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Mind Map-2

Electrostatic Potential And Capacitance

Electric potential due to a charged conducting spherical shell

At a point on the surface or inside the spherical shell
$V = \frac{1}{4\pi \epsilon_0}\frac{q}{R}$ $(r \le R)$

At a point outside the spherical shell
$V = \frac{1}{4\pi \epsilon_0}\frac{q}{r}$ $(r > R)$

Electric potential due to a charged non-conducting sphere

At a point on the surface or inside the sphere
$= \frac{1}{4\pi \epsilon_0}\frac{q}{R}$ $(r \le R)$

At a point outside the non-conducting sphere
$V = \frac{1}{4\pi \epsilon_0}\frac{q}{r}$ $(r > R)$

Electrostatic potential due to infinite thin plane sheet of charge

$V = -\frac{\sigma r}{2\varepsilon_0} + C$

σ = uniform surface charge density

Electric potential due to a dipole

On axial line
$V = \frac{1}{4\pi \varepsilon_0}\frac{p}{r^2}$

On equatorial line V = 0
At general point,
$V_g = \frac{kP\cos\theta}{r^2}$

Due to charged circular ring

(i) At a point distance x away from the centre of the ring
$V = \frac{kQ}{\sqrt{x^2+k^2}}$

(ii) At centre,
$V_{centre} = \frac{kQ}{k}$

Electrostatic potential

(V_0) = work done w_∞ / charge (q_0)

Positive potential due to +(ve) charge and negative potential due to –(ve) charge

Electrostatic potential energy of a

(i) System of 'n' charges $U = \frac{K}{2}\sum_{\substack{i,j\\ i\ne j}}^{n}\frac{Q_1Q_2}{r_{ij}}$

(ii) Uniformly charged sphere, $U = \frac{30Q^2}{20\pi\varepsilon_0 R}$

(iii) Uniformly charged thin spherical shell $U = \frac{Q^2}{8\pi\varepsilon_0 R}$

(iv) Energy density $U_e = \frac{1}{2}\varepsilon_0 \in^2$

Equipotential surface

Imaginary surface joining the points of same potential in an electric field

- The direction of electric field is perpendicular to the equipotential surface or lines.
- A metallic surface of any shape is an equipotential surface.

Electrostatic potential due to a point charge
$V = K\frac{q}{r}$

Electrostatic potential due to a system of charges
$V = V_1 + V_2 + V_3 ... + V_n$
$V = K\sum_{i=1}^{n}\frac{q_i}{r_i}$

Electric potential due to continuous charge distribution
$V = \int dV = \int\frac{dQ}{4\pi\epsilon_0 r}$

Relation between electric potential and field,
$E = -\frac{dV}{dr}$

Negative of the slope of the V–r graph denotes intensity of electric field, tanθ
$\tan\theta = \frac{V}{r} = -E$

Combination of Charged Drops

If n identical drops each having radius r Capacitance, c, Charge, q, Potential, v and energy, u. If these drops are combined to form a big drop of radius, R,

Charge on big drop: Q = nq

Potential of big drop: $V = \frac{Q}{C} = \frac{nq}{n^{1/3}}$ $V = n^{2/3}v$

Capacitance

(c) = $\frac{\text{Charge (Q)}}{\text{Potential (V)}}$

Capacitance of a parallel plate capacitor

$C = \frac{KA\varepsilon_0}{d}$ K = dielectric constant

- If a dielectric slab is partially filled between the plates.
  $\Rightarrow C' = \frac{\varepsilon_0 A}{d - t + \frac{t}{K}}$
- If a number of dielectric slabs are inserted between the plate as shown.
  $C' = \frac{\varepsilon_0 A}{d - (t_1 + t_2 + t_3 + ...) + \left(\frac{t_1}{K_1} + \frac{t_2}{K_2} + \frac{t_3}{K_3} + ...\right)}$
- When a metallic slab is inserted between the plates
  $C' = \frac{\varepsilon_0 A}{(d-t)}$

Energy stored in a capacitor

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

Energy loss when two isolated charged conductors are connected to each other
$= \frac{1}{2}\frac{C_1C_2(V_1 - V_2)^2}{C_1 + C_2}$

Combination of capacitors

Series grouping of capacitors
Equivalent capacitance
$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + ... + \frac{1}{C_n}$

In series combination potential difference and energy distributes in the reverse ratio of capacitance

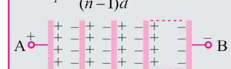
i.e., $V \propto \frac{1}{C}$ and $U \propto \frac{1}{C}$.

If n identical capacitors each having capacities C are connected

$C_{eq} = \frac{C}{n}$

If n identical plates are arranged as shown they constitute $(n-1)$ capacitors in series. If each capacitor has capacitance $\frac{\varepsilon_0 A}{d}$ then

$C_{eq} = \frac{\varepsilon_0 A}{(n-1)d}$



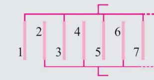
In this situation except two extreme plates each plate is common to adjacent capacitors. Here, effective capacitance C_{eq} is even less than the least of the individual capacitances.

Parallel grouping of capacitors
Equivalent capacitance
$C_p = C_1 + C_2 + ... C_n$

In parallel combination change and energy distributes in the ratio of capacitance i.e., $Q \propto C$ and $U \propto C$

If n identical capacitors are connected in parallel, then Equivalent capacitance $C_{eq} = nC$ and Change on each capacitor $Q' = \frac{Q}{n}$

If n identical plates are arranged such that even numbered of plates are connected together and odd numbered plates are connected together, then $(n-1)$ capacitors will be formed and they will be in parallel grouping.



Equivalent capacitance
$C' = (n-1)C$
where C = capacitance of a capacitor $= \frac{\varepsilon_0 A}{d}$

If C_p is the effective capacity when n identical capacitors are connected in parallel and C_s is their effective capacity when connected in series, then $\frac{C_p}{C_s} = n^2$.

Spherical capacitor

Spherical capacitor: It is of two concentric conducting spheres of radii a and b $(a < b)$. Inner sphere is given charge $+Q$, while outer sphere is earthed

Capacitance, $C = 4\pi\varepsilon_0 b\frac{ab}{b-a}$.

In the presence of dielectric medium (dielectric constant K) between the spheres

$C' = 4\pi\varepsilon_0 K\frac{ab}{b-a}$

If outer sphere is given a charge $+Q$ while inner sphere is earthed

Capacitance $C' = 4\pi\varepsilon_0 \cdot \frac{b^2}{b-a}$

This arrangement is not a capacitor. But it's capacitance is equivalent to the sum of capacitance of spherical capacitor and spherical conductor

i.e., $4\pi\varepsilon_0 \cdot \frac{b^2}{b-a}$

$= 4\pi\varepsilon_0 \cdot \frac{ab}{b-a} + 4\pi\varepsilon_0 b$

Cylindrical capacitor: It consists of two co-axial cylinders of radii a and b $(a < b)$, inner cylinder is given charge $+Q$ while outer cylinder is earthed. Common length of the cylinders is l

Capacitance, $C = \frac{2\pi\varepsilon_0 l}{\log_e\left(\frac{b}{a}\right)}$

Mind Map-3

Current Electricity

Series grouping of resistances
Equivalent resistance, $R_s = R_1 + R_2 + ... + R_n$
In this case same current flows through each resistance but potential difference distributes in the ratio of resistance

Parallel grouping of resistances
Equivalent resistance,
$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_n}$$
In this case same potential across each resistance but current distributes in the reverse ratio of their resistances

After stretching, if length increases by n times then resistance will increase by n^2 times i.e., $R_2 = n^2 R_1$. Similarly if radius be reduced to $\frac{1}{n}$ times then area of cross-section decreases $\frac{1}{n^2}$ times so the resistance becomes n^4 times i.e., $R_2 = n^4 R_1$.
After stretching, if length of a conductor increases by x%, then resistance will increase by $2x$% (valid only if $x < 10\%$).

Grouping of resistances

Resistance (R) Obstruction offered to flow of electrons

On length (ℓ) and area of cross-section (A)
$$\left.\begin{matrix} R \propto l \\ \propto \frac{1}{A} \end{matrix}\right\} R = \rho \frac{l}{A}$$
ρ = resistivity
Resistivity depends on the material of the conductor only.

Resistance, $R \propto \frac{\ell^2}{m}$
ℓ = length and m = mass of conducting wire

Dependence of resistance

Ohm's law If the physical conditions remain same, current $I \propto V \Rightarrow V = IR$
R-electric resistance
Substances which obey ohm's law called ohmic and that do not obey called non-ohmic substances.

Colour coding of Resistance
R = AB × C ± D% A, B – First two significant figures of resistance C-multiplier D-tolerance to remembers the sequence of colour code **B B Roy** Great **Britain** Very **Good Wife**

On temperature
$R_t = R_0(1 + \alpha t)$
α = temperature coefficient of resistance

Current density (J)
Current per unit cross sectional area
(A) $\vec{J} = \frac{I}{A} = \frac{\vec{E}}{\rho}$

Conductivity (σ)
Reciprocal of resistivity $\sigma = \frac{1}{\rho}$
Conductance, $C = \frac{1}{\text{resistance}}$

Electric Current (I) The time rate of flow of charge (Q) through any cross-section
$$I = \frac{Q}{t};\ I = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt}$$

Drift velocity (V_d)
Average uniform velocity acquired by free electrons $V_d = \frac{i}{neA} = \frac{J}{ne} = \frac{V}{\rho \ell ne}$
$$V_d = \frac{E}{\rho ne}$$
Direction of drift velocity for electrons in a metal is opposite to that of applied electric field.

Mobility (μ)
Drift velocity per unit electric field $\mu = \frac{V_d}{E}$

- Using n conductors of equal resistance, the number of possible combinations is 2^{n-1}.
- If the resistances of n conductors are totally different, then the number of possible combinations will be 2^n.
- If n identical resistances are first connected in series and then in parallel, the ratio of the equivalent resistance is given by $\frac{R_s}{R_p} = \frac{n^2}{1}$.
- If a wire of resistance R is cut in n equal parts and then these parts are collected to form a bundle, then equivalent resistance of combination will be $\frac{R}{n^2}$.
- If equivalent resistance of R_1 and R_2 in series and parallel be R_s and R_p respectively, then $R_1 = \frac{1}{2}\left[R_s + \sqrt{R_s^2 - 4R_sR_p}\right]$ and $R_2 = \frac{1}{2}\left[R_s - \sqrt{R_s^2 - 4R_sR_p}\right]$.

