is $0^\circ 41'$ E at Delhi.
- Declination is greater at higher latitudes and smaller near equator.
- $B_E \sin I = Z_E$, $B_E \cos I = H_E$, $\tan I = Z_E/H_E$

6 MAGNETIC PROPERTIES OF MATERIALS

Properties	Diamagnetic	Paramagnetic	Ferromagnetic
χ	$-1 \leq \chi \leq 0$	$0 < \chi < k$ (k is a small positive number)	$\chi \gg 1$
μ_r	$0 \leq \mu_r < 1$	$1 < \mu_r < 1 + k$	$\mu_r \gg 1$
μ	$\mu < \mu_0$	$\mu > \mu_0$	$\mu \gg \mu_0$
Magnetisation	Weak magnetisation is opposite direction	Weak magnetisation in same direction	Strong magnetisation in same direction
Movement in non-uniform magnetic field	(Weak tendency) from strong to weak magnetic field	(Weak tendency) from weak to strong magnetic field	(Strong tendency) from weak to strong magnetic field
Magnet	Weak Repulsion	Weak Attraction	Strong Attraction
<i>E.g.</i>	Bi, Au, Pb, Si, H ₂ O, NaCl N ₂ (STP), Ag, superconductor	Al, Na, O ₂ (STP), Pt, W	Fe, Co, Ni, Fe ₂ O ₃ and Gd
Mag. Field lines			
Susceptibility	Independent of temperature $\chi_m \propto T^0$ 	Inversely proportional to temperature $\chi_m = \frac{C\mu_0}{T}$ Where C is curie constant 	Curie temperature: The temperature at which ferromagnetic substance becomes paramagnetic Disappearance of magnetisation with temperature is gradual. Beyond curie temperature Susceptibility obeys Curie-Weiss law $\chi_m = \frac{C}{T - T_C}$ ($T > T_C$) T_C for iron is 1043 K T_C for nickel is 631 K 

- Domain formation is special characteristic of ferromagnetic material. Typical domain size is 1 mm and domain contains about 10^{11} atoms.

7 HYSTERESIS LOOP



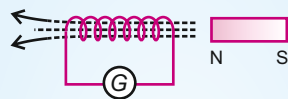
- Retentivity:** The value of B at $H=0$
- Coercivity:** The value of H for which net magnetic field becomes zero.
- Energy is lost in the form of heat during complete cycle of magnetisation and de-magnetisation.
- Hysteresis curve of soft iron is tall and narrow.
- Hysteresis curve of steel is broad

8 PERMANENT MAGNETS AND ELECTROMAGNETS

Permanent Magnets	Electromagnets
Material should have	Material should have
<ul style="list-style-type: none"> High Retentivity High Coercivity High permeability 	<ul style="list-style-type: none"> Low Retentivity High permeability Low Coercivity
Material used for making these magnets are Alnico, Cobalt, Steel, Ticonal	Material used for making these magnets is soft Iron
These materials retain their ferromagnetic property for long period of time.	Electromagnets are used in electric bells, loud speakers and telephone diaphragms.

1 FARADAY'S EXPERIMENTS

(a) **First experiment** : Relative motion between a bar magnet and wire loop produces a small amount of current.



(b) **Second experiment** : If one coil is connected to a battery and another coil is moved towards or away from it, electric current is produced in neighbouring coil.

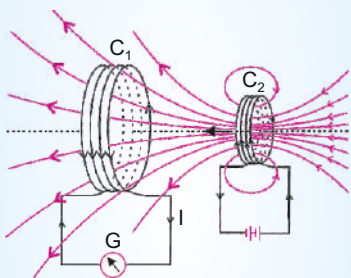
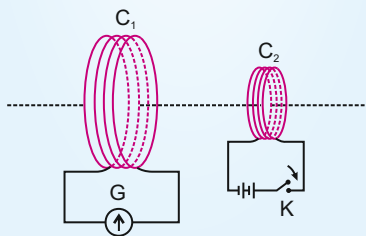


Fig. : Current is induced in coil C_1 due to motion of the current carrying coil C_2 .

(c) **Third experiment** : Galvanometer shows a momentarily deflection when tapping key K is pressed



2 MAGNETIC FLUX

Magnetic flux through a surface of area \vec{A} placed in uniform magnetic field \vec{B} is written as $\phi_B = \vec{B} \cdot \vec{A} = BA \cos\theta$

For non-uniform magnetic field

$$\phi = \int \vec{B} \cdot d\vec{A}$$

3 FARADAY'S LAWS OF INDUCTION

Conclusion of experiments was formulation of laws:

- (1) The magnitude of the induced emf in a circuit is equal to the time rate of change of magnetic flux through the circuit.
- (2) Mathematically the emf induced is given by

$$\varepsilon = - \frac{d\phi_B}{dt}$$

- Negative sign indicates the direction of ε and hence the direction of current in the closed loop.
- If loop contains N turns, change of flux is associated with each turn.

$$\varepsilon = - N \left(\frac{d\phi_B}{dt} \right)$$

- The induced emf can be increased by increasing the number of turns of closed coil.

4 LENZ'S LAW

- LENZ'S LAW**: This law gives the polarity of induced emf. The polarity of induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produced it.
- The law is in accordance with the law of conservation of energy.

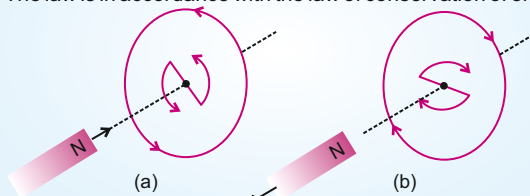
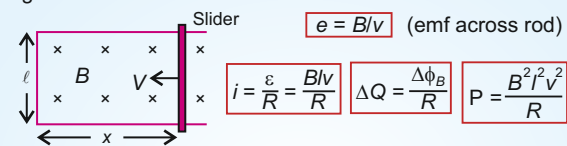


Fig. : Illustration of Lenz's law.

5 MOTIONAL EMF

(1) **Straight conductor in motion**: In uniform and time independent magnetic field.



- Mechanical energy which is needed to move arm is converted into electric energy and then to thermal energy.

(2) **Rod rotated about one end** :



Fleming's Right hand Rule : This gives the direction of induced emf or current in a conductor moving in a magnetic field. If we stretch forefinger, central finger and thumb of our right hand in mutually perpendicular directions such that forefinger along field, thumb along direction of motion of conductor then central finger will give the direction of induced current.

6 EDDY CURRENTS

Electric currents are induced in well defined path in a conductor like circular loops, when bulk piece of conductor is subjected to changing magnetic flux, induced currents are produced in them known as eddy currents.

The eddy currents are also called Foucault currents after its discovery.

- The changing magnetic flux induces current.
- These currents are used to advantage in many applications.
 - (1) Magnetic braking of trains
 - (2) Electromagnetic damping
 - (3) Induction furnace
- Eddy currents dissipate energy in the form of heat energy.
- Eddy currents are minimized using laminations of metal to make a metal core

1 ALTERNATING CURRENT

Current which changes continuously in magnitude and periodically in direction.

2 ROOT MEAN SQUARE VALUE

r.m.s. value of a function over a period T is

given by
$$\sqrt{\frac{\int f(t)^2 dt}{\int dt}}$$

- RMS current is equivalent to dc current that would produce same average power loss as alternating current.

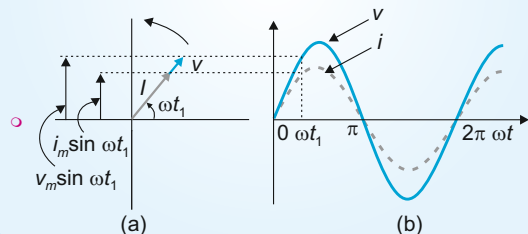
3 AVERAGE VALUE

Average value of a function over a period T

is given by
$$\langle f(t) \rangle = \frac{1}{T} \int_0^T f(t) dt$$

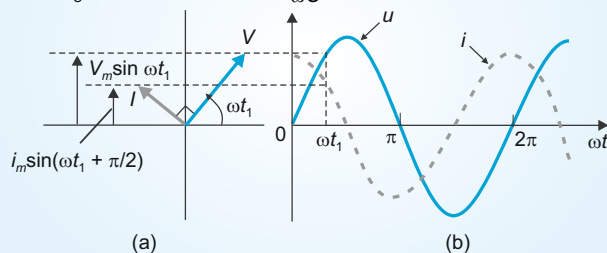
4 PURELY RESISTIVE CIRCUIT

- Let applied voltage is $\varepsilon = \varepsilon_0 \sin \omega t$
- Alternating voltage is in phase with current
- $I = \frac{\varepsilon}{R} = I_0 \sin \omega t$
- $I_0 = \frac{\varepsilon_0}{R}$
- $P_{av} = \frac{1}{2} I_0^2 R$



5 PURELY CAPACITIVE CIRCUIT

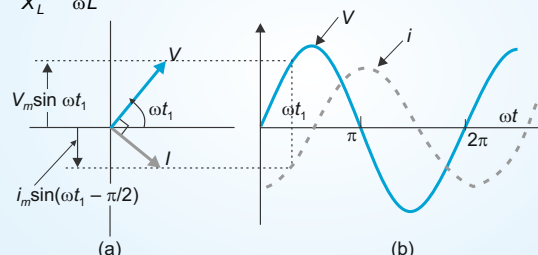
- Let applied voltage is $\varepsilon = \varepsilon_0 \sin \omega t$
- Current leads the voltage by a phase angle $\pi/2$
- $I = I_0 \sin(\omega t + \frac{\pi}{2})$
- $I_0 = \frac{\varepsilon_0}{X_C} = \omega C \varepsilon_0$, where $X_C = \frac{1}{\omega C}$



- Instantaneous power = $\frac{\varepsilon_0 I_0}{2} \sin[2\omega t]$
- Average power = 0

6 PURELY INDUCTIVE CIRCUIT

- Let applied voltage is $\varepsilon = \varepsilon_0 \sin \omega t$
- Current lags behind the voltage by a phase angle $\pi/2$
- $I = I_0 \sin(\omega t - \pi/2)$
- Current reaches maximum value later than voltage by one fourth of period.
- $I_0 = \frac{\varepsilon_0}{X_L} = \frac{\varepsilon_0}{\omega L}$, where $X_L = \omega L$

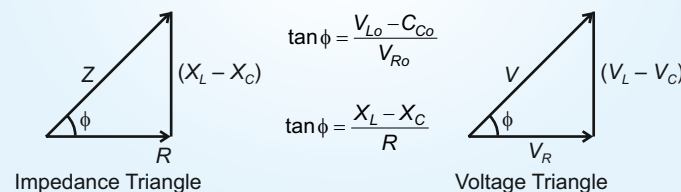


- Instantaneous power supplied = $-\frac{I_0 V_m}{2} \sin 2\omega t$
- Average power supplied by an inductor over one complete cycle is zero.