Electric cell Source of energy that maintains continuous flow of charge in a circuit

Electrical energy
$H \propto I^2$, $\propto R$, $\propto t$ — **Jule's heating law** $H = I^2Rt$; Electrical power $P = \frac{V^2}{R}$

In series combination, power consumed $P_{total} = \frac{P}{n}$
Brightness ∝ power ∝ V ∝ $R \propto \frac{1}{P_{rated}}$
In parallel combination $P_{total} = nP$
Brightness ∝ power ∝ I ∝ $\frac{1}{R}$

Groupings of cells

Cells in series Current in the circuit, $I = \frac{n\varepsilon}{R + nr}$

Cells in parallel Current in the circuit current $I = \frac{\varepsilon}{R + \frac{r}{m}}$

Cells in series and parallel i.e. mixed Current in the circuit, $I = \frac{n\varepsilon}{\frac{nr}{m} + R}$

Meter bridge Based on Wheatstone bridge
$\frac{P}{Q} = \frac{R}{S} \Rightarrow \frac{l}{100 - l} = \frac{R}{S}$

Balanced condition of wheatstone bridge
$\frac{P}{Q} = \frac{R}{S}$

Kirchhoff's laws

Ist law/Junction law Algebraic sum of all the current meeting at a junction is zero i.e. $\Sigma I = 0$

2nd law/Loop rule Algebraic sum of changes in potential around any closed loop is zero. $\Sigma^E = \Sigma^{IR}$

Potentiometer used to
(i) Compare emfs
$\frac{E_1}{E_2} = \frac{l_1}{l_2}$
(ii) Find internal resistance of cell
$r = \left(\frac{E}{V} - 1\right)S$

Potential gradient (x)
Potential difference per unit length of wire $x = \frac{V}{L} = \frac{\text{volt}}{\text{m}}$
where $V = iR = \left(\frac{e}{R + R_h + r}\right)R$ So,
$$x = \frac{V}{L} = \frac{iR}{L} = \frac{i\rho}{A} = \frac{e}{(R + R_h + r)} \cdot \frac{R}{L}$$
(I) Potential gradient directly depends upon
(a) The resistance per unit length (R/L) of potentiometer wire.
(b) The radius of potentiometer wire (i.e., Area of cross-section)
(c) The specific resistance of the material of potentiometer
(d) The current flowing through potentiometer wire (i)
(ii) potential gradient indirectly depends upon
(a) The emf of battery in the primary circuit
(b) The resistance of rheostat in the primary circuit

Sensitivity of potentiometer
A potentiometer is more sensitive, if it measures a small potential difference more accurately.
(i) The sensitivity of potentiometer is assessed by its potential gradient. The sensitivity is inversely proportional to the potential gradient.
(ii) In order to increase the sensitivity of potentiometer.
(a) The resistance in primary circuit will have to be decreased.
(b) The length of potentiometer wire will have to be increased

- **When cell is discharging:** When cell is discharging current inside the cell is from cathode to anode. Current $I = \frac{E}{r + R}$
or $E = IR + Ir = V + Ir$ or $V = E - Ir$
When current is drawn from the cell potential difference is less than emf of cell. Greater is the current drawn from the cell smaller is the terminal voltage. When a large current is drawn from a cell its terminal voltage is reduced.
- **When cell is charging:** When cell is charging current inside the cell is from anode to cathode. Current $I = \frac{V - E}{r}$ or $V = E + Ir$
During charging terminal potential difference is greater than emf of cell.

When cell is in open circuit: In open circuit $R = \infty$ ∴ $I = \frac{E}{R + 1} = 0$ So $V = E$
In open circuit terminal potential difference is equal to emf and is the maximum potential difference which a cell can provide.
- **When cell is short circuited:** In short circuit $R = 0$ so $I = \frac{-E}{(R + r)}$ and $V = IR = 0$
In short circuit current from cell is maximum and terminal potential difference is zero.

Power transferred to load by cell:
$P = I^2R = \frac{E^2R}{(r + R)^2}$ so, $P = P_{max}$
if $\frac{dP}{dR}$ and $P = P_{max}$ if $r = R$
Power transferred by cell to load is maximum when r = R and
$$P_{max} = \frac{E^2}{4r} = \frac{E^2}{4R}$$

Mind Map-4

Moving Charges And Magnetism

⊗ **Cross,** if magnetic field is directed perpendicular and into the plane of the paper
• **Dot**, if magnetic field is directed perpendicular and out of the plane of the paper.

Galvanometer to ammeter conversion : Low resistance or shunt connected in parallel $S = \left(\frac{I_g}{I - I_g}\right)G$
Reading of ammeter is always less than actual current in the circuit.

Galvanometer to voltmeter conversion : High resistance in series $R = \frac{V}{I_g} - G$
Greater the resistance of volt-meter, more accurate its reading.

Magnetic field due to a straight current carrying conductor of infinite lenght $B = \frac{\mu_0 I}{2\pi R}$

Biot-Savart's law
Magnetic field due to current carrying element, $dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta_n}{r^2}$
It is an imverse-square law and is the magnetic analogue of coulomb's law

Magnetic field due to a current carrying circular loop

On the axis of circular loop $B = \frac{\mu_0 NIa^2}{2(r^2+a^2)^{3/2}}$
If a >> r, $B = \ell$ $\frac{\mu_0}{4\pi}\cdot\frac{2NiA}{a^3}$

At the centre of circular loop $B = \frac{\mu NI}{2R}$
Magnetic field due to circular current carrying are $B = \frac{\mu_0 I}{2r}$

Direction of magnetic field- Depends upon the direction of current. **Right hand thumb rule-** Thumb points in the direction of current, curling of fingers represents direction of magnetic field.

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

Magnetic field due to a current carrying wire at a point which lies at a perpendicular distance r from the wire $B = \frac{\mu_0}{4\pi}\cdot\frac{1}{r}(\sin\phi_1 + \sin\phi_2)$

or, $B = \frac{\mu_0}{4\pi}\cdot\frac{1}{r}(\cos\alpha - \cos\beta)$

For a wire of finite length Magnetic field at a point which lies on perpendicular bisector of finite length wire $B = \frac{\mu_0}{4\pi}\cdot\frac{1}{r}(2\sin\phi)$

For a wire of infinite length When the linear conductor is of infinite length and the point lies near the centre of the conductor.
$B = \frac{\mu_0}{4\pi}\frac{i}{r}(\sin 90° + \sin 90°) = \frac{\mu_0 2i}{4\pi r}$

For a wire of semi-infinite length When the linear conductor is of infinite length and the point lies near the end
$B = \frac{\mu_0}{4\pi}\cdot\frac{i}{r}(\sin 90° + \sin 0°) = \frac{\mu_0 i}{4\pi r}$

For axial position of wire When point lies on axial position of current carrying conductor then magnetic field $B = 0$

Magnetic field due to a **solenoid**.
Inside a long solenoid $B = \mu_0 nI$
At a point on one end $B = \frac{\mu_0 nI}{2}$
n = number of turns per unit length

Magnetic field within the solenoid is uniform and parallel to the axis of solenoid.

Ampere's circuital law
$\oint Bdl = \mu_0 \Sigma i$ Absolute permeability of air or vacuum,
$\mu_0 = 4\pi\times10^{-7}\frac{Wb}{Amp - metre}$

Amperic law is analogous to Gauss's law $\oint \vec{E}\cdot d\vec{s} = \frac{q}{\epsilon_0}$
This law is valid for symmetrical current distributions and is based on the principle of electromagnetism

Magnetic field due to a **toroid**
$B = \mu_0 nI$; $n = \frac{N}{2\pi r}$

Toroid is like an endless cylindrical solenoid. Number of turns per unit length $n = \frac{N}{2\pi r}$

Magnetic field due to a cylindrical wire.
Outside the cylinder Magnetic field $B_{out} = \frac{\mu_0 i}{2\pi r}$ and $B_{surface} = \frac{\mu_0 i}{2\pi r}$

Inside the hollow cylinder
Magnetic field inside the hollow cylinder is zero.

Inside the solid cylinder
Magnetic field $B = \frac{\mu_0}{2\pi}\cdot\frac{ir}{R^2}$

Inside the thick portion of hollow cylinder:
$B = \frac{\mu_0 i}{2\pi r}\cdot\frac{(r^2 - R_1^2)}{2\pi r(R_2^2 - R_1^2)}$

Motion of a charged particle in a uniform magnetic field follows a circular path, radius $r = \frac{MV\sin\theta}{Bq}$

Force acting on a charged particle moving in a uniform magnetic field F = qVB sin θ = q(V × B)

Zero force i.e., F = 0 on a charged particle, if field $\vec{B} = 0$
charge q = 0
charge is at rest, v = 0
when θ = θ° or 180°

Trajectory of a particle is a straight, line, if the direction of a particle moving with velocity $\vec{v}$ parallel or anti-parallel to $\vec{B}$
i.e., θ = 0 or θ = 180°

Force on a conductor carrying current in a uniform magnetic field,
$F = IBl\sin\theta$
$F = I(B \times l)$

Lorentz force
$F = q[\vec{E} + \vec{V}\times\vec{B}]$
Electric force, $\vec{F}_e = q\vec{E}$
Magnetic force, $\vec{F}_m = q(\vec{v}\times\vec{B})$

• When $\vec{V}, \vec{E}$ and $\vec{B}$ are all collinear $F_{magnetic} = 0$
$\vec{F}_e, = q\vec{E} \Rightarrow \vec{a} = \frac{\vec{F}}{m} = \frac{q\vec{E}}{m}$
• When $\vec{V}, \vec{E}$ and $\vec{B}$ are mutually perpendicular
$\vec{F} = \vec{F}_e \Rightarrow \vec{F}_m = 0$
$\Rightarrow a = \frac{\vec{F}}{m} = 0$

Trajectory of a particle is a circle if particle velocity $\vec{v}$ perpendicular to $\vec{B}$ i.e., θ = 90° and radius of path,
$r = \frac{mV}{qB} = \frac{1}{B}\sqrt{\frac{2mV}{q}}$

Force between two parallel current carrying conductors
$F = \frac{\mu_0}{4\pi}\cdot\frac{2I_1I_2}{r}\times l$

Direction of force If two conductors carry current in same direction, force between them is attractive and if carry currents in opposite direction force between them is repnisive

Trajectory of a particle is helical if a charged particle is moving at an angle to the field other than 0°, 90°, 180° and radius of path $r = \frac{m(V\sin\theta)}{qB}$

If two charges q_1, q_2 are moving with velocities v_1 and v_2 and at any instant distance between then is 'r'
$F_{magnetic} = \frac{\mu_0}{4\pi}\frac{q_1q_2v_1v_2}{r^2}$
For charges moving with same velocity
$F_{magnetic} < F_{electrostatic}$

Torque experienced by a current carrying loop in a uniform magnetic field $\vec{T} = MB\sin\theta\hat{n}$
$= M \times B$

• **Torque** experienced is zero when θ = 0 i.e. plane of the coil is perpendicular to the field.
• **Torque** is maximum when θ = 90° i.e., plane of the coil is parallel to the field, $T_{max} = NBiA$
• **Work** done, W = MB(1 – cos θ)
W_{max}, if θ = 180°
$W_{max} = 2MB$
• Potential energy,
$U = -MB\cos\theta \Rightarrow U = -\vec{M}.\vec{B}$

Cyclotron.
A device used to accelerate positively charged particles like α-particles, deuterons, etc. to acquire sufficient energy to carry out nuclear disintegration.
• Cyclorton frequency $v = \frac{qB}{2\pi m}$
Cyclotron frequency also known as magnetic resonance frequency
• Time period, $T = \frac{2\pi m}{qB}$
• Maximum energy gained by charged particle
$E_{max} = \left(\frac{q^2B^2}{2m}\right)r^2$

Mind Map-5

Magnetism And Matter

Bar magnet: Consists of two equal and opposite magnetic poles separated by a small distance.
Effective length, $Le = \frac{5}{6} Lg$,
Lg = geometric length

Magnet field due to a bar magnet. Magnetic field is measured in $tesla = \text{Wbm}^{-2}$

Repulsive Like poles always repel one another. It is sure test of magnet

Attractive Unlike poles always attract so 4th pole of a magnet attracts north pole of another magnet and vice-versa

Directive: A freely suspended magnet always points in north south direction

At a point on axial line $B = \frac{\mu_0}{4\pi}\frac{2M}{d^3}$

At a point on equatorial line $B = \frac{\mu_0}{4\pi}\frac{M}{(r^2+\ell^2)^{3/2}}$

Pole strength of the magnet depends on
- Nature of material of magnet
- Area of cross-section i.e., $m \propto A$
- Independent of length of magnet

Pole of a magnet always exist in pair Monopoles do not exist

Properties of magnet

When a bar magnet is placed in magnetic field
- Torque experienced, $\tau = MB \sin\theta = \vec{M} \times \vec{B}$
- Work done, $W = MB(1 - \cos\theta) = \vec{M}\cdot\vec{B}$
- Potential energy, $U = -MB\cos\theta$ = angle made by bar magnet or dipole with the field.
- When a magnetic dipole moves from unstable equilibrium to stable equilibrium in a magnetic field, then kinetic energy decreases by 2 MB.

Gauss's law in magnetism Net magnetic flux through any closed surface is always zero i.e., $\oint \vec{B}\cdot\vec{ds} = 0$

Magnetism Property of attracting a piece of iron, cobalt, nickel etc.

Coulomb's law in magnetism
Force between two magnetic poles
$F = K\frac{m_1 m_2}{r^2} = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{r^2}$

Bohr magneton $\mu_B = \frac{eh}{4\pi m} = 9.27\times10^{-24}\,A/m^2$
It is as a natural unit of magnetic moment
Magnetic moment of straight current carrying wire = 0 Magnetic moment of toroid = 0

Magnetic permeability Degree extent to which magnetic lines of force can enter a substance.
$\mu = \mu_0\,\mu_r$; where μ_0 = absolute permeability of air or free space = $4\pi\times10^{-7}$ tesla × m/amp. and μ_r = Relative permeability of the medium
$= \frac{B}{B_0} = \frac{\text{flux density in material}}{\text{flux density in vacuum}}$.

Intensity of magnetising field ($\vec{H}$)
Degree or extent to which a magnetic field can magnetise a substance $H = \frac{B}{\mu}$ A/m

Intensity of magnetisation (I)
Degree to which a substance is magnetised when place in a magnetic field.

Magnetic susceptibility (χ_m)
Property of the substance which shows how easily a substance can be magnetised. $\chi_m = \frac{1}{H}$

Relation between permeability and susceptibility
$B = B_0 + B_m \Rightarrow B = \mu_0 H + \mu_0 I$
$= \mu_0(H + I) = \mu_0 H(1 + \chi_m)$ or, $\mu_r = (1 + \chi_m)$

Earth's magnetic elements

Angle of dip or inclination (δ) Angle made by direction of earth's magnetic field with the horizontal
δequator = 0; δpole = 90°

Horizontal component of earth's magnetic field is horizontal only at the magnetic equator Horizontal component
$B_v = B\sin\theta$ $B_H = B\cos\theta$
$B = \sqrt{B_v^2 + B_H^2}$ and $\tan\theta = \frac{B_v}{B_H}$

Angle of declination Angle between magnetic meridian and geographic meridian At a place it is expressed as θ° East or θ° west

Magnetic field lines Imaginary lines in a magnetic field which continuously represent the direction of magnetic field

Form continuous closed loop Start from N-pole end S-pole outside the magnet and its opposite inside the magnet

Properties of magneticfield lines

Tangent to the field line at a given point represents the direction of the net magnetic field

Come out of surface at any angle

Two magnetic field lines do not intersect each other

Deflection magnetometer
Works on the principle of tangent law.
Tan A position: In this position the magneto-meter is set perpendicular to magnetic meridian.
$B_H \tan\theta = \frac{\mu_0}{4\pi}\cdot\frac{2Mr}{(r^2-l^2)^2}$ or $B_H \tan\theta = \frac{\mu_0}{4\pi}\cdot\frac{2M}{r^3}$

Tan B position: The arms of magnetometer are set in magnetic meridian, so that the magnetic field due to magnet is at equatorial position.
$B_H \tan\theta = \frac{\mu_0}{4\pi}\cdot\frac{M}{(r^2+l^2)^{3/2}}$ $\tan\theta = \frac{\mu_0}{4\pi}\cdot\frac{M}{r^3}$

Comparison of magnetic moments
$\frac{M_1}{M_2} = \frac{\tan\theta_1}{\tan\theta_2}$

According to null deflection method
$\frac{M_1}{M_2} = \left(\frac{d_1}{d_2}\right)^3$

Vibration Magnetometer
Vibration Magnetometer is used for comparison of magnetic moment and magnetic fields.

Comparison of horizontal components of earth's magnetic field at two places
$T = 2\pi\sqrt{\frac{I}{MB_H}}$ since I and M of the magnet are constant,
$T^2 \propto \frac{I}{B_H} \Rightarrow \frac{(B_H)_1}{(B_H)_2} = \frac{T_2^2}{T_1^2}$

In a uniform magnetic field time period of oscillation of a freely suspended magnet $T = 2\pi\sqrt{\frac{I}{MB}}$

Tangent galvanometer
$B = B_H \tan\theta$ where $B = \frac{\mu_0 ni}{2r}$
$\Rightarrow \frac{\mu_0 Ni}{2r} = B_H \tan\theta \Rightarrow i = k\tan\theta$ where $k = \frac{2rB_H}{\mu_0 N}$
reduction factor.

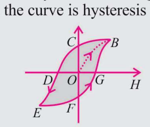
Magnetic Materials

Ferromagnetics Strongly magnetised in the direction of magnetic field e.g., Fe, Co, Ni
μ_r, I, $\chi_m >> 1$

Paramagnetics Magnetised in the direction of magnetic field e.g., Al, Mn ; etc,
μ_r, I, $\chi_m > 1$ positive

Diamagnetics Magnetised in a direction opposite to the direction of magnetic field e.g., Bi, Cu, Hg etc.
μ_r, I and χ_m are negative

Hysteresis Curve
Hysteresis is the lack of retracibility as shown in figure and the curve is hysteresis loop.



Curie Law
$\chi \propto \frac{1}{T} \Rightarrow \chi = \frac{C}{T}$;
where C = Curie constant, T = absolute temperature.
On increasing temperature, the magnetic susceptibility of paramagnetic materials decreases and vice versa but magnetic susceptibility of ferromagnetic substance does not change.

Curie temperature (T_c)
Temperature above which a ferromagnetic material behave like a paramagnetic material.
At this temperature the ferro-magnetism of the substances suddenly vanishes.

Curie-weiss law: At tempe-rature above Curie tempe-rature the magnetic susce-ptibility of ferromagnetic materials is inversely proportional to $(T - T_c)$

Mind Map-6

ELECTROMAGNETIC INDUCTION (EMI)

Direction of induced current
Fleming's Right Hand Rule
Thumb, forefinger, central finger of right hand stretched perpendicular to each other then if thumb → direction of motion; forefinger → direction of magnetic field then central finger → induced current

Induced current in a coil rotated in uniform magnetic field

$I = \frac{NBA\,\omega \sin \omega t}{R} = \frac{e}{R} = -\frac{N}{R}\cdot\frac{d\phi}{dt}$ Induced charge $dq = idt = -\frac{N}{R}\cdot d\phi$

i.e, independent of time. Induced power $P = \frac{e^2}{R} = \frac{N^2}{R}\left(\frac{d\phi}{dt}\right)^2$

Depends on time and resistance

Faraday's laws of electromagnetic Induction

Ist law When magnetic flux linked with the circuit changes an emf is induced in the circuit
• Induced emf persists as long as change or cutting of flux

2nd law Induced emf ∝ rate of change of magnetic flux $e = \frac{d\phi}{dt}$

For 'N' turns $e = -\frac{Nd\phi}{dt}$

–(ve) sign indicates 'e' opposes $d\phi$

Magnetic flux, Total number of magnetic lines of force passing normally through an area placed in a magnetic field $\phi_B = \vec{B}.A = BA \cos \theta$

The emf is induced by changing magnetic flux. Flux can be changed by changing
(i) the magnitude of magnetic field at the site of the loop $\left[|emf| = A\frac{dB}{dt}\right]$
(ii) the area of the loop
$\left[|emf| = B\frac{dA}{dt} = Bl\frac{dx}{dt} = BlV\right]$
(iii) Angle between $\vec{B}$ and area A

Lenz's law Direction of induced emf or current is always in such a way that it opposes cause due to which it is produced. It is in accordance with conservation of energy

Motional emf $e = -\frac{d\phi}{dt} = -Blv$

In vector form, $e = (\vec{V} \times \vec{B})\cdot l$

Across the end of rod $e = \frac{1}{2}B\omega l^2$

$e_{net} = \frac{1}{2}B\omega l^2; \omega = 2\pi v$ $e_{net} \propto N^{\circ}$, i.e., total emf does not depends on number of spokes '*N*'.

Motional EMI due to Translatory motion
• When a conducting rod, length l moving with uniform velocity $\vec{v}$ perpendicular to a uniform magnetic field $\vec{B}$ directed into the plane of paper, then $e = Bvl$

If rod is moving by making an angle θ with the direction of magnetic field or length, induced emf $e = Bvl \sin \theta$

• **Motion of conducting rod on an inclined plane**
Induced emf across the ends of the conductor $e = Bv \sin(90° - \theta)l$
$= Bvl \cos \theta$

Induced current $i = \frac{Bvl\cos\theta}{R}$

Motional EMI in Loop by Generated Area
• If conducting rod moves on two parallel conducting rails.
Induced emf $|e| = \frac{d\phi}{dt} = Bvl$

(i) **Induced current:** $i = \frac{e}{R} = \frac{Bvl}{R}$

(ii) **Magnetic force:** $F_m = Bil = B\left(\frac{Bvl}{R}\right)l = \frac{B^2vl^2}{R}$

(iii) **Power dissipated in moving conductor**

$$P_{ext} = \frac{dW}{dt} = Fext.v = \frac{B^2vl^2}{R}\times v = \frac{B^2v^2l^2}{R}$$

(iv) **Electrical power**

$$P_{thermal} = \frac{H}{t} = i^2R = \left(\frac{Bvl}{R}\right)^2\cdot R; P_{thermal} = \frac{B^2v^2l^2}{R}$$

Motion of conducting rod in a vertical plane: If conducting rod is released from rest (at t = 0) then with rise in its speed (v), induced emf (e), induced current (I), magnetic force (F_m), increases but it's weight remains constant.
Rod will achieve a constant maximum (terminal) velocity v_T if $F_m = mg$
or $\frac{B^2v_Tl^2}{R} = mg \Rightarrow v_T = \frac{mgR}{B^2l^2}$

Motional EMI due to Rotational Motion
• Emf induce across the ends of the rod, $e = BAv$, $e = \frac{1}{2}Bl^2\omega = Bl^2\pi v$
$= \frac{Bl^2\pi}{T}$ where v = frequency (revolution).
• **Cycle wheel:** Each spoke of length l is rotating with angular velocity ω in a given magnetic field.
Due to flux cutting each metal spoke becomes identical cell of emf e.