7 SERIES LCR CIRCUIT

- $\varepsilon = \varepsilon_0 \sin \omega t$ and $I = I_0 \sin(\omega t - \phi)$
- $I_0 = \frac{\varepsilon_0}{Z}$, where $Z = \sqrt{R^2 + (X_L - X_C)^2}$, $\varepsilon_0^2 = (V_{R0})^2 + (V_{C0} - V_{L0})^2$
- Phase difference between current and voltage is ϕ , $\tan \phi = \frac{X_L - X_C}{R}$
- If $X_L > X_C \Rightarrow \phi$ is +ve (Inductive)
- If $X_L < X_C \Rightarrow \phi$ is -ve (Capacitive)
- If $X_L = X_C \Rightarrow \phi = 0$ (Resistive)

Impedance and Voltage Triangles



8 POWER IN AC CIRCUITS

$$P_{avg} = \varepsilon_{rms} I_{rms} \cos \phi = \frac{\varepsilon_0 I_0}{2} \cos \phi = I_{RMS}^2 Z \cos \phi$$

$$= I_{rms}^2 R = \left(\frac{\varepsilon_{rms}}{Z} \right)^2 R$$

9 POWER FACTOR

- Power factor: $\cos \phi = \frac{R}{Z}$
- In pure resistive circuit $\phi = 0^\circ \Rightarrow \cos \phi = 1$
- In pure inductive circuit or pure capacitive circuit $\phi = \pm \frac{\pi}{2} \Rightarrow \cos \phi = 0$
- In series LCR circuit at resonance, $X_L = X_C$
 $\Rightarrow Z = R$ and $\phi = 0^\circ$
 $\Rightarrow \cos \phi = 1$ (POWER FACTOR)

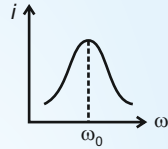
10 RESONANCE IN LCR SERIES CIRCUIT

- When $X_L = X_C \Rightarrow Z = R$
- Current become maximum

$$i_0 = \frac{V_0}{R}$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$\Delta\omega = \frac{R}{2L}$$



where $\omega_1 = \omega_0 + \Delta\omega$

$\omega_2 = \omega_0 - \Delta\omega$

- Quality factor**
It is a measure of sharpness of resonance

$$Q = \frac{\omega_0}{2\Delta\omega} = \frac{\text{Resonance frequency}}{\text{Band width}}$$

$$= \frac{\omega_0 L}{R}$$

$$= \frac{1}{\omega_0 RC}$$

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}}$$

- Resonance circuits are used in tuning mechanism of radio or TV set.
- Resonance phenomenon is exhibited by a circuit having both L and C present in circuit.
- If resonance is not sharp, maximum current is less, the circuit is close to resonance for a larger range of $\Delta\omega$ of frequencies and tuning of circuit will not be good. For good quality L be large and R low.

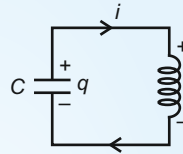
11 LC OSCILLATIONS

$$\frac{d^2q}{dt^2} + \frac{1}{LC}(q) = 0$$

$$q = q_0 \cos(\omega_0 t + \phi)$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$U_{\text{Total}} = \frac{q_m^2}{2C} = \frac{1}{2} Li_m^2$$



Analogies Between Mechanical and Electrical Quantities

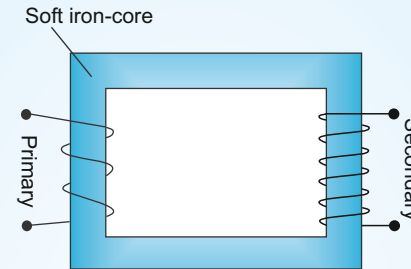
Mechanical system	Electrical (system)
Mass (m)	Inductance (L)
Force constant (K)	Reciprocal capacitance ($\frac{1}{C}$)
Displacement (x)	Charge (q)
Velocity ($v = \frac{dx}{dt}$)	Current ($i = \frac{dq}{dt}$)
Mechanical energy $E = \frac{1}{2} kx^2 + \frac{1}{2} mv^2$	Electromagnetic energy $U = \frac{q^2}{2C} + \frac{1}{2} Li^2$

- Every inductor has resistance. This introduces damping effect on charge and current and oscillation finally die away.
- Total energy is radiated away from the system in the form of electromagnetic waves. The Radio and TV transmission depend on this radiation.

12 TRANSFORMER

- To change an alternating voltage from one to another of greater or smaller value, we use transformer.

A transformer consists of two sets of coils, insulated from each other. It works on mutual induction principle.



$$\frac{\epsilon_P}{\epsilon_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S} = \frac{\phi_P}{\phi_S} = \text{constant}$$

- Efficiency of transformer

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{\epsilon_S I_S}{\epsilon_P I_P}$$

Step-up Transformer

- Number of turns in primary binding is lesser than in secondary binding
- $N_S > N_P$
- $E_S > E_P$
- $I_S < I_P$

Step-down Transformer

- Number of turns in secondary binding is lesser than in primary binding
- $N_S < N_P$
- $E_S < E_P$
- $I_S > I_P$

- Output voltage of transformer is out of phase with input.
- Energy losses in a transformer are due to
 - Flux Leakage
 - Resistance of winding
 - Eddy currents
 - Hysteresis

1 MAXWELL'S EQUATIONS

$$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\epsilon_0} \quad (\text{Gauss's Law of electrostatics})$$

$$\oint \vec{B} \cdot d\vec{A} = 0 \quad (\text{Gauss's Law of magnetism})$$

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\phi_B}{dt} \quad (\text{Faraday's Law of EMI})$$

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \left(i_c + \epsilon_0 \frac{d\phi_E}{dt} \right) \quad \text{Maxwell-Ampere's circuital theorem}$$

- These equations express all basic laws of electromagnetism

2 DISPLACEMENT CURRENT

- Source of a magnetic field is not just the conduction electric current but also time varying rate of change of electric field.
- It arises whenever the electric flux is changing with time.

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

- Changing electric field must also produce a magnetic field.

5 SPECTRUM OF ELECTROMAGNETIC WAVES AND PROPERTIES

A. RADIO WAVES

- Wavelength greatest
- Produced by vibrating electrons
- AM BAND : 530 kHz to 1710 kHz,
- SHORT band: 3 MHz to 54 MHz
- FM band : 88 MHz to 108 MHz
- UHF band : CELLULAR PHONE

B. MICRO WAVES

- Wavelength 0.1 m to 1 mm (Frequency GHz)
- Produced by special vacuum tubes (Klystrons, Magnetrons and Gunn diodes)
- Used in radar system
- Micro wave oven works with microwaves
- Used in speed guns

C. INFRARED WAVES

- Wavelength 1 mm to 700 nm
- Produced in vibration of atoms and molecules
- These are called heat waves
- Used in physical therapy
- Trapped by greenhouse gases
- Remote switches
- Infrared detector

D. VISIBLE RAYS

- Wave length 700 nm to 400 nm from electrons in atom by transitions from high to lower level
- Detected by human eye
- Different animals are sensitive to different ranges of wave length

3 ELECTROMAGNETIC WAVES

Sources of Waves

- Through accelerating charges
- Through oscillating electric dipoles
- By harmonically oscillating electric charges
- Oscillating fields of electromagnetic waves can accelerate charges and can produce oscillating currents
- Electromagnetic waves in interaction with matter interacts through its electric and magnetic field which set in oscillating charges present in all matter
- Mechanism of absorption and scattering depends on wavelength of electromagnetic wave, nature of atoms and molecules in medium

E. UV RAYS

- Wavelength 400 nm to 1 nm
- Sun is important source
- Absorbed by glass used by welders
- Used in eye surgery (LASIK)
- UV lamps for water purification

F. X-RAY

- Wavelength 10 nm to 10^{-4} nm
- Obtained from bombarding a metal target by high energy electron
- Used as diagnostic tools to treat cancer.

G. γ -RAYS

- Wavelength 10^{-10} m to 10^{-14} m
- Produced in nuclear reaction
- Emitted by radioactive nuclei
- used in medicine to destroy cancer cells

4 NATURE OF ELECTROMAGNETIC WAVES

- Waves are sinusoidal, having variation of electric and magnetic field at right angles to each other and perpendicular to direction of wave propagation.
- Frequency of electromagnetic wave equals the frequency of oscillating charge.
- Energy associated with propagating wave comes from energy of source, the accelerated charge.
- Produced and detected by Hertz in 1887 in laboratory. This verified a basic prediction of Maxwell's equation.
- No material medium is involved in vibration of electric and magnetic fields.
- E.M. wave carry energy and energy is shared equally by electric and magnetic fields.
- Electromagnetic wave other than light also have same velocity in vacuum.
- Wave transports momentum and exerts pressure

$$P = \frac{U}{c}, \quad (U = \text{Energy transfer for complete absorption by surface})$$

- The magnitude of total momentum delivered.
- So wave can carry energy from one place to another.
- $E_x = E_0 \sin(kz - \omega t)$ and $B_0 = E_0/c$
- $B_y = B_0 \sin(kz - \omega t)$ (wave equations)

- k = wave vector and speed of propagation is, $v = \frac{\omega}{k}$

$$\text{in medium, speed of wave, } v = \frac{1}{\sqrt{\mu\epsilon}}$$

$$\text{In vacuum, } c = \frac{1}{\sqrt{\mu_0\epsilon_0}}$$

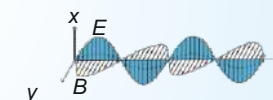
- This is fundamental constant. These waves can be polarized.

$$\text{Energy density in } E \text{ field, } u_E = \frac{1}{2} \epsilon_0 E^2$$

$$\text{Energy density in } B \text{ field, } u_B = \frac{B^2}{2\mu_0}$$

$$u_E = u_B$$

$$I = \epsilon_0 E_m^2 c$$



ORDER OF FREQUENCY

- Gamma rays > X rays > U.V > Visible > Infrared > microwaves > short radio waves > FM and TV > AM Radio > Long Radio waves

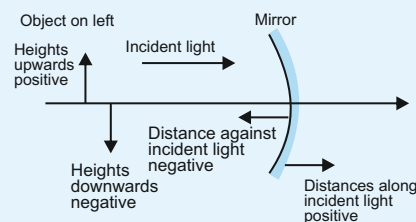
1 REFLECTION OF LIGHT

Law of Reflection

- Incident ray, reflected ray and normal to reflecting surface at the point of incidence lie in the same plane.
- Angle of incidence is equal to angle of reflection.