Eddy current Induced, when magnetic flux linked with the conductor changes

Applications of eddy currents
→ Electromagnetic damping
→ Induction furnace
→ Magnetic braking
→ Electric power meter

Inductance is analogous to inertia opposes any change of current in the circuit
• It is inherent property of electrical circuit.

Coefficient of self inductance
$L = \frac{N\phi}{i}$ $e = -L\frac{di}{dt}$
L is measured in Wb/amp or henery.

The induced e.m.f. is produced in the inductance due to rate of current through it.

$e = -L\frac{dI}{dt}$

The induced e.m.f. in the inductor opposes the e.m.f. $\frac{d\phi}{dt}$

Instantaneous induced e.m.f. produced in a coil $e = e_0 \sin \omega t = nBA\,\omega \sin \omega t$
(i) when $\omega t = 0, \pi$ i.e., coil is vertical, e.m.f. $e = 0$
(ii) when $\omega t = \pi/2$ i.e., coil is horizontal, e.m.f. e = +(ve) maximum.
(iii) when $\omega t = \frac{3}{2}\pi$ i.e., coil is horizontal, e.m.f. e = –(ve) minimum.

Self inductance of a long solenoid
$L = \frac{\mu_0 N^2 A}{l}$
Self inductance for
• Circular coil, $L = \mu_0 \pi N^2 r$
• Toroid, $L = \frac{\mu_0 N^2 r}{2}$
• Square coil, $L = \frac{\sqrt[2]{2}\mu_0 N^2 r}{\pi}$
• Coaxial cylinders, $L = \frac{\mu_0}{2\pi}\log_e\frac{r_2}{r_1}$

Self inductance depends on-
• Number of turns (N)
• Area of cross-section (A)
• Permeability of medium (μ_0)
And not depends on-
Change in current flowing

Magnetic potential energy of inductor
$\mu = \frac{1}{2}Li^2 = \frac{N\phi i}{2}$

Mutual Inductance Induced emf in a circuit due to change in magnetic flux in its neighbouring circuit. Coefficients of mutual inductance
$M = \frac{\phi}{I}$; If N = number of turns
$N\phi = MI$

Coefficient of mutual inductance between two long solenoids
$M = \frac{\mu_0 N_1 N_2 A}{l}$

Mutual Inductance depends on
• Number of turns of both coils (N_1 & N_2)
• Coefficient of self inductance of both coils (L_1 & L_2)
• Area of cross-section of coils
• Magnetic permeability of medium between the coils (μ_r)
• Distance between two coils ($M \propto d$)
• Orientation between primary and secondary coil.
• Coupling factor

$$\left(K = \frac{\text{magnetic flux linked in secondary}}{\text{magnetic flux linked in primary}}\right)$$

between primary and secondary coil. $0 \le K \le 1$

AC Generator or Dynamo
Produces electrical energy from mechanical energy. It works on EMI principle.

Mind Map-7

ALTERNATING CURRENT

Direction of current Changes alternatively and its magnitude changes continuously

RMS value of alternating current and voltage

$$I_{rms} = \sqrt{\frac{I_1^2 + I_2^2 + ...}{n}}$$

$$\sqrt{\overline{I^2}} = \sqrt{\frac{\int_0^T I^2 dt}{\int_0^T dt}} = \frac{I_0}{\sqrt{2}}$$

$$I_{rms} = \frac{I_0}{\sqrt{2}} \quad V_{rms} = \frac{V_0}{\sqrt{2}}$$

Mean or average value of alternating current and voltage

$$\overline{I^2} = \frac{1}{T}\int_0^T I^2 dt = \frac{I_0^2}{2}$$

i.e., Average of square of instantaneous values in one cycle

$$I_{mean} = \frac{2I_0}{\pi} \quad V_{mean} = \frac{2V_0}{\pi}$$

Peak current (I_0) and voltage (V_0): The maximum value of current and voltage

$$\text{Peak factor} = \frac{\text{Peak value of ac}}{\text{rms value of ac}}$$

$$\textbf{Form factor} = \frac{\textbf{rms value of ac}}{\textbf{average value during half cycle}}$$

$I_0 = \sqrt{2}\, I_{rms}$ $\quad V_0 = \sqrt{2}\, V_{rms}$

Impedance (*Z*) Opposition offered by ac circuits to the flow of ac through it.
Admittance (*Y*) Reciprocal of impedance

$$\left(Y = \frac{1}{Z}\right).Z = \frac{V_0}{i_0} = \frac{V_{rms}}{i_{rms}}$$

Susceptance (*S*): Reciprocal of reactance $\left(S = \frac{1}{X}\right)$.

(i) inductive susceptance,

$$S_L = \frac{1}{X_L} = \frac{1}{2\pi\nu L}$$

(ii) Capacitive susceptance,

$$S_c = \frac{1}{X_c} = \omega C = 2\pi\nu C.$$

Reactance (X) Opposition offered by inductor or capacitor or both to the flow of ac through it.

(i) Inductive reactance (X_L) Opposition offered by inductive circuit $X_L = \omega L = 2\pi\nu L$; $\nu_{dc} = 0$

$\therefore$ for dc, $X_L = 0$.

(ii) Capacitive reactance (X_c) : Opposition offered by capacitive circuit

$$X_c = \frac{1}{\omega C} = \frac{1}{2\pi\nu C} \quad \therefore \text{ for dc } X_c = \infty.$$

- All ac meters read rms value
- All ac meters are based on heating effect of current
- In hot wire meters deflection, $\theta \propto i_{rms}^2$
- Frequency of ac in India is 50 Hz

Alternating current(I) and alternating voltage (V)

$I = I_0 \sin\omega t$; $V = V_0 \sin\omega t$

Phase is the physical quantity which represents both the instantaneous value and direction of alternating quantity at any instant.

RC Circuit

Current: $I = I_0 \sin(\omega t + \phi)$

Voltage: $V = \sqrt{V_R^2 + V_C^2}$

Impedance: $Z = \sqrt{R^2 + X_C^2}$

Phase difference: $\tan^{-1}\frac{1}{\omega CR}$

Power factor: $\cos\phi = \frac{R^2}{\sqrt{R^2 + X_C^2}}$

Leading quantity: Current

LC Circuit

Current: $I = I_0 \sin\left(\omega t \pm \frac{\pi}{2}\right)$

Voltage: $V = V_L - V_C$

Impedance : $Z = X_L - X_C$

Phase difference: $\phi = 90^\circ$

Power factor : $\cos\phi = 0$

Leading quantity: Either voltage or current

LR Circuit

Current: $I = I_0 \sin(\omega t + \phi)$

Voltage : $V = \sqrt{V_R^2 + V_L^2}$

Impedance: $Z = \sqrt{R^2 + X_L^2}$

Phase difference: $\phi = \tan^{-1}\frac{\omega L}{R}$

Power factor : $\cos\phi = \frac{R}{\sqrt{R^2 + X_L^2}}$

Leading quantity : voltage

AC Circuit

Ac is more dangerous than dc
Sinusoidal wave form is used as alternating current/voltage

Inductive (L) Circuit

Current : $I = I_0 \sin\left(\omega t - \frac{\pi}{2}\right)$

Phase difference between V and I : $\phi = 90^\circ$ or $\pi/2$

Power factor : $\cos\phi = 0$

Power : P = 0

Phasor : Voltage leads the current by $\pi/2$

Capacitive (C) Circuit

Current : $I = I_0 \sin(\omega t + \pi/2)$

Phase difference between V and I : $\phi = 90^\circ$ or $-\pi/2$ Power factor : $\cos\phi = 0$ Power : P = 0

Phasor : Current leads the voltage by $\pi/2$

Resistive (R) Circuit

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

Phase difference between V and I : $\phi = 0^\circ$ Power factor: $\cos\phi = 1$

Power : $P = \frac{V_0 I_0}{2}$

Phasor : Current and voltage both in same phase

LCR series Circuit

Current : $I = I_0 \sin(\omega t \pm \phi)$: Voltage :

$V = \sqrt{R^2 + (V_L - V_C)^2}$

Impedance $Z = \sqrt{R^2 + (X_L - X_C)^2}$;

Phase difference $\frac{X_L - X_C}{R}$

At resonance $X_L = X_C \Rightarrow Z_{min} = R$

Band-width: $\Delta\omega = \frac{R}{L}$;

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

Power in ac circuit

P = V i cos ϕ: *V* and *I* are *r.m.s* values of voltage and current.

Instantaneous power: If in a circuit $V = V_0 \sin\omega t$ and $i = i_0 \sin(\omega t + \phi)$ then $P_{instantaneous} = Vi = V_0 i_0 \sin(\omega t + \phi)$

Average power or True power

Average of instantaneous power in an ac circuit over a full cycle.

$$P_{av} = V_{rms} i_{rms} \cos\phi = \frac{V_0}{\sqrt{2}} \cdot \frac{i_0}{\sqrt{2}} \cos\phi$$

$$= \frac{1}{2} V_0 i_0 \cos\phi = i_{rms}^2 R = \frac{V_{rms}^2 R}{Z^2}$$

Apparent or virtual power: Product of apparent voltage and apparent current in an electric circuit

$$P_{app} = V_{rms} i_{rms} = \frac{V_0 i_0}{2}.$$

Power Factor

It is the *cosine* of the angle of lag or lead i.e. $\cos\phi$ Also ratio of resistance and impedance i.e. $\frac{R}{Z}$

$$\frac{\text{True power}}{\text{Apparent power}} = \frac{W}{VA} = \frac{kW}{kVA} = \cos\phi.$$

Efficiency of transformer

$$n\% = \frac{P_{output}}{P_{input}} \times 100 = \frac{V_s I_s}{V_p I_p} \times 100$$

- In practical, $P_{input} = P_{output} + P_{losses}$

Power losses in transformer is due to

- heating effect • flux leakage
- eddy currents
- hysteresis and humming

Uses of Transformer

- In the transmission of ac over long distance
- In voltage regulators for computer, TV etc
- For welding purposes in step-down transformer

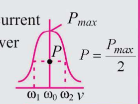
Transformer Device Changes a low voltage of high current into a high voltage of low current and vice-versa

- Transformer works on ac only
- can increase or decrease either voltage or current but not both simultaneously
- Effective resistance between primary and secondary winding is infinite

Half power frequencies

Frequencies at which the power in the circuit is half of the maximum power i.e., power at resonance

The current in the circuit at half power frequencies (HPF) is $\frac{1}{\sqrt{2}}$ or 0.707 or 70.7% of maximum current



(a) $\omega_1 \to$ lower half power frequency. At this frequency the circuit is capacitive.