Sign-convention

- In sign convention, all distances measured in the same direction as incidence ray are taken positive and those measured in the direction opposite of incident ray are taken negative.
- The heights taken above the principal axis are positive and below negative.



Focal Length of Spherical Mirrors

- The distance between focus and pole of a mirror is called focal length.
- Focal length is equal to half of radius of curvature of the curved spherical mirror.

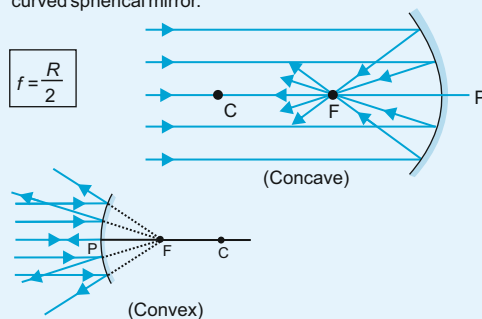


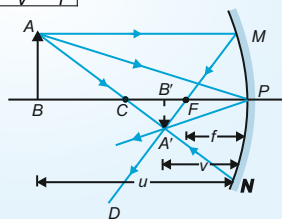
Image Formation by Spherical Mirrors

- The image by a mirror is real if rays after reflection actually meet and virtual if rays are not actually meeting but appear to diverge from a point.
- An incident ray passing through centre of curvature of mirror retraces its path.

Mirror equation is $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ and magnification formula

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

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



2 REFRACTION OF LIGHT

- When a beam of light encounters another transparent medium, part of light is reflected back. This called internal reflection. The rest of light enter other medium.
- When light is incident obliquely, its propagation direction changes in other medium, this phenomenon is called refraction.

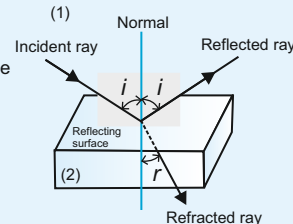
- Red light travels faster than blue light in same medium.

Law of Refraction

- The incident ray, refracted ray and normal to interface at the point of incidence, all lie in same plane.
- The ratio of sine of angle of incidence to the sine of angle of refraction is constant.

$$\frac{\sin i}{\sin r} = n_{21}$$

n_{21} is refractive index of second medium with respect to first.

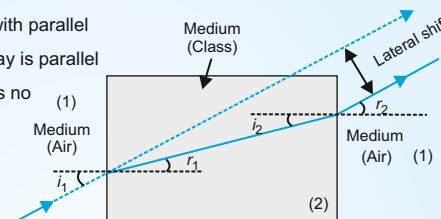


- Optical denser medium has high refractive index. Mass density of optical denser medium may be less than mass density of rarer medium.

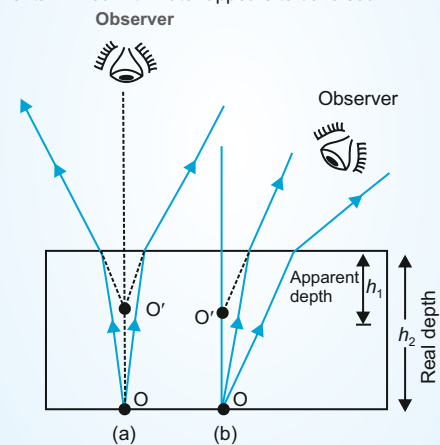
- Elementary results from laws of refraction are

(1) $n_{32} = n_{31} \times n_{12}$

- (2) For rectangular slab with parallel faces, the emergent ray is parallel to incident ray, there is no deviation but has lateral shift.

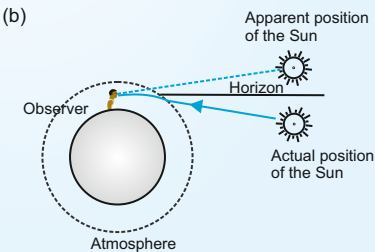


- (3) Bottom of tank filled with water appears to be raised.



$$\text{Apparent depth} = \frac{\text{Real depth}}{n_{21}}$$

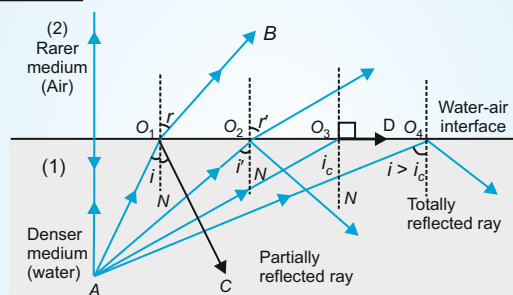
- (4) Sun is visible a little before the actual sunrise and until a little after the sunset, this time difference is about 2 minute, the sun appears oval shaped.



3 TOTAL INTERNAL REFLECTION

- If angle of incidence, for light traveling from denser to rarer medium is greater than certain angle called critical angle for the media, no light is transmitted.

$$\sin i_c = \frac{1}{n_{12}} \quad n_{12}: \text{refractive index of denser medium w.r.t rarer medium.}$$



- Higher is value of refractive index, smaller will be critical angle.

Substance	Ref. index	Critical angle
Water	1.33	48.75°
Flint glass	1.62	37.31°
Diamond	2.42	24.41°

Phenomenon based on TIR are

- Mirage
- Sparkling of diamond
- Special prisms of flint glass to bend light by 90° and 180°
- Optical fibre for communication

7 THIN LENSES IN CONTACT

- When thin lenses are kept in contact

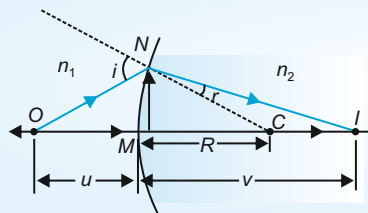
$$P = P_1 + P_2 + P_3 + \dots$$

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

- This combination helps to get diverging or converging lens combination of desired magnification.

- Net power is individual power's algebraic sum. Some terms may be positive (convex) and some terms may be negative (concave) on right hand side.

4 REFRACTION AT SPHERICAL SURFACES



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

R = radius of curvature of the curved spherical surface.
It holds for any curved surface (for paraxial approximation).

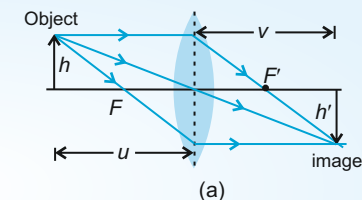
5 REFRACTION BY LENSES

- A lens is a transparent optical medium bounded by two surfaces. At least one surface should be spherical.
- After two refraction through a lens, image is formed. The thin lens formula becomes

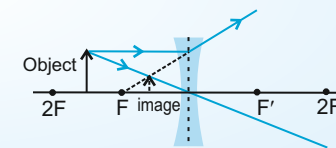
$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

$$m = \frac{\text{Size of image}}{\text{Size of object}} = \frac{h'}{h} = \frac{v}{u} = \frac{f}{f+u} = \frac{f-v}{f}$$

- Formula is valid for convex and concave lenses and magnification produced by lens (for paraxial approximation)



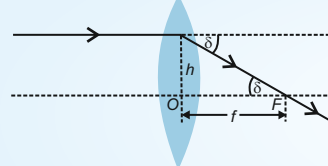
(a)



(b)

6 POWER OF THIN LENS

- It is measure of its convergence or divergence ability.



- The power P of a lens is defined as the tangent of the angle by which it converges or diverges a beam of light parallel to the principal axis falling at unit distance from the optical centre.

- A lens of shorter focal length bends incident ray more and has high power.

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

- Its SI unit is dioptre (D)

$$1D = 1 \text{ m}^{-1}$$

- It is positive for converging lens and negative for diverging lens.

Lens maker's formula

$$P = \frac{1}{f} = (n - 1) \left[\frac{1}{R_1} - \frac{1}{R_2} \right]$$

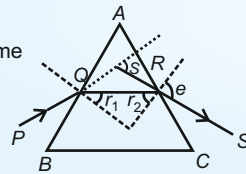
- n is relative refractive index of glass with respect to surrounding and R₁ and R₂ are radii of curvature of two surfaces.
- A converging lens in a transparent liquid of refractive index greater than lens glass behaves like a diverging lens and vice versa.

8 REFRACTION THROUGH A PRISM

- For any triangular prism angle between incidence ray and emergent ray is called angle of deviation

$$\delta = i + e - A$$

- δ remains same if i and e are interchanged.

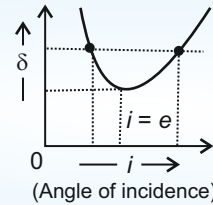


When $\delta = D_m$

$$i = e, D_m = 2i - A$$

$$r = r_1 = r_2 \text{ or } r_1 = A/2$$

The refracted ray inside prism becomes parallel to its base.



- Refractive index of prism is calculated by formula.