(b) $\omega_2 \to$ upper half power frequency., It is greater than ω_0.

Step-up transformer

$K > 1$ $K = \frac{N_s}{N_p} = \frac{E_s}{E_p} = \frac{I_p}{I_s}$

$N_s > N_p$; $I_s < I_p$

$V_s > V_p$; $E_s > E_p$

$R_s > R_p$

Step-down transformer

$K < 1$ $K = \frac{N_p}{N_s} = \frac{E_p}{E_s} = \frac{I_s}{I_p}$

$N_s < N_p$; $I_s > I_p$

$V_s < V_p$; $E_s < E_p$

$R_s < R_p$

Mind Map-8

ELECTROMAGNETIC WAVES

Constituted by mutually perpendicular time varying electric and magnetic fields $E = E_0 \sin(kx - \omega t)$ and $B = B_0 \sin(kx - \omega t)$

Conduction current
Arises due to flow of electrons in a definite closed path

Displacement current (I_D)
Due to time varying electric field

$$I_D = \varepsilon_0 \frac{d\phi_E}{dt}$$

Intensity of Wave
Time average rate per unit area at which energy is transported

$$I = \frac{1}{2}\varepsilon_0 E_0^2 C$$

Different types of electromagnetic waves

Radio waves
Wavelength > 0.1 m
Uses: in telecommunication and RADAR

Microwave
Wavelength 0.1 m to1 mm Uses : in microwave oven

Infra -red
Wavelength 1 mm to 700 mm Uses : treat muscular strain

Visible Wavelength : 700 nm to 400 nm
Uses : to see objects

Ultra-violet
Wavelength 400 nm to 1nm
Uses : Preserve food and purifying water

X-ays
Wavelength: 1 nm to 10^{-3} nm
Uses : Medical diagnosis

γ-rays
Wavelength : < 10^{-3}nm
Uses : in medical science & to get information on nuclear structure

Electromagnetic wave with pointing vector $\vec{S}$, incident on a perfectly absorbing surface then,

$$P = \frac{S}{C}$$

If incident on a perfectly reflecting surface then,

$$P = \frac{2S}{C}$$

Radiation pressure exerted by an electromagnetic wave

$$P = \frac{\text{energy associated with em waves (u)}}{\text{speed of light in vacuum(c)}}$$

Energy associated with an electromagnetic wave

$$U = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}$$

Rate per unit area at which energy is transported via an electromagnetic wave is given by **pointing vector**

$$\vec{S} = \frac{\vec{E}\times\vec{B}}{M_0}$$

Maxwell discovered that all the basic principles of electromagnetism can be formulated in terms of four fundamental equations, called **Maxwell's equations**. These are:

(i) Gauss's law for electricity

$$\oint \vec{E}\cdot d\vec{A} = \frac{q}{\varepsilon_0}.$$

(ii) Gauss's law for magnetism

$$\oint \vec{B}\cdot d\vec{A} = 0.$$

(iii) Faraday's law of induction

$$\oint \vec{E}\cdot d\vec{l} = \frac{-d\phi_B}{dt}$$

(iv) Ampere's law

$$\oint \vec{B}\cdot d\vec{l} = \mu_0\left(i_C + \varepsilon_0 \frac{-d\phi_E}{dt}\right)$$

Characteristics of electromagnetic waves

Do not require any material medium for propagation and form a set of orthogonal vectors

Produced by accelerated charge

Travels with speed of light in free space

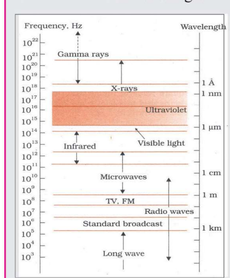
$$C = \frac{1}{\sqrt{\mu_0\varepsilon_0}} = 3\times10^8 \text{ m/s}$$

In free space; magnitude of electric field (E) / magnetic field (B) = C (speed of light in vacuum)

Transverse in nature
$\vec{E}$ and $\vec{B}$ are perpendicular to each other

Oscillating electric and magnetic fields are in phase and their magnitudes bear constant ratio $C = \frac{E_0}{B_0}$

EM Spectrum
The array obtained on arranging all the electromagnetic waves in an order on the basis of their walvelengths



Wave impedance(Z)
Hinderance by the medium in the wave propagation.

$$Z = \sqrt{\frac{\mu}{\varepsilon}} = \sqrt{\frac{\mu_r}{\varepsilon_r}}\sqrt{\frac{\mu_0}{\varepsilon_0}}$$

For vaccum or free space

$$Z = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 376.65\Omega$$

Mind Map-9

RAY OPTICS AND OPTICAL INSTRUMENTS

Ray optics
Optics - branch of study of light (EM waves wavelength 400 nm to 750 nm). The path of light (always travel in straight line) is ray of light

Refraction of light Bending of light ray while passing from one medium to another medium
- A ray of light bends towards the normal, while going from rarer to denser medium
- And bends away from the normal while going from denser to rarer medium
- Refraction of light takes place because the speed of light is different in the two media

Laws of refraction

Snell's law $\mu = \frac{\sin i}{\sin r}$

For two media

$${}_1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{\sin i}{\sin r}$$

The incident ray, the normal and the refracted ray all lie in the same plane

Refractive index,

$$\mu = \frac{c}{v} = \frac{\text{real depth}}{\text{apparent depth}}$$

Total internal Reflection Ray totally reflected back to denser medium

Phenomena based on TIR
- Mirage - optical illusion in deserts
- Looming - optical illusion in cold countries
- optical fibre
- Brilliance of diamond

Necessary conditions for TIR
(i) ray of light must travel from denser to rarer medium
(ii) $\angle i > \angle c$ for two media

Critical angle (c) Angle *i* in denser medium for which angle of refraction in rarer medium is 90° $\mu = \frac{1}{\sin C}$

Reflection of light Turning back of light in the same medium after striking the reflecting surface or mirror
- After reflection, velocity, frequency and wavelength of light remains same but intensity decreases
- If reflection takes place from denser medium then phase change 'π'

Laws of reflection
- The incident ray the normal and the reflected ray all lie in the same plane
- The angle of incidence (I)is always equal to angle of reflection (r) i.e., $\angle i = \angle r$

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

When two plane mirrors are held at an angle θ with their reflecting surfaces facing each other and an object is placed between them, images are formed by successive reflections.

$f_{concave}$ = negative
f_{convex} = positive
and $f_{plane} = \infty$

Relation between focal length (f) and radius of curvature, R

$$f = \frac{R}{2}$$

Magnification

$$m = \frac{v}{u} = \frac{\text{height of image}}{\text{height of object}}$$

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

Refraction at a single spherical surface $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$

(A) In case, the object (real or virtual) is situated in rarer medium so that the incident ray travels in rarer medium and the refracted ray travels in denser medium, then the relation between *u, v*,R, μ_1 and μ_2 is

$$-\frac{\mu_1}{u} + \frac{\mu_2}{v} = \frac{\mu_2 - \mu_1}{R}$$

(B) In case, the object (real or virtual) is situated in denser medium, so that the incident ray travels in denser medium and refracted ray travels in rarer medium then the relation between *u, v,* R, μ_1 and μ_2 is

$$-\frac{\mu_2}{u} + \frac{\mu_1}{v} = \frac{\mu_1 - \mu_2}{R}$$

(C) The factor $\frac{\mu_2 - \mu_1}{R}$ is called power of the spherical refracting urface. It gives the measure of the degree to which the refracting surface can converge or diverge the rays of light passing through it.

Optical Instruments

Telescope provide angular magnification of distant objects magnification by telescope

When final image is formed at near point

$$M = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$$

Length of the telescope,

$$L = f_0 + |u_e|$$

When final image is formed at infinity

$$M = -\frac{f_0}{f_e}$$

Length of the telescope,

$$L = f_0 + f_e$$

Microscope Forms large image of tiny objects

Magnification produced by simple microscope

Image formed at near point $M = 1 + \frac{D}{f}$ D = 25 cm

Image formed at infinity $M = \frac{D}{f}$

Magnification by compound microscope

When final image is formed at infinity

$$M = -\frac{v_0}{u_0}\frac{D}{f_e}$$

Length of the microscope

$$L = |v_0| + f_e$$

When final image is formed at near point

$$M = -\frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$$

Length of the microscope

$$L = |v_0| + |u_e|$$

Refraction by lens

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

$f_{concave}$ = negative
f_{convex} = positive
and $f_{plane} = \infty$

Power of a lens

$$P = \frac{1}{f(\text{in metre})}$$

Unit of power of lens is diopter (D)

$P_{convex} \rightarrow$ Positve
$P_{concave} \rightarrow$ Negative
and $P_{plane} \rightarrow$ Zero

Focal length of lens-**Lens maker's formula**

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

When one face of a lens is silvered, it behaves as a concave mirror. If f_e is the effective focal length of the lens, then $\frac{1}{f_e} = \frac{2}{f_\ell} + \frac{1}{f_m}$ is the focal length of the mirror

(i) Plano-convex lens silvered at plane surface, then

$$f_e = \frac{R}{2(\mu - 1)}$$

(ii) Plano-convex lens silvered at plane surface, then

$$f_e = \frac{R}{2\mu}$$

Refraction through Prism

Prism Formula

$$\mu = \frac{\sin\left(\frac{A + \delta m}{2}\right)}{\sin A/2}$$

Angle of deviation $\delta = A(\mu - 1)$
- When prism is thin, then value of A will be small (≤ 10°) $\delta_m = (n-1)A$
- Condition for maximum deviation i_1 or $i_2 = 90°$.

Dispersive power

$$\omega = \left(\frac{\mu_v - \mu_r}{\mu_y - 1}\right)$$

Dispersion Without Deviation (Direct Vision Spectroscope)
- To produce dispersion without mean deviation we use a combination of two prisms of different materials such that

$$A' = -\left(\frac{\mu - 1}{\mu' - 1}\right)A \text{ or } \frac{A'}{A} = \frac{(\mu - 1)}{(\mu' - 1)}$$

- Net dispersion caused

$$= (\mu_v - \mu_R)A + (\mu'_v - \mu'_R)A'$$
$$= (\mu - 1)A(\omega - \omega') = \delta(\omega - \omega')$$

Deviation Without Dispersion (Achromatic Prism)
- To produce deviation without dispersion we use a combination of two prisms of different materials such that $A' = \left[\frac{\mu_V - \mu_R}{\mu_V - \mu_R}\right]A$

Mind Map-10

WAVE OPTICS
Describes the connection between waves and rays of light

Doppler's effect in light

Source of light moves towards the stationary observer

$v' = v\sqrt{\frac{(1+v/c)}{1-v/c}}$ and $\lambda' = \lambda\sqrt{\frac{(1-v/c)}{(1+v/c)}}$

(For $v << c$).