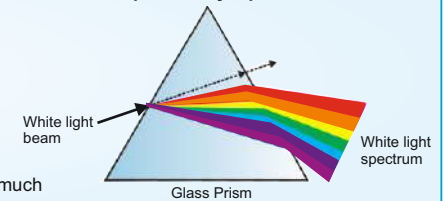
$$n_{21} = \frac{n_2}{n_1} = \frac{\sin\left(\frac{A + D_m}{2}\right)}{\sin(A/2)}$$

- For small angle thin prism

$$D_m = (n_{21} - 1)A$$

- It implies thin prism don't deviate light much

Dispersion by a prism

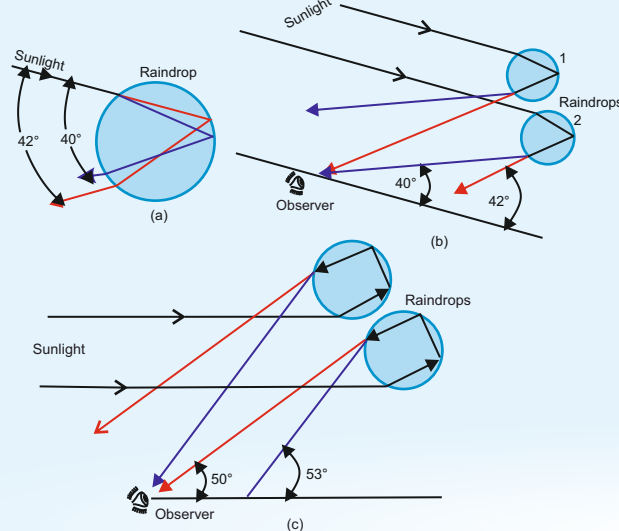


9 NATURAL PHENOMENA DUE TO SUNLIGHT

Dispersion of Light

- The phenomenon of splitting of light into constituent colours is known as dispersion.
- Dispersion takes place due to different refractive index of medium for different wavelengths.
- Chromatic aberration in thick lenses is due to dispersion.
- Rainbow is an example of dispersion of light (sun) by water drops
- In vacuum speed of light is independent of wavelength. So Vacuum is non dispersive medium.

Rainbow



Rainbow: (a) The sun rays incident on a water drop get refracted twice and reflected internally by a drop; (b) Enlarge view of internal reflection and refraction of a ray of light inside a drop form primary rainbow; and (c) Secondary rainbow is formed by rays undergoing internal reflection twice inside the drop.

10 OPTICAL INSTRUMENTS

Eye Defects Cure

- Myopia → Concave lens
- Hypermetropia → Convex lens
- Astigmatism → Cylindrical lens

Simple Microscope

- Microscope : A simple magnifier or microscope is a converging lens of high power.
- Angular magnification is equal to ratio of angular size of image to angular size of object
- Final image at near point

$$m = \left[1 + \frac{D}{f}\right]$$

- Final image at infinity

$$m = \frac{D}{f}$$

Compound Microscope

- For large magnification objective and eye piece should have low focal length
- Final image at near point

$$m = m_o \times m_e = \frac{v_o}{u_o} \left[1 + \frac{D}{f_e}\right]$$

- Final image at infinity

$$m = \frac{v_o}{u_o} \left(\frac{D}{f_e}\right)$$

Telescope

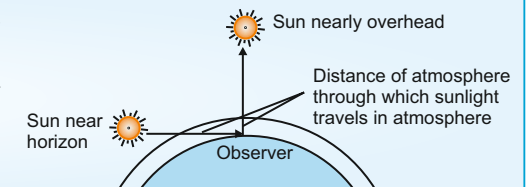
- It is used to provide angular magnification for distant objects
- Final image at infinity

$$m = \frac{f_o}{f_e} \text{ and } L = f_o + f_e$$

- Final image at near point

$$m = \frac{f_o}{f_e} \left[1 + \frac{f_e}{D}\right] \text{ and } L = f_o + \frac{Df_e}{D + f_e}$$

Scattering of light: Light of shorter wavelength is scattered much more than of longer wavelength. Amount of scattering is inversely proportional to fourth power of wavelength.



1 HUYGEN'S PRINCIPLE

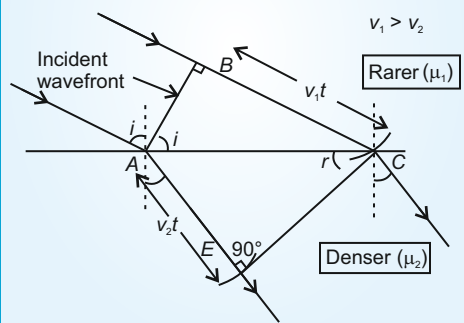
- Huygen gave a geometrical method for the propagation of wave in any medium.
- Wavefront** : Surface of constant phase. The line drawn perpendicular to wavefront gives direction of propagation of wave and energy.
- Each point on primary wavefront behaves like a new wave source from which secondary waves emit in all directions.
- If we draw the envelope of these secondary wavelets then it will give the position of secondary wavefront.
- The shape of wavefront depends on shape of wave source.
- Point source - Spherical wave fronts
- Line source - Cylindrical wavefronts
- at a large distance from the source, a small portion of wavefront is planar.

2 REFRACTION OF PLANE WAVEFRONT

$$\text{From } \triangle ABC, \sin i = \frac{BC}{AC}$$

$$\text{From } \triangle AEC, \sin r = \frac{AE}{AC}$$

$$\frac{\sin i}{\sin r} = \frac{BC}{AE} = \frac{v_1 t}{v_2 t} = \frac{v_1}{v_2} = \frac{\mu_2}{\mu_1}$$



3 REFLECTION OF A PLANE WAVEFRONT AT PLANE SURFACE

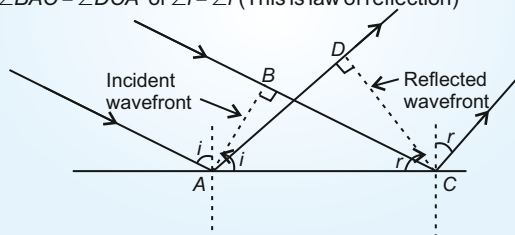
From $\triangle ABC$ and $\triangle ACD$, $BC = AD = vt$

$$\angle ABC = \angle ADC = 90^\circ$$

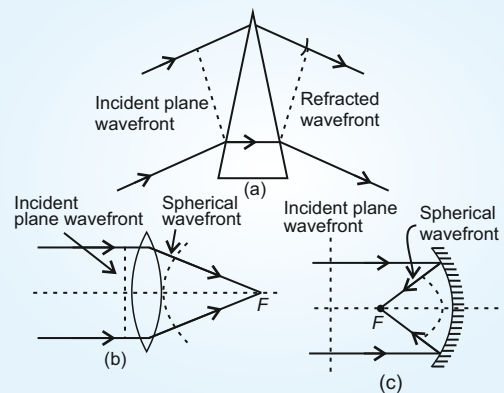
AC is common.

So $\triangle ABC$ and $\triangle ACD$ are congruent

$$\therefore \angle BAC = \angle DCA \text{ or } \angle i = \angle r \text{ (This is law of reflection)}$$



4 REFRACTION OF PLANE WAVE BY PRISM, LENS AND MIRROR



5 THE DOPPLER'S EFFECT

When the source moves away from observer the frequency as measured by source will be smaller and wavelength will be longer, this is called red shift. Towards the observer, there is an apparent decrease in wavelength, this is called blue shift.

$$\frac{\Delta v}{v} = - \frac{v_{\text{radial}}}{C}$$

6 COHERENT SOURCE

- If the phase difference between two waves reaching at a point remains constants with time, then the sources are said to be coherent.
- When the phase difference between two waves change with time it is incoherent.

7 PRINCIPLE OF SUPERPOSITION

- If number of waves reach at a point, then the resultant displacement of point is the vector sum of displacement of individual waves at that point and at that time.

- Consider two waves reach at origin $y_1 = a_1 \cos \omega t$, $y_2 = a_2 \cos(\omega t + \phi)$

From superposition law resultant amplitude is $A = \sqrt{a_1^2 + a_2^2 + 2a_1 a_2 \cos \phi}$

- For A_{max} or constructive interference**

Phase difference, $\phi = 0, 2\pi, 4\pi \dots 2n\pi$

Path difference, $\Delta x = \lambda, 2\lambda, \dots n\lambda$ where $n = 0, 1, 2, 3 \dots$

$$A_{\text{max}} = (a_1 + a_2), I_{\text{max}} \propto (a_1 + a_2)^2$$

- For A_{min} or destructive interference**

Phase difference, $\phi = \pi, 3\pi, 5\pi \dots (2n + 1)\pi$

Path difference, $\Delta x = \lambda/2, 3\lambda/2 \dots, (2n + 1)\lambda/2$ where $n = 0, 1, 2, 3, \dots$

$$A_{\text{min}} = (a_1 - a_2), I_{\text{min}} \propto (a_1 - a_2)^2$$

- If $a_1 = a_2 = a$, $A = 2a \cos(\phi/2)$ and $I_1 = I_2 = I_0 \Rightarrow I = 4I_0 \cos^2(\phi/2)$

- When phase difference between two vibrating sources changes rapidly with time, two sources are incoherent and the intensities just add up. i.e. $I = I_1 + I_2$

8 YOUNG'S DOUBLE SLIT EXPERIMENT

- Path difference, $\Delta x = S_2P - S_1P$, $\Delta x = yd/D$

- For constructive interference or bright fringes

$$yd/D = n\lambda, n = 0 \pm 1, \pm 2, \dots$$

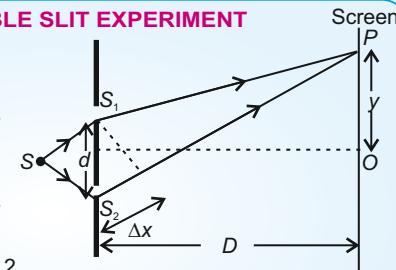
- For destructive interference or Dark fringes

$$yd/D = (2n + 1)\lambda/2, n = 0 \pm 1, \pm 2, \dots$$

- Distance between two consecutive bright (or dark) fringe called fringe width (β)

$$\beta = x_{n+1} - x_n = \lambda D/d$$

- The fringe pattern is hyperbolic, for large distances the fringe will be nearly straight lines.



9 DIFFRACTION

The phenomena of bending of waves at the narrow holes and sharp edges is called diffraction. This is exhibited by all types of waves.

Single slit diffraction

Path difference at point P

$$\Delta x = NP - LP = NQ; \Delta x = a \sin \theta \approx a \theta$$

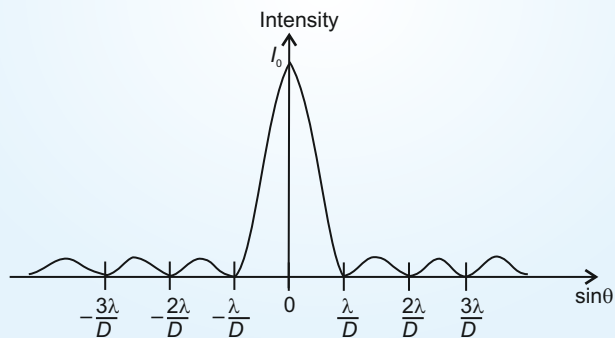
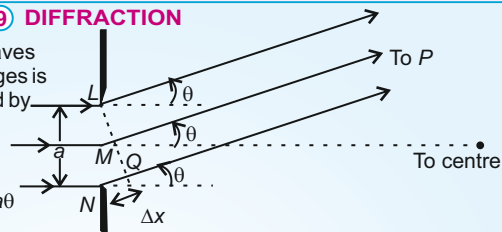
For central maxima $\theta = 0$

For secondary maxima : $\theta = (n + 1/2) \lambda / a$ where $n = \pm 1, \pm 2, \pm 3, \dots$

For minima : $\theta = n \lambda / a$ where $n = \pm 1, \pm 2, \pm 3, \dots$

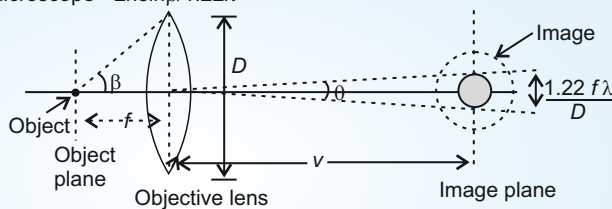
Width of central fringe $W_c = 2 \lambda D / a$

Width of secondary fringe $W = \lambda D / a$

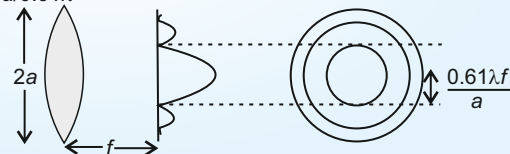


10 RESOLVING POWER OF OPTICAL INSTRUMENTS

- It is the ability to resolve the image of two nearby objects distinctly.
- Resolving power of microscope = $2n \sin \beta / 1.22 \lambda$



- The product $n \sin \beta$ is called the numerical aperture.
- Resolving power of telescope = $a / 0.61 \lambda$



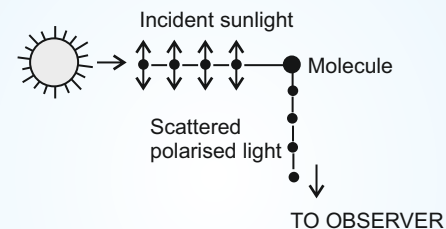
11 VALIDITY OF RAY OPTICS

Fresnel's Distance :

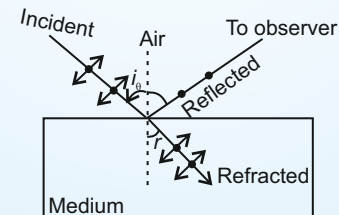
- Distance at which diffraction spread is equal to the size of aperture. $z_f \approx a^2 / \lambda$
- This gives the distance beyond which divergence of beam of width a becomes significant.
- Ray optics is valid in the limit of wavelength tending to zero.

12 POLARISATION

- The phenomena of restricting the vibration of electric vector only in one direction perpendicular to the direction of propagation is called polarisation.
- Malus' law** : The intensity of transmitted light passed through an analyser is $I = I_0 \cos^2 \theta$ where, I_0 = Intensity of polarised light after passing through polariser.
 θ = Angle between axis of polariser and analyser
- Polarisation by scattering** : An observer looking at 90° to the direction of sun. The radiations scattered by the molecules perpendicular to the incident unpolarised light (figure) is polarised.
- Scattering of light by molecules studied by C.V. Raman is called Raman effect.



- Polarisation by Reflection** : When an unpolarised light is incident at Brewster's angle (i_b), then reflected light is polarised and refracted light is partially polarised. Brewster's angle depends on refractive index of two media,
 $\mu = \tan i_b$ and $i_b + r = 90^\circ$



- Electric field vector perpendicular to plane of incidence is reflected.

1 ELECTRON EMISSION

Thermionic Emission

- The process of emission of electrons when a metal is heated is known as thermionic emission
- The emitted electrons are called thermions
- Emitted number of thermions depends on temperature of metal surface

Field Emission

- The process of emission of free electrons when a strong electric field ($\approx 10^8$ V/m) is applied across the metal surface is called field emission or cold emission, as in spark plug.

Photoelectric Emission

- The process of emission of electrons when light of suitable frequency is incident on metal surface is called as photoelectric emission
- Emitted electrons are called photoelectrons
- Number of photoelectrons emitted depends on the intensity of incident light

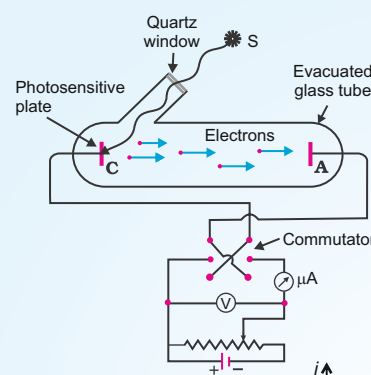
Secondary Emission

- The process of emission of free electrons when highly energetic electron beam is incident on a metal surface is called secondary emission.
- The emitted electron is called secondary electrons.

2 PHOTOELECTRIC EFFECT

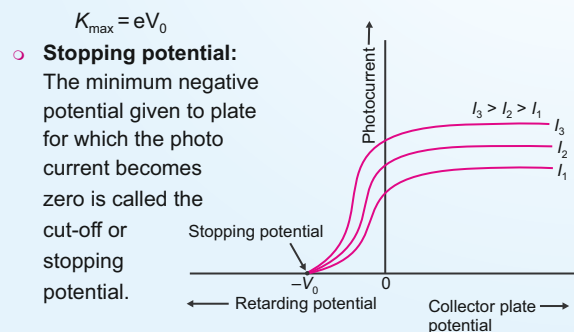
- The phenomenon of photoelectric emission was discovered in 1887 by Heinrich Hertz
- Wilhelm Hallwachs and Philipp Lenard investigated the phenomenon of photoelectric emission in detail during 1886-1902.
- Certain metals like zinc, cadmium, magnesium etc responded only to ultraviolet light to cause electron emission. However, some alkali metals such as Lithium, Sodium, Potassium, Caesium and rubidium were sensitive to visible light.

3 EXPERIMENTAL STUDY OF PHOTOELECTRIC EFFECT



- Effect of Intensity:** The number of photoelectrons emitted per second or photoelectric current is directly proportional to the intensity of radiation.
- Effect of potential on photoelectric current:**
 - For a given frequency of incident radiation, stopping potential is independent of intensity.
 - Maximum kinetic energy

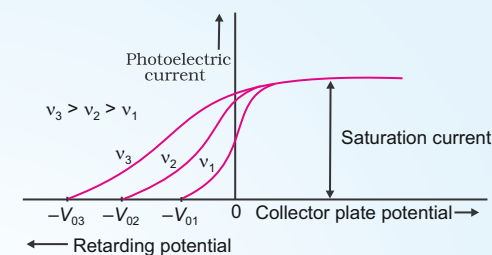
$$K_{\max} = eV_0$$



3. Effect of frequency of incident radiation on stopping potential:

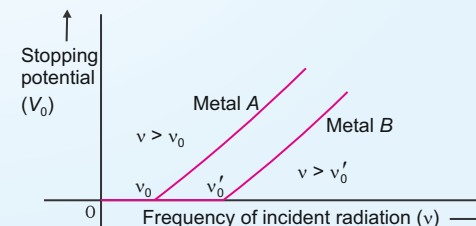
- Saturation current is independent of frequency
- Stopping potential depends on frequency of radiation.

$$(h\nu - h\nu_0 = eV_0)$$



- The maximum kinetic energy of photoelectrons varies linearly with the frequency of incident radiation, but is independent of intensity.
- For a frequency less than threshold ($\nu < \nu_0$) no photoelectric emission is possible even if intensity is large.
- **Threshold frequency (ν_0):** The minimum frequency of incident radiation required to emit electrons called threshold frequency. It is different for different metals.
- **Work function (ϕ_0):** The minimum energy of incident radiation required to emit electrons from metal called work function

$$\phi_0 = h\nu_0$$
- Emission starts in a time of the order of 10^{-9} s or less.



4 EINSTEIN'S PHOTOELECTRIC EQUATION: ENERGY QUANTUM OF RADIATION

In 1905 Albert Einstein proposed that radiation energy is built up of discrete units—the so called quanta of energy radiation. Later it was called photon. Each photon has energy ($h\nu$). When energy of photon striking at surface is greater than work function (ϕ_0), electron is emitted

Maximum kinetic energy of electrons

$$K_{\max} = eV_0 = h\nu - \phi_0 \quad h = \text{Planck's constant} = 6.626 \times 10^{-34} \text{ Js}$$

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

This is equation of straight line with slope $\left(\frac{h}{e}\right)$

- $\left(\frac{h}{e}\right)$ is independent of nature of material
- All photons of frequency (ν), have the same energy ($h\nu$), momentum, $P = \left(\frac{h}{\lambda}\right)$
- Photons are electrically neutral
- Increase in intensity of a given frequency means increase in number of photons per second crossing a given area.