(a) Apparent frequency $v' = v\left(1+\frac{v}{c}\right)$ and

(b) Apparent wavelength $\lambda' = \lambda\left(1-\frac{v}{c}\right)$

(c) Doppler's shift $\Delta\lambda = \lambda.\frac{v}{c}$

Source of light moves away from the stationary observer: In this case $v' < v$ and $\lambda' > \lambda$

$v' = v\sqrt{\frac{(1-v/c)}{(1+v/c)}}$ and $\lambda' = \lambda\sqrt{\frac{(1+v/c)}{1-v/c}}$

For $v << c$)

(a) Apparent frequency $v' = v\left(1-\frac{v}{c}\right)$ and

(b) Apparent wavelength $\lambda' = \lambda\left(1+\frac{v}{c}\right)$

(c) Doppler's shift, $\Delta\lambda = \lambda\frac{v}{c}$

Wavefront
Locus of all particles vibrating in same phase

Forms of wavefront

Cylindrical wavefront
Linear light source
Effective distance -finite

Intensity $I \propto \frac{1}{r}$

Amplitude $A \propto \frac{1}{\sqrt{r}}$

Plane wavefront Light source at large distance: Effective distance infinite Intensity and amplitude independent of distance

Spherical wavefront Point light source
Effective distance- finite

Intensity $I \propto \frac{1}{r^2}$

Amplitude $A \propto \frac{1}{r}$

Huygens' principle
Each point on the primary wavefront is the source of a secondary wavelets
- The locus of the secondary wavelets in the forward direction gives the position of new wavefront at any subsequent time.
- Direction of wave propagation and wavefront are mutually perpendicular to each other.

Drawbacks of wave theory
- Cannot explain photo electric effect, comptan and Raman effect
- Hypothetical medium in vacuum is not true imagination

Coherent sources of light
Sources of light, emitting light of same wavelength same frequency having a zero or constant phase difference.

Interference of light
Redistribution of energy due to superposition of waves

Constructive interference
Phase diff. $\delta = 2n\pi$

Path difference, $\Delta x = 2n(\lambda/2)$

Time interval between two waves $\Delta t = 2n\frac{T}{2}$

Resultant amplitude, $A = a_1 + a_3$

Resultant intensity, $I = (\sqrt{I_1} + \sqrt{I_2})^2$

Destructive interference
Phase diff. $\delta = (2n - 1)\pi$; Path diff. $\Delta x = (2n - 1)\ \lambda/2$

Time interval between two waves, $\Delta t = (2n - 1)T/2$

Resultant amplitude $A = a_1 - a_2$

Resultant intensity $I = (\sqrt{I_1} - \sqrt{I_2})^2$

Superposition of waves.
When two similar waves propagate simultaneously then resultant displacement

$\vec{y} = \vec{y}_1 + \vec{y}_2$

For two waves, $y_1 = a_1 \sin\omega t$ and $a_2 \sin(\omega t + \phi)$ meeting at a point, Resultant wave, $y = A \sin(\omega t + \phi)$

Resultant amplitude

$A = \sqrt{a_1^2 + a_2^2 + 2a_1a_2\cos\phi}$

Resultant intensity,

$I \propto (\text{amplitude})^2$;

$\tan\theta = \frac{a_2 \sin\phi}{a_1 + a_2\cos\phi}$

- **Diffraction of light :** The phenomena of bending of light waves around the sharp edges of opaque obstacles or aperture and their encroachment in the geometrical shadow of obstacle or aperture and their encroachment in the geometrical shadow of obstacle or aperture is defined as diffraction of light.

  Necessary conditions of diffraction of waves : The size of the obstacle (a) must be of the order of the wavelength of the wave (λ). i.e. $\frac{a}{\lambda} \approx 1$

- **Fraunhoffer diffraction at single slit :** Diffraction occurs due to superposition between the wavelets originated from same wavefront. For diffraction, size of aperture is order of wavelength of wave.

  $a\ \sin\theta = \lambda$, for first order minima

  Width of principal maxima $= 2\theta = 2\sin^{-1}(\lambda/a)$

For secondary maximum

Path diff. $= \frac{(2n+1)\lambda}{2}$

Linear distance $= \frac{(2n+1)D\lambda}{2a}$

For secondary minimum path difference $= n\lambda$

Linear distance $= \frac{nD\lambda}{a}$

$= \frac{n\lambda f}{2}$; f = D focal length of converging lens

Angular width of central maxima $= 2\theta = \frac{2\lambda}{a}$

Linear width central maxima $= 2x = 2D\theta = \frac{2\lambda D}{a}$

Law of Malus

$I = I_0\cos^2\theta$

I – intensity of transmitted light from analyser

Also, $A^2 = A_0^2\ \cos^2\theta$

$\Rightarrow A = A_0\cos\theta$

If $\theta = 0°, I = 0, A = 0$

If $\theta = 90°, I = 0, A = 0$

$I = \frac{I_{unpolarised}}{2}\cos^2\theta$

i.e., If an unpolarised light into plane polarised light its intensity becomes half.

Polarisation
Restricting the vibration of light in a particular direction perpendicular to the direction of propagation of wave

Brewster's law $\mu = \tan\theta_p$, θ_p = angle of polarisation

For $i < \theta_p$ or $i > \theta_p$ Both reflected and refrected rays becomes partially polarised.

For glass $\theta_p \approx 57°$ and for water $\theta_p \approx 53°$

Fringe visibility : $V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$

V_{max}, if $I_1 = I_2 = I_0$ or $I_{min} = 0$

If widths of slits S_1 and S_2 are unequal the brightness of the bright fringe and the darkness of the dark fringe decreases.

If $I_1 >> I_2$ then $I_{max} = I_{min}$

Young's double slit experiment (YDSE)

Fringe width (β)

Distance between centres of two consecutive bright or dark fringes $\beta = \frac{D}{d}\lambda$

Angular width of fringe, $\alpha D = \beta \Rightarrow \alpha = \frac{\beta}{D} = \frac{\lambda}{d}$

In YDSE pringe pattern shifting

- Fringe shift $= \frac{D}{d}(\mu - 1)t = \frac{\beta}{\lambda}(\mu - 1)t$
- Additional path difference $= (\mu - 1)t$
- If sift is equivalent to n fringes then $n = \frac{(\mu-1)t}{\lambda}$ or $t = \frac{n\lambda}{(\mu - 1)}$
- Shift is independent of the order of fringe (i.e., shift of zero order maxima = shift of n^{th} order maxima).
- Shift is independent of wavelength.

Distance between central fringe and n^{th} dark fringe

$X_n = \frac{(2n-1)\lambda D}{2d}$

$= \frac{(2n-1)\beta}{2}$ n = 1, 2, 3

Distance between central fringe and n^{th} bright fringe

$X_n = \frac{n\lambda D}{d}$

D = distance between source and screen ;
d = distance between two slits

Mind Map-11

Dual Nature of Radiation and Matter

Light has dual nature-wave and particle like nature

Thermionic emission
Emission of electrons by suitably heating of metal surface. It is used in conventional electron tubes like television picture tubes.

Field emission
Emission of clectrons by applying a very strong electric field to a metal. **It is also called cold emission.**

Photoelectric emission
Emission of free electrons from the surface of metals when light radiation of suitable frequency fall on it
- **Threshold frequency** Minimum frequency of incident radiation to eject the electrons (v_0)
  No photoelectron emission, if $v < v_0$

Methods of electron emission

- **Cathode rays**, are fast moving electrons
- They exert mechanical force on the objects they strike
- Produce fluorescence
- Produce heat when they strike a metal surface
- They are deflected by both electric and magnetic field.
- Velocity ranging $\frac{1}{30}$th to $\frac{1}{10}$th to velocity of light.

Electron emission
Emission of electrons from the surface of metal

Work function
Minimum energy required to just escape electron from metal surface $\phi_0 = hv_0 = \frac{hc}{\lambda_0}$

In electron volt, $E(eV) = \frac{hc}{e\lambda}$

$= \frac{12375}{\lambda(Å)} = \frac{12400}{\lambda(Å)}$

Einstein's photoelectric equation

$$K_{max} = \frac{1}{2}mv_{max}^2 = h(v - v_0) = hv - hv_0$$

$$= hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right) \quad hv = hv_0 + K_{max}$$

$$K_{max} = eV_0 \quad v_{max} = \sqrt{\frac{2h(v - v_0)}{m}}$$

$$K_{max} = \frac{1}{2}mv_{max}^2 = eV_0$$

$$= hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right) = hc\left(\frac{\lambda_0 - \lambda}{\lambda\lambda_0}\right)$$

$$v_{max} = \sqrt{\frac{2hc}{m}\frac{(\lambda_0 - \lambda)}{\lambda\lambda_0}}$$

$$V_0 = \frac{h}{e}(v - v_0) = \frac{hc}{e}\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$$

$$= 12345\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$$

Millikan's oil drop experiment
Charge on an oil droplet always an integral multiple of elementary charge 1.602×10^{-19} C

$$q = \frac{6\pi\eta(v_1 + v_2)d}{v}\left[\frac{9\eta v_1}{2g(\rho - \sigma)}\right]^{1/2}$$

V_1 = Terminal velocity of drop when no electric field is applied
V_2 = Terminal velocity when electric field applied

Photon Tiny packets of light energy Energy of a photon $E = hv$

Mass of photon Rest mass of the photon is zero. But it's effective mass $E = mc^2 = hv$

$\Rightarrow m = \frac{E}{c^2} = \frac{hv}{c^2} = \frac{h}{c\lambda}$

Also, known as kinetic mass of the photon

Momentum of the photon
Momentum $p = m \times c = \frac{E}{c} = \frac{hv}{c} = \frac{h}{\lambda}$

Effect of intensity of light on photocurrent for a fixed frequency of incident radiation. Photoelectric current ∝ intensity of incident light

Effect of potential on photo-electric current. For a fixed frequency and intensity of incident light photoelectric current increases with increase in the potential

Number of emitted photons: The number of photons emitted per second from a source of monochromatic radiation of wavelength λ and power P

$(n) = \frac{P}{E} = \frac{P}{hv} = \frac{P\lambda}{hc}$ E = energy of each photon

Intensity of light (I) $I = \frac{E}{At} = \frac{P}{A}$ $\left(\frac{E}{t} = P = \text{radiation power}\right)$

At a distance r from a point source of power P intensity is given by

$I = \frac{P}{4\pi r^2} \Rightarrow I \propto \frac{1}{r^2}$, for a line source $I \propto \frac{P}{2\pi l} \Rightarrow I \propto \frac{1}{r}$.

Number of photons falling per second (n) power of radiation P and E is the energy of a photon then $n = \frac{P}{E}$

Photocell Converts a change in intensity of illumination into a change in photocurrent It is a technological application of photoelectric effect.

Stopping potential Photoelectric current becomes zero at a particular value of negative potential v_0 called stopping potential or cut-off potential

Stopping potential varies linearly with the frequency of incident radiation for a given photosensitive material

Uses of photocell
- Count the persons entering an auditorium
- Burglar alarm.
- In motion picture and television

X-rays Electromagnetic radiations of very short wavelength, 0.1 Å to 100 Å and high energy which are emitted when fast moving electrons or cathode rays strike a target of high atomic mass.