5 PHOTOCCELL

- It is a device which converts light energy into electrical energy.
- The photocurrent produced is of order of microampere.
- In gas filled photocell, current is increased due to ionization of the gas.
- It is also called electronic eye
- It is used in operation of control system and in light measuring devices

6 WAVE NATURE OF MATTER

de-Broglie proposed that the wavelength λ associated with a particle of momentum P is

$$\lambda = \frac{h}{P} = \frac{h}{mv} = \frac{h}{\sqrt{2Km}}$$

- If a charged particle having charge q accelerate from rest through a potential V .

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

- For electron, $\lambda = \frac{1.227}{\sqrt{V}}$ nm.
- For proton, $\lambda = \frac{0.0286}{\sqrt{V}}$ nm.
- For α -particle, $\lambda = \frac{0.0101}{\sqrt{V}}$ nm.

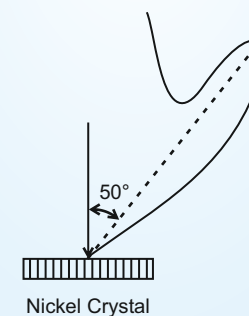
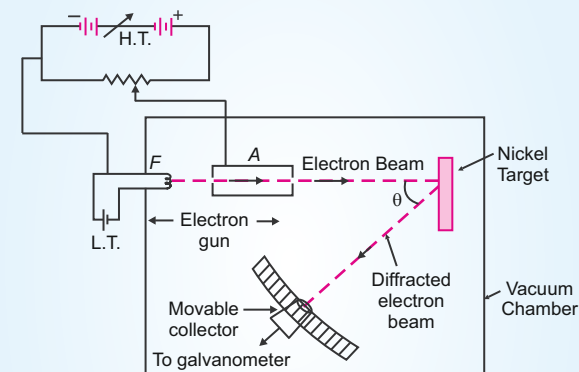
- According to Heisenberg, it is not possible to measure both the position and momentum of a particle at the same time exactly.
- $\Delta x \Delta p \approx \frac{h}{2\pi}$

8 ELECTRON MICROSCOPE

- It is a practical device that relies the wave characteristics of electron.
- Resolving power of electron microscope $\propto \frac{1}{\lambda}$
 $\propto \sqrt{V}$ (V is accelerating potential)
- Resolving power of electron microscope is approximately 10^5 times the resolving power of optical microscope.

7 DAVISSON AND GERMER EXPERIMENT

- The experimental set up used by Davisson and Germer is as shown in figure to verify wave nature of electrons
- The experiment was performed by varying the voltage from 44 V to 68 V. It was noticed that strong peak appeared in intensity (I) of scattered electron for voltage 54 V at scattering angle 50°



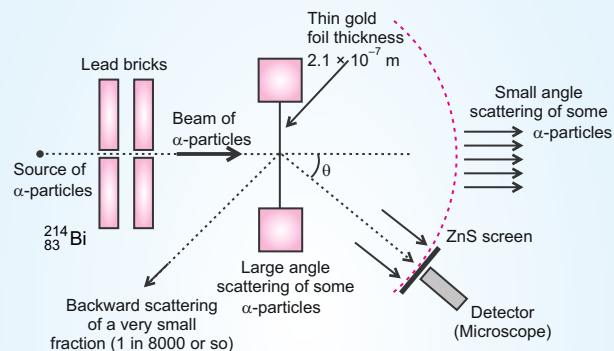
1 ATOMIC MODELS

Thomson's Model Rutherford Model Bohr's Model

Thomson's Model

Atom is a spherical cloud of positive charge with electrons embedded into it, like seeds in watermelon.

α -Particle Scattering Experiment and Rutherford nuclear model of atom



Conclusions

1. Only about 0.14% of incident α -particle scatter by more than 1°
2. About 1 in 8000 deflect by more than 90°
3. Size of nucleus to be about 10^{-15} m to 10^{-14} m
4. For large impact parameter the α -particle goes nearly undeviated.
5. In case of head on collision, the impact parameter is minimum and α -particle rebound back ($\theta \cong \pi$)

Rutherford's Model

According to Rutherford most of the mass of atom and all its positive charge are concentrated in a tiny space of the order of 10^{-14} m, called nucleus and electrons revolve around it. Centripetal force is obtained from electrostatic attraction between electron and nucleus.

Draw backs

- (i) Stability of atom
- (ii) Line spectrum of atoms

2 IMPACT PARAMETER

It is perpendicular distance of initial velocity vector of the α particle from the centre of nucleus.

$$b = \frac{Ze^2 \cot\left(\frac{\theta}{2}\right)}{4\pi\epsilon_0 E}$$

Electron orbit

- radius (r) = $\frac{e^2}{4\pi\epsilon_0 mv^2}$
- Kinetic energy (K) = $\frac{e^2}{8\pi\epsilon_0 r}$
- Potential energy (U) = $-\frac{e^2}{4\pi\epsilon_0 r}$
- Total energy (E) = $K + U = -\frac{e^2}{8\pi\epsilon_0 r}$

Bohr's Model

Bohr combined classical and quantum concepts and gave the theory in terms of three postulates.

1. An electron can revolve in certain stable orbits without emission of radiant energy.
2. Electron can revolve only in those orbits in which angular momentum is integral multiple of $\left(\frac{h}{2\pi}\right)$
$$L = mv_n r_n = \frac{nh}{2\pi}, \quad n = 1, 2, 3, \dots$$
3. When an electron makes a transition from one of the specified non radiatory orbit to another lower energy orbit then radiate energy equal to the difference of energy equal to final and initial state.

- Bohr's model is applicable for hydrogen and hydrogen like elements.

Limitations of Bohr's Model

- Bohr's model is applicable for single electron atom/ions.
- Bohr's model correctly predict the frequencies of the light emitted by hydrogenic (hydrogen like) atoms but unable to explain the relative intensities of light

3 DIFFERENT QUANTITIES FOR HYDROGEN LIKE ELEMENTS

- Radius of the n^{th} orbit:

$$r_n = \left(\frac{\epsilon_0 h^2}{\pi m e^2}\right) \frac{n^2}{Z} = 0.529 \frac{n^2}{Z} \text{ \AA}$$

$$\Rightarrow r_n \propto \frac{n^2}{Z}$$

- Speed of electron in n^{th} orbit:

$$v_n = \frac{e^2 Z}{2h\epsilon_0 n} = \frac{c Z}{137 n}$$

$$\Rightarrow v_n \propto \frac{Z}{n}$$

- Energy of electron in n^{th} orbit

$$E_n = -\left(\frac{me^4}{8\epsilon_0^2 h^2}\right) \frac{Z^2}{n^2} \text{ J} = (2.18 \times 10^{-18}) \frac{Z^2}{n^2} \text{ J}$$

$$\text{or } E_n = -\frac{13.6Z^2}{n^2} \text{ eV}$$

$$\Rightarrow E_n \propto \frac{Z^2}{n^2}$$

- Time period of revolution of electron in n^{th} orbit.

$$T = \left(\frac{4\epsilon_0 h^3}{me^4}\right) \frac{n^3}{Z^2}$$

$$= \frac{n^3}{Z^2} (1.51 \times 10^{-16} \text{ s})$$

$$\Rightarrow T \propto \frac{n^3}{Z^2}$$

4 HYDROGEN SPECTRUM

1. Lyman series

$$\frac{1}{\lambda} = R \left[\frac{1}{1^2} - \frac{1}{n^2} \right], n = 2, 3, 4 \dots \infty$$

lies in U.V. region

2. Balmer series

$$\frac{1}{\lambda} = R \left[\frac{1}{2^2} - \frac{1}{n^2} \right], n = 3, 4, 5 \dots \infty$$

Mostly lies in visible region

3. Paschen series

$$\frac{1}{\lambda} = R \left[\frac{1}{3^2} - \frac{1}{n^2} \right], n = 4, 5, 6 \dots \infty$$

lies in near infra red region

4. Bracket series

$$\frac{1}{\lambda} = R \left[\frac{1}{4^2} - \frac{1}{n^2} \right], n = 5, 6, 7 \dots \infty$$

lies in infra red region

5. Pfund series

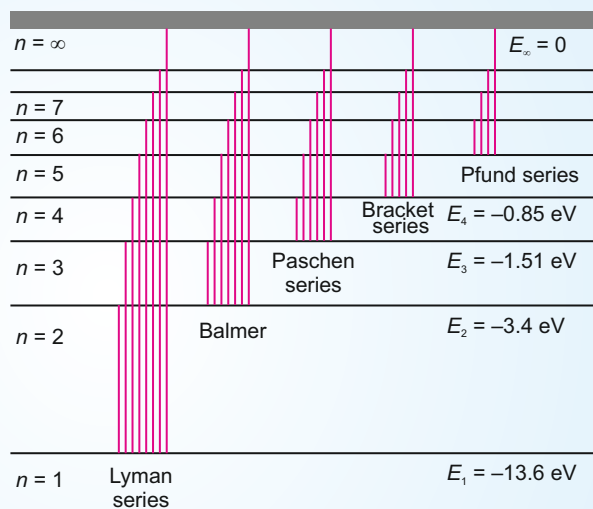
$$\frac{1}{\lambda} = R \left[\frac{1}{5^2} - \frac{1}{n^2} \right], n = 6, 7, 8 \dots \infty$$

lies in far infra red region

Rydberg constant

$$R = \frac{me^4}{8\epsilon_0 h^3 c} = 1.03 \times 10^7 \text{ m}^{-1} \text{ (By Bohr-model)}$$

$$R = 1.097 \times 10^7 \text{ m}^{-1} \text{ (from Balmer empirical formula)}$$



(Line spectra originate in Transition between energy levels)

5 DE BROGLIE'S EXPLANATION OF BOHR'S SECOND POSTULATE OF QUANTISATION

de-Broglie explained second postulate of Bohr's atomic model by assuming an electron has wave nature.