Types of X-rays
(i) Continuous X-rays
(ii) Characteristic X-rays

Davisson and Germer experiment
Confirms the wave nature of electrons

Application of X-rays
- In industry to detect defects in metallic structure
- To determine internal structure of crystal using Bragg's law $n\lambda = 2d \sin\theta$
- In radio therapy
- In medicine and surgery

Absorption of X-Rays
X-rays are absorbed when they are incident on substance.
Intensity of emergent X-rays $I = I_0 e^{-\mu x}$
So intensity of absorbed X-rays $I' = I_0 - I$
$= I_0(1 - e^{-\mu x})$ where x = thickness of absorbing medium, μ = absorption coefficient.

Properties of X-rays
- X-rays are invisible
- They travel in a straight line with speed of light.
- X-rays are measured in Roentgen.
- X-rays carry no charge so they are not deflected in magnetic field and electric field.
- They ionise gases.
- X-rays do not pass through heavy metals and bones.
- They affect photographic plates.
- Long exposure to X-rays is injurious for human body.
- Lead is the best absorber of X-rays.
- For X-ray photography of human body parts, $BaSO_4$ is the best absorber.
- They show all the important properties of light rays like, reflection, interference, diffraction and polarization etc.

Matter Waves (de-Brogile Waves)
Waves associated with moving particle and it propagates in the form of wave packets with group velocity.
- **de-Broglie wavelength**

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE}} \Rightarrow \lambda \propto \frac{1}{p} \propto \frac{1}{v} \propto \frac{1}{\sqrt{E}}$$

- **de-Broglie wavelength associated with the charged particles**

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}}$$

$$\lambda_{Electron} = \frac{12.27}{\sqrt{V}}Å, \lambda_{proton} = \frac{0.286}{\sqrt{V}}Å,$$

$$\lambda_{Deuttron} = \frac{0.202}{\sqrt{V}}Å, \lambda_{\alpha-particle} = \frac{0.101}{\sqrt{V}}Å$$

- **de-Broglie wavelength associated with uncharged particles:** For Neutron de-Broglie wavelength

$$\lambda_{Neutron} = \frac{0.286 \times 10^{-10}}{\sqrt{E(\text{in } eV)}}m = \frac{0.286}{\sqrt{E(\text{in } eV)}}Å$$

Energy of thermal neutrons at ordinary temperature
$\because E = kT \Rightarrow \lambda = \frac{h}{\sqrt{3mkT}}$; where T = Absolute temperature,
k = Boltzmann's constant = 1.38×10^{-23} Joule/kelvin,

- **Ratio of wavelength of photon and electron**

$$\frac{\lambda_{ph}}{\lambda_e} = \frac{c}{E}\sqrt{2mK} = \sqrt{\frac{2mc^2K}{E^2}}$$

Characteristics of Matter waves
- Matter waves are not electromagneticin nature.
- de-Broglie or matter wave is independent of the charge on the material particle.
- Electron microscope works on the phenomena of de-Broglie waves.
- The phase velocity of the matter waves can be greater than the speed of the light.
- Matter waves can propagate in vacuum, hence not mechanical waves.
- de-Broglie's matter-wave concept is analogous to the Bohr's hypothesis.

$2\pi r = n\lambda$, where $\lambda = \frac{h}{mv}$

$\Rightarrow 2\pi r = n\frac{h}{mv}$ or, $mvr = \frac{nh}{2\pi}$

Mind Map-12

Atoms
Consists of elementary particles electrons, protons and neutrons

Model of atom

Bohr model of Hydrogen atom
Electron can revolve only in those orbits in which angular momentum about the nucleus is an integral multiple of $\frac{h}{2\pi}$ i.e., $mvr = \frac{nh}{2\pi}$
- The radiation of energy occurs only when an electron jumps from one permitted orbit to another.

J.J Thomson model of atom
First model of atom Plum pudding model-positive charge is uniformly distributed and negatively charged electrons are embedded in it like seeds in a watermelon

Rutherford nuclear model
Entire positive charge and most of the mass of the atom is concentrated in nucleus and electrons revolving around the nucleus

Drawbacks of Bohr model
- Unable to explain the fine structure of spectral lines
- Valid only for single electron system
- Orbits taken as circular but according to Sommerfield these are elliptical.
- Intensity of spectral lines could not be explained.
- Nucleus was taken as stationary but it also rotates on its own axis.
- It does not explain the Zeeman effect and Stark effect.
- It does not explain the doublets in the spectrum of some of the atoms like sodium (5890 Å and 5896 Å).

Various parameters

Radius of n-th orbit
$r_n = \frac{n^2h^2}{4\pi^2 KZe^2 m}$
$= 0.53\frac{n^2}{Z}$ Å

Speed of electron in n-th orbit
$v_n = \frac{2\pi KZe^2}{nh}$
$= 2.2\times10^6 \frac{Z}{n}$ m/s

Potential energy (U_n) in n-th orbit
$U_n = \frac{-KZe^2}{r_n} = \frac{-27.2}{n^2} Z^2 eV$

Kinetic energy $E_k = \frac{KZe^2}{2r_n} = \frac{13.6Z^2}{n^2}$ ev

Drawbacks of Rutherford's Model
- It could not explain stability of atom
- According to this model the spectrum of atom must be continuous where as practically it is a line spectrum.
- Unable to explain the distribution of electrons outside the nucleus.

Some other quantities for revolution of electron in n^{th} orbit

Quantity	Formula
Angular speed	$\omega_n = \frac{v_0}{r_n} = \frac{\pi m z^2 e^4}{2\varepsilon_0^2 n^3 h^3}$
Frequency	$v_n = \frac{w_n}{2\pi} = \frac{mz^2e^4}{4\varepsilon_0^2 n^3 h^3}$
Time period	$T_n = \frac{1}{v_n} = \frac{4\varepsilon_0^2 n^3 h^3}{mz^2 e^4}$
Angular momentums	$L_n = mv_n r_n = n\left(\frac{h}{2\pi}\right)$
Magnetic field	$B = \frac{\mu_0 i_n}{2r_n} = \frac{\pi m^2 z^3 e^7 \mu_0}{8\varepsilon_0^3 n^5 h^5}$

- Number of a-particles scattered per unit area
$N(\theta) \propto \frac{1}{\sin^4 \theta/2}$
- Impact parameter $b = \frac{1}{4\pi\epsilon_0}\frac{Ze^2 \cot\frac{\theta}{2}}{\frac{1}{2}mv^2}$

θ = angle of scattering

Rutherford α- particle scattering experiment
- Most of the α-particles passed through the gold foil i.e., atom has lot of empty space
- Only about 0.14% of the α-particles scatter by more than 1° and one α-particle in every 8000 α-particles deflected by > 90°
- Positively charged particles protons confined to core called nucleus, size about 10^{-15} to 10^{-14} m

Distance of closest approach
Minimum distance upto from the nucleus which α-particle approach

$r_0 = \frac{Ze^2}{mv^2\pi\varepsilon_0} = \frac{4kZe^2}{mv^2}$

$k = \frac{1}{4\pi\varepsilon_0}$
$= 9\times10^9 Nm^2c^{-2}$

ε_0 = permittivity of free space

Various series of line spectra of hydrogen atom

Lyman series
$\bar{v} = \frac{1}{\lambda}$
$= R\left[\frac{1}{1^2} - \frac{1}{n^2}\right]$
n = 2, 3, 4.........
in uv-region

Balmer series
$\bar{v} = \frac{1}{\lambda}$
$= R\left[\frac{1}{2^2} - \frac{1}{n^2}\right]$
n = 3, 4, 5
in visible region

Paschem series
$\bar{v} = \frac{1}{\lambda}$
$= R\left[\frac{1}{3^2} - \frac{1}{n^2}\right]$
n = 4, 5, 6, ...
In infra-red ration

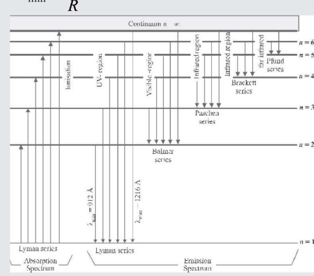
Brackett series
$\bar{v} = \frac{1}{\lambda}$
$= R\left[\frac{1}{4^2} - \frac{1}{n^2}\right]$
n= 5, 6, 7 ......
In infra-red region

P-fund seried
$\bar{V} = \frac{1}{\lambda} = R\left[\frac{1}{5^2} - \frac{1}{n^2}\right]$
n= 6, 7, 8, ...
In infra-red region

Hydrogen Spectrum and Spectral Series
Spectral lines arising from the transition of electron forms a spectra series.
- According to the Bohr's theory the wavelength of the radiations emitted from hydrogen atom

$\frac{1}{\lambda} R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] \Rightarrow \lambda = \frac{n_1^2 n_2^2}{(n_2^2 - n_1^2)R} = \frac{n_1^2}{\left(1 - \frac{n_1^2}{n_2^2}\right)R}$

where n_2 = outer orbit (electron jumps from this obrit), n_1 = inner orbit (electron falls in this orbit).
- First line of the series is called first member. For this line wavelength is maximum (λ_{max})
For maximum wavelength if $n_1 = n$ then $n_2 = n + 1$
- $\lambda_{max} = \frac{n^2(n+1)^2}{(2n+1)R}$
- Last line of the series is called series limit. For this line wavelength is minimum (λ_{min})
For minimum wavelength $n_2 = \infty$, n_1 = n,
so $\lambda_{min} = \frac{n^2}{R}$



Transition of Electron
When an electron makes transition from higher energy level energy $E_2(n_2)$ to a lower energy level, energy $E_1(n_1)$ then
Energy of emitted radiation
$\Delta E = E_2 - E_1 = \frac{-RchZ^2}{n_2^2} - \left(\frac{RchZ^2}{n_1^2}\right) = 13.6Z^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

Frequency of emitted radiation
$v = \frac{\Delta E}{h} = \frac{E_2 - E_1}{h} = RcZ^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

Wave number/wavelength
Wave number is the number of waves in unit length
$\bar{v} = \frac{1}{\lambda} = \frac{v}{c} \Rightarrow \frac{1}{\lambda} = RZ^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) = \frac{13.6Z^2}{hc}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

Recoiling of an atom: Due to transition of electron, photon is emitted and the atom is recoiled.
Recoil momentum of atom = momentum of photon
$= \frac{h}{\lambda} = hRZ^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$
Also recoil energy $= \frac{p^2}{2m} = \frac{h^2}{2m\lambda^2}$

Number of spectral lines
If electron falls from orbit n_2 to n_1 then the number of spectral lines emitted $N_E = \frac{(n_2 - n_1 + 1)(n_2 - n_1)}{2}$
If electron falls from nth orbit to ground state (i.e., $n_2 = n$ and n_1 = 1) then number of spectral lines emitted
$N_E = \frac{n(n-1)}{2}$

Mind Map-13

Isotopes
Nuclides with same atomic number, Z but different mass number, A or no. of neutrons N
e.g., $_1H^1$, $_1H^2$, $_1H^3$, $_8O^{16}$, $_8O^{17}$, $_8O^{18}$

Isobars
Nuclides with same mass number, A or no. of neutrons N but different atomic number Z
e.g., $_1H^3$, $_2He^3$; $_6H^{14}$, $_7N^{14}$

Isotones
Nuclides with same number of neutrons (N) Atomic number (Z) and mass number (A) are different but (A-Z) same,
e.g., $_{14}Be^9$, $_5Be^{10}$, $_6C^{13}$, $_7N^{14}$

Mirror nuclei
Nuclei having the same mass number, A but number of proton (Z) and number of neutron (A-Z) interchanged. e.g., $_1H^3$ and $_2He^3$, $_3Li^7$ and $_4Be^7$

Nuclide $^A_Z X$
Atomic mass A = Protons + neutrons
Atomic no. Z = no. of protons

Nuclear stability $\left(\frac{N}{Z}\text{ ratio}\right)$
- For ligher nuclei-greatest stability when $\frac{N}{Z} = 1$
- For heavier nuclei-greater stability only when they have more neutrons than protons.