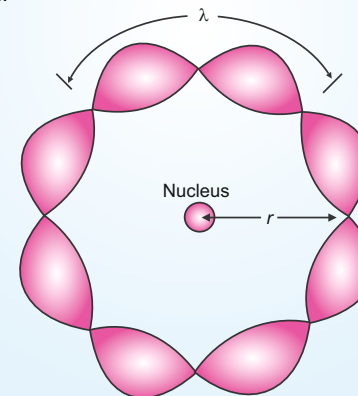
The circumference of orbit should be integer multiple of de-Broglie wavelength of electron in n^{th} orbit.

○ $2\pi r_n = n\lambda, n = 1,2,3,\dots$

or

$$mv_n r_n = \frac{nh}{2\pi}$$

○ This is quantum condition proposed by Bohr for an angular momentum of an electron.



6 LASER

Acronym: light amplification by stimulated emission of radiation.

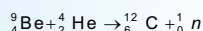
- It involves population inversion.
- It is highly coherent
- Laser light is highly monochromatic
- Divergence of laser beam is very less
- If there are N atoms, each emitting light with intensity I , then net intensity produced by ordinary source is proportional to NI whereas in laser source, it is proportional to $N^2 I$
- There are low power lasers with a power of 0.5 mW, called pencil lasers which serve as pointers. These lasers are used for delicate surgery of eye or glands in stomach.
- Laser can cut and weld steel.

1 ATOMIC MASSES AND COMPOSITION OF NUCLEUS

- Before discovery of neutron, nucleus was assumed to be made up of protons and electrons but later this was ruled out using argument of quantum theory.

2 DISCOVERY OF NEUTRON

- In 1932 James Chadwick observed emission of neutral radiation, when beryllium nuclei was bombarded with α -particle on the basis of energy and momentum conservation. Chadwick concluded that it was a new type of neutral particle called neutron.



- All nuclides with same atomic number but having different mass are called isotopes.
- All nuclides with same mass number are called isobars.
- Nuclides with same neutron but different atomic number are called isotones.
- $A = Z + N$

3 SIZE OF NUCLEUS

- The radius of nucleus with mass number 'A' is $R = R_0 A^{1/3}$ where, $R_0 = 1.2 \times 10^{-15}$ m.
- Density of nucleus is approximately 2.3×10^{17} kg/m³ and is independent of mass number.

4 MASS ENERGY AND NUCLEAR BINDING ENERGY

- Mass energy** : Einstein showed that mass is another form of energy and one can convert into other form. Einstein gave the famous mass energy equivalence relation $E = mc^2$.
- $1u = 931.5 \text{ MeV}/c^2$

5 NUCLEAR BINDING ENERGY

- The difference in mass of a nucleus (${}_Z X^A$) and its constituents, ΔM , is called the mass defect.

$$\Delta M = [Zm_p + (A-Z)m_n] - M$$

- If one wants to break the nucleus into protons and neutrons. This extra energy $(\Delta M)c^2$, has to be supplied. This energy called binding energy.

$$E_b = \Delta Mc^2$$

7 LAW OF RADIOACTIVE DECAY

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

$$N = N_0 e^{-\lambda t}$$

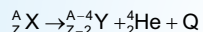
$$\text{Half life: } T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.6931}{\lambda}$$

- λ = Decay constant.

$$\text{Mean life, } \tau = \frac{1}{\lambda} = 1.44 T_{1/2}$$

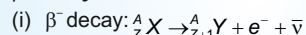
α -Decay : During α -decay, atomic number decreases by two and mass number by four.

- It is nuclei of helium

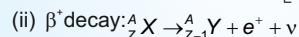


$$Q = (m_x - m_y - m_{\text{He}}) C^2$$

- β -Decay** :



$$Q = [m({}_Z X^A) - m({}_{Z+1} Y^A)] C^2$$



$$Q = [m({}_Z X^A) - m({}_{Z-1} Y^A) - 2m_e] C^2$$

- γ -Decay** :

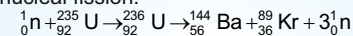
- Like an atom, a nucleus also has discrete energy levels, the ground state and excited states. When a nucleus in an excited state spontaneously decays to ground state (or to lower energy state), a photon is emitted. This is called γ -decay.
- The difference in nuclear energy levels is of the order of MeV.

6 NUCLEAR FORCE

- Inside the nucleus, a large attractive force is required to bind the nucleons against repulsion. The force is called nuclear force.
- It is strongest attractive force. $F_{p-p} = F_{n-n} = F_{p-n}$
- It is charge independent force i.e.
- It is short range force.
- It has property of saturation.
- For a distance ($r < 0.8$ fm) it is repulsive force.

8 NUCLEAR FISSION

- When a slow moving neutron strikes a heavy nucleus, which breaks into two intermediate mass nuclear fragments. This is called nuclear fission.



- The energy released (the Q-value) in the fission of single uranium is of the order of 200 MeV.
- Multiplication factor (K) = $\frac{\text{Rate of production of neutrons}}{\text{Rate of loss of neutrons}}$
- Uncontrolled chain reaction is the principle of atom bomb.
- Controlled chain reaction is the principle of nuclear reactors.

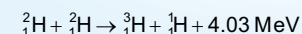
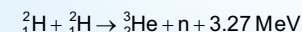
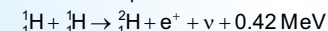
9 NUCLEAR REACTOR

- U^{235} or Pu^{239} is used as fuel in a nuclear reactor.
- D_2O , graphite and beryllium oxide are used as moderator to slow down the fast neutrons.
- Rate of reaction is controlled by control rods made of cadmium or boron
- Air, ice cold water, molten sodium or CO_2 are used as coolant.

10 NUCLEAR FUSION

It is the phenomenon in which two or more lighter nuclei combine to form a single middle weight nucleus.

Some examples of nuclear fusion.



1 SEMICONDUCTOR

- Its conductivity or resistivity lies between conductor and insulator
 - Negative temperature coefficient of resistance
 - Band gap is less than 3 eV
- Intrinsic Semiconductor**
- It is pure semiconductor
 - Carriers are thermally generated
 - At 0 K, behaves like insulator
 - $n_e = n_h = n_i$
- Extrinsic Semiconductor**
- Conductivity is increased by doping.
- p-type semiconductor**
- Doped with trivalent atom
 - Holes are majority carriers
 - $n_h \gg n_e$
- n-type semiconductor**
- Doped with pentavalent atom
 - Electrons are majority carriers
 - $n_e \gg n_h$
 - Law of mass action $n_e n_h = n_i^2$

2 p-n JUNCTION

- A p-type semiconductor is brought in contact with a n-type semiconductor
- A depletion layer is formed at junction.
- Thickness of depletion layer decreases with increase in doping and forward biasing

Biasing of p-n junction


Forward biasing

- Width of depletion layer decreases
- Effective barrier potential decreases
- Low resistance at junction
- Current flow is of the order of mA

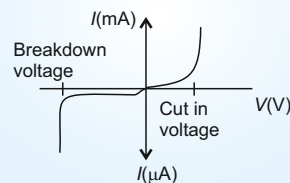
Reverse biasing

- Width of depletion layer increases
- Effective barrier potential increases
- High resistance at junction
- Current flow is of the order of μA
- Breakdown occurs at high reverse bias voltage

3 SEMICONDUCTOR DIODE

- It is a device having single p-n junction
- Symbol: Anode  Cathode

V-I characteristics



4 APPLICATION OF DIODE

Diode as a Rectifier

Half wave-rectifier

- It rectifies either positive or negative cycle only, of input signal
- Frequency of output and input are same

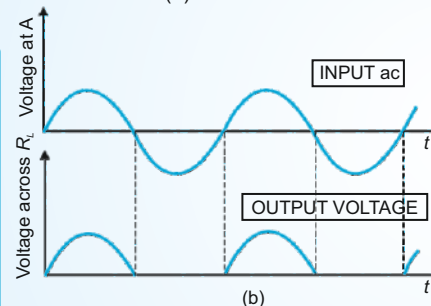
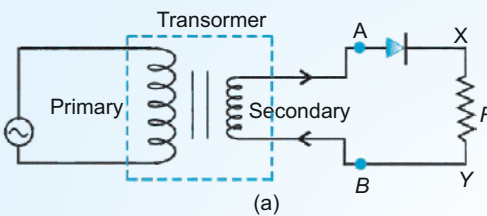


Figure : (a) Half-wave rectifier circuit, (b) Input ac voltage and output voltage waveforms from the rectifier circuit.

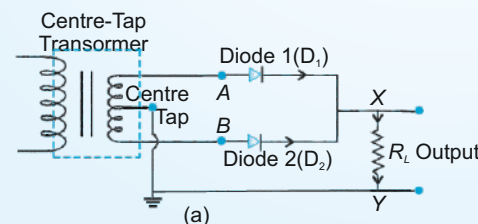


Figure: (a) A Full-wave rectifier circuit; (b) Input wave forms given to the diode D_1 at A and to the diode D_2 at B; (c) Output waveform across the load R_L connected in the full-wave rectifier circuit.

Zener diode as a Voltage Regulator

- Zener diode is highly order reverse doped p-n junction diode
- It is operated as regulator when diode is in reversed bias
- The output voltage is fixed and is equal to Zener voltage

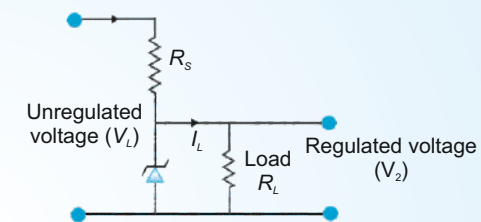
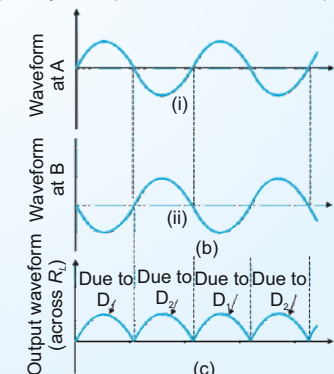


Figure: Zener diode as DC voltage regulator

Full wave rectifier

- It rectifies both the cycles of input
- Frequency of output is two times the frequency of input



5 OPTOELECTRONIC DEVICE

Light Emitting Diode

- It is generally operated in forward bias
- It is used to transmit optical signals
- V-I characteristics is same as of normal p-n junction diode
- E_g should be in range of energy of visible light
- Band width of emitted light is 100 Å to 500 Å

Photodiode

- It is generally operated in reverse bias
- It is used to detect the optical signal
- V-I characteristics lies in 3rd quadrant
- Reverse current increases with increase in intensity of incoming signal

Solar Cell

- It is used in unbiased condition
- It generates emf from solar radiations
- V-I characteristics lies in 4th quadrant
- Semiconductor with E_g closed to 1.5 eV are ideal material for solar cell.

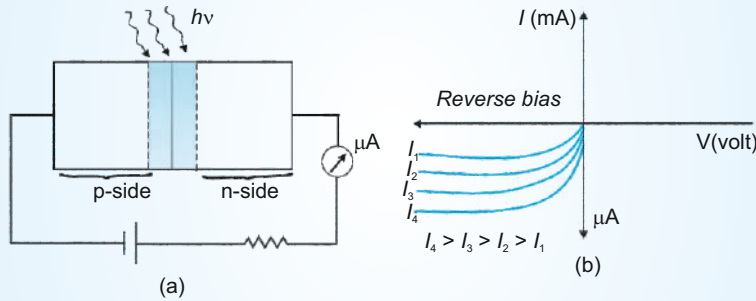


Fig. : (a) An illuminated photodiode under reverse bias, (b) I-V characteristics of a photodiode for different illumination intensity $I_4 > I_3 > I_2 > I_1$

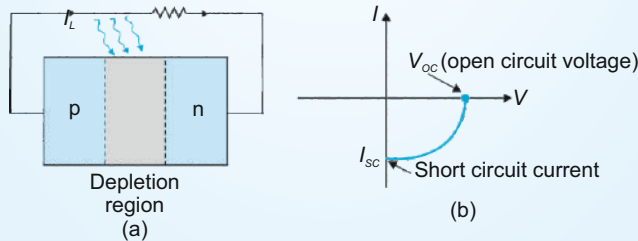
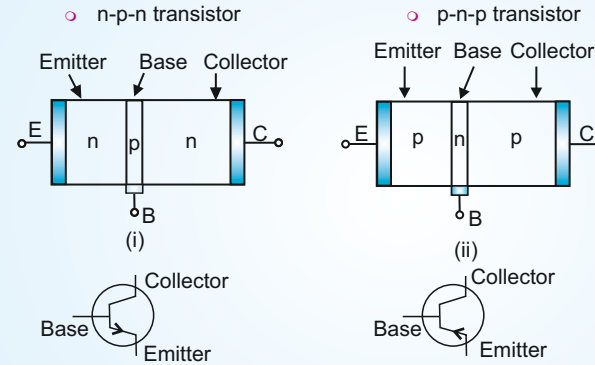


Figure : (a) A typical illuminated p-n junction solar cell; (b) I-V characteristics of a solar cell.

6 JUNCTION TRANSISTOR

- It is two junction and three terminal device
- Fundamental action of transistor is transfer resistor
- Length profile $L_C > L_E > L_B$
- Doping profile $E > C > B$

Types of transistor



Modes of Operation

E-B junction	B-C junction	Mode of operation	Application
Forward	Reverse	Active	Amplifier
Forward	Forward	Saturation	Switch (on)
Reverse	Reverse	Cut off	Switch (off)

Configuration of transistor (BJT)

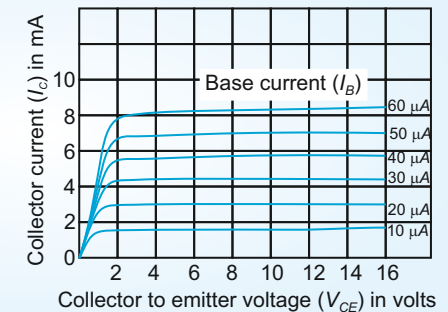
- Common base configuration
- Common emitter configuration
- Common collector configuration

7 COMMON EMITTER (CE) CONFIGURATION

Transistor characteristics

- Input resistance $(r_i)_{CE} = \frac{\Delta V_{BE}}{\Delta I_B}$
- Output resistance $(r_o)_{CE} = \frac{\Delta V_{CE}}{\Delta I_C}$
- Transconductance $(g_m) = \left(\frac{\Delta I_C}{\Delta V_{BE}} \right)$
- Current gain of different configuration $\alpha_{ac} = \frac{\Delta I_C}{\Delta I_E}$, $\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}$, $\gamma_{ac} = \frac{\Delta I_E}{\Delta I_B}$

- Output characteristics of CE amplifier



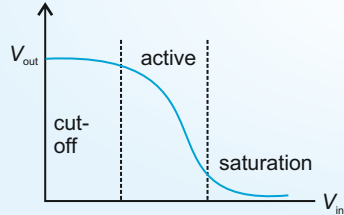
8 APPLICATION OF TRANSISTOR

○ Transistor as an amplifier

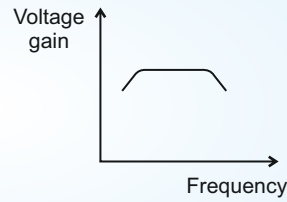
• Voltage gain $(A_v) = \frac{V_o}{V_i}$
 $= -\beta \frac{R_{out}}{R_{in}} = -g_m R_{out}$

• Power gain $(A_p) = A_v \times \beta_{ac}$

○ Transistor as a switch



○ Variation of voltage gain with frequency is given as

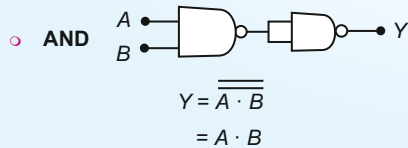
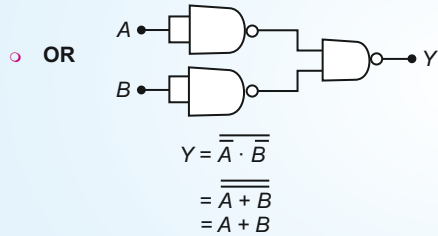
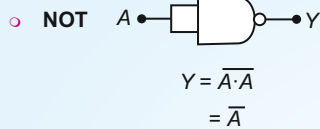


○ Transistor as an oscillator

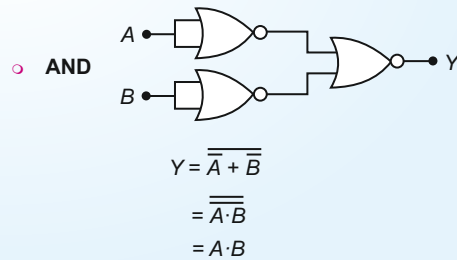
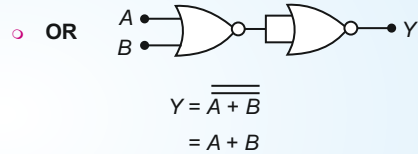
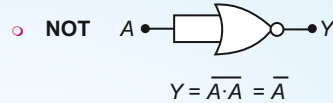
• Barkhausen criteria for sustained oscillation is $A\beta = 1$

11 REALISATION OF BASIC GATES USING NAND OR NOR GATES

Using NAND only



Using NOR only



9 LOGIC GATES

Logic gate	Symbol	Characteristic equation	Truth table															
NOT		$Y = \overline{A}$	<table border="1"> <tr><td>A</td><td>Y</td></tr> <tr><td>0</td><td>1</td></tr> <tr><td>1</td><td>0</td></tr> </table>	A	Y	0	1	1	0									
A	Y																	
0	1																	
1	0																	
OR		$Y = A + B$	<table border="1"> <tr><td>A</td><td>B</td><td>Y</td></tr> <tr><td>0</td><td>0</td><td>0</td></tr> <tr><td>0</td><td>1</td><td>1</td></tr> <tr><td>1</td><td>0</td><td>1</td></tr> <tr><td>1</td><td>1</td><td>1</td></tr> </table>	A	B	Y	0	0	0	0	1	1	1	0	1	1	1	1
A	B	Y																
0	0	0																
0	1	1																
1	0	1																
1	1	1																
AND		$Y = A \cdot B$	<table border="1"> <tr><td>A</td><td>B</td><td>Y</td></tr> <tr><td>0</td><td>0</td><td>0</td></tr> <tr><td>0</td><td>1</td><td>0</td></tr> <tr><td>1</td><td>0</td><td>0</td></tr> <tr><td>1</td><td>1</td><td>1</td></tr> </table>	A	B	Y	0	0	0	0	1	0	1	0	0	1	1	1
A	B	Y																
0	0	0																
0	1	0																
1	0	0																
1	1	1																
NAND		$Y = \overline{A \cdot B}$	<table border="1"> <tr><td>A</td><td>B</td><td>Y</td></tr> <tr><td>0</td><td>0</td><td>1</td></tr> <tr><td>0</td><td>1</td><td>1</td></tr> <tr><td>1</td><td>0</td><td>1</td></tr> <tr><td>1</td><td>1</td><td>0</td></tr> </table>	A	B	Y	0	0	1	0	1	1	1	0	1	1	1	0
A	B	Y																
0	0	1																
0	1	1																
1	0	1																
1	1	0																
NOR		$Y = \overline{A + B}$	<table border="1"> <tr><td>A</td><td>B</td><td>Y</td></tr> <tr><td>0</td><td>0</td><td>1</td></tr> <tr><td>0</td><td>1</td><td>0</td></tr> <tr><td>1</td><td>0</td><td>0</td></tr> <tr><td>1</td><td>1</td><td>0</td></tr> </table>	A	B	Y	0	0	1	0	1	0	1	0	0	1	1	0
A	B	Y																
0	0	1																
0	1	0																
1	0	0																
1	1	0																

10 BOOLEAN LOGIC

- $A + A = A$
- $A + 0 = A$
- $\overline{A+B} = \overline{A} \cdot \overline{B}$
- $A \cdot A = A$
- $A \cdot 0 = 0$
- $\overline{A \cdot B} = \overline{A} + \overline{B}$
- $A + 1 = 1$
- $A \cdot \overline{A} = 0$
-
- $A \cdot 1 = A$
- $A + \overline{A} = 1$