Atomic mass unit (amu) 1 amu
$= \frac{1}{12}$ of mass of $_6C^{12}$ atom
1 u = 1.660539 × 10^{-27} kg, 1amu = 931 Mev

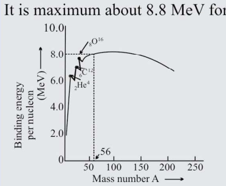
Composition of Nucleus
(Protons + neutrons)
Size of nucleus, radius $R = R_0A^{1/3}$
$R_0 = 1.1 \times 10^{-15}$ m
Density $\rho = \frac{3m}{4\pi R_0^3} = 2.3 \times 10^{17}$ kg/m^3
No. of nucleon (mass of proton + mass of neutron) per unit volume = 10^{44} nucleon/m^3
Mass of proton m_p = 1.00727u = 1.67 × 10^{-27} kg
Mass of neutron m_n = 1.00866u = 1.67 × 10^{-27} kg
Mass of electron m_e = 0.00055u = 9.1 × 10^{-31} kg

Mass defect
Sum of masses of nuclons–mass of nucleus (Δm) = M – m
= $[Zm_p + (A - Z)m_n - m]$

Binding energy
$E_b = \Delta mc^2$
Binding energy per necleon
$= \frac{\text{Total binding energy}}{\text{Mass number}}$
$= \frac{\Delta m \times 931}{A} = \frac{MeV}{\text{Nucleon}}$
Binding energy per nucleon ∝ stability of nucleons

Packing fraction
$f = \frac{\Delta m}{A}$
$= \frac{\text{Exact nuclear mass} - \text{Mass number}}{\text{Mass number}}$
Packing fraction may be +(ve), –(ve) or zero

Binding energy per nucleon current
It is maximum about 8.8 MeV for $F_e^{(56)}$



Nuclei
Nuclei consists of protons and neutrons.

- Nuclear forces bound nucleons in the nucleus
- These are attractive forces
- These are short range forces, do not exist at large distance greater than 10^{-15} m
- Nuclear forces are the strongest forces in nature and non-centra
- **Nuclear Force** Acting inside the nucleus or acting between the nucleons due to

Radioactive series

Series	Mass number	Starting isotope	Stable end product	Natural/Artificial
Thorium	4n	$_{90}Th^{232}$	$_{82}Pb^{208}$	Natural
Neptunium	4n+1	$_{93}Np^{237}$	$_{83}Bi^{209}$	Artificial
Uranium	4n+2	$_{92}U^{238}$	$_{82}Pb^{206}$	Natural
Actinium	4n+3	$_{92}U^{235}$	$_{82}Pb^{207}$	Natural

Radioactivity
Disintegration of heavy elements into comparatively lighter elements by emission of α, β and γ radiation

α-decay i.e., doubly ionised helium ion After emission of one α-particle atomic no. decreases by 2 and mass number by 4

β-decay i.e., fast moving electrons After emission of one β-particle atomic number increases by 1 and mass number remains unchanged

γ-decay
After emission there is no change in atomic number and mass number

Nuclear energy

Nuclear Fission Splitting of a heavy nucleus into two or more lighter nuclei
$_{92}U^{235} + {_0n^1} \rightarrow {_{56}Ba^{141}} + {_{36}Kr^{92}} + 3{_0n^1}$ + energy
Atom bomb
Works on the principle of nuclear fission

Nuclear fusion Combining two lighter nuclei to form one heavy nucleus
$_1H^2 + {_1H^2} + {_1H^2} \rightarrow {_2He^4} + {_1H^1} + {_0n^1}$ + 21.6 Mev
Hydrogen bomb
Works on the principle of nuclear fusion

Moderator Slow down fast moving neutrons e.g.: heavy water, graphite

Coolant Remove heat e.g: cold water, liquid oxygen

Control rods Absorb neutrons e.g., boron, cadmium etc.

Property	α – rays	β – rays	γ – rays
1. Nature	These are doubly ionized helium atom $_2He^4$ Charge $q = +2e = 3.2 \times 10^{-19}$C Mass $m = 2p + 2n = 4$amu $= 4 \times 1.6 \times 10^{-27}$ kg	These are beam of fast moving electrons ($_-\beta^0$) and positions ($_+\beta^0$) charge $_-\beta^0 = -e = -1.6 \times 10^{-19}$C $_+\beta^0 = +e = 1.6 \times 10^{-19}$C $m(_-\beta^0) = m(_+\beta^0)$ $= 9.1 \times 10^{-31}$kg	These are electromagnetic radiations of high frequency and travel in form of photons. Charge q = 0 (chargeless) Rest mass = 0 Effective mass $= \frac{h\nu}{c^2} = \frac{h}{\lambda c}$
2. Speed	Speed ranges between 1.4×10^7 to 2.20×10^7 m/s $v_\alpha \sim 0.05$ c	Speed ranges from 1% to 90% of velocity of light $v_\beta \sim 0.9$c	Speed equals velocity of light $v_\gamma = c$
3. Ionising power $(\alpha > \beta > \gamma)$	These have maximum ionizing power (10000)	Their ionizing power is less than α particles and more than γ rays (100)	Their ionizing power is least (1)
4. Penetration power $(\alpha < \beta < \gamma)$	The penetration power is smallest. Can only penetrate through 0.01 mm thick Al sheet (1)	Penetration power is about 100 times that of α rays, can penetrate through 1 mm thick Al sheet (100)	Penetration power is very large. 10,000 times that of X - rays. Can penetrate about 30 cm thick Al sheet (10,000)
5. Range	Range is very small (few cms in air)	Range is more than α rays (few meters in air)	Range is very large (many hundreds of meter in air)
6. Nature of spectrum	Line spectrum	Continuous spectrum	Line spectrum
7. Interaction with matter	Produces heat	Produces heat	Produces photoelectric effect, Compton effect and pair production
8. Effect on photographic plate and ZnS	Affects photographic plate and produces fluorescense on ZnS	Affects photographic plate and produces fluorescence on ZnS	Affects photographic plate and produces fluorescence on ZnS
9. Effect of electric and magnetic field	Suffers small deflection	Suffers large deflection	Pass undeflected

Rate of decay law
$\left(\frac{-dN}{dt}\right) \propto N \Rightarrow -\frac{dN}{dt} = \lambda N$
No. of undecayed atoms at any instant $N = N_0e^{-\lambda t}$

Half life $t_{1/2} = \frac{0.693}{\lambda}$
Mean life $\tau = \frac{1}{\lambda} = \frac{1}{0.693}(t_{1/2})$
Time interval, undecayed atom (N) becomes $\frac{1}{e}$ times or 0.37 times of original number.

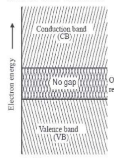
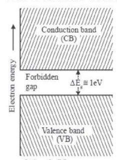
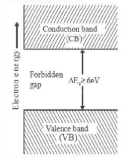
Activity of radioactive element
$A = \left(-\frac{dN}{dt}\right) = \lambda N = \lambda N_0e^{-\lambda t}$
Activity after time, t
$A = A_0e^{-\lambda t}$

Uses of radiaoactive isotope
- In medicine-for cancer Co-60 for testing blood circulation Na-24
- In archaeology-for determining age of archaeological sample C-14
- In agriculture-as fertilisers P-31

Mind Map-14

Semiconductor Electronics: Materials, Devices And Simple Circuits

Comparison Between Conductors, Semiconductors and Insulators

Property	Conductors	Semiconductors	Insulators
1. Resistivity range	$10^{-6}-10^{-8}\,\Omega m$	$10^{5}-10^{0}\,\Omega m$	$10^{7}-10^{16}\,\Omega m$
2. Conductivity range	$10^{+6}-10^{+8}$ mho/m	$10^{-5}-10^{0}$ mho/m	$10^{-7}-10^{-16}$ mho/m
3. Temp. coefficient of resistance (α)	Positive	Negative	Negative
4. Flow of current	Due to free electrons	Due to electrons and holes	No current flow
5. Energy band diagram			
6. Forbidden energy gap	$\cong$ 0eV	$\cong 0.1-3$eV	$\geq$6eV
7. Examples	Pt, Al, Cu, Ag, etc.	Ge (0.67eV), Si (1.14eV), C, Ga, As GaF_2 etc.	Wood, plastic, diamond, mica

Semiconductor

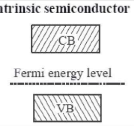
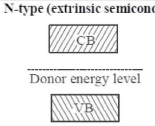
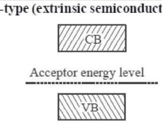
N-type semiconductor
Si or Ge doped with pentavalent As, Sb, Bi etc.
Electrons majority and holes minority carriers $n_e >> n_h$

P-type semiconductor
Si or Ge doped with trivalent, B, Al etc.
Electrons minority and holes majority carriers $n_h >> n_e$

Extrinsic or impure semiconductor
Due to desirable addition of impurity atoms or dopants This is to improve conductivity

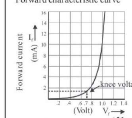
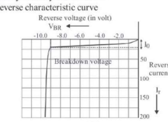
Intrinsic or pure semiconductors
e.g., Si, Ge Intrinsic carrier concentration $n_i = n_e = n_h$
Total current $I = n_e + n_h$

Comparison of Intrinsic, N-type, & P-type and Extrinsic Semiconductor

	Intrinsic semiconductor	N-type (extrinsic semiconductor)	P-type (extrinsic semiconductor)
1.			
2.	Current due to both electrons and holes	Current mainly due to electrons	Current mainly due to holes
3.	$n_e = n_h = n_i$	$n_h << n_e$ ($N_D \simeq n_e$)	$n_h >> n_e$ ($N_A \simeq n$)
4.	$I = I_e + I_h$	$I \simeq I_e$	$I \simeq I_h$
5.	Quantity of electrons and holes are equal	Majority carrier - electrons Minority carrier - holes	Majority carrier - holes Minority carrier - electrons
6.	Current density $J = ne\,[v_e + v_h]$	$J \cong e\,n_h\,v_h$	$J \cong e\,n_e\,v_e$
7.	Conductance $\sigma = \frac{1}{\rho} = en\,[\mu_e + \mu_h]$	$\sigma = \frac{1}{\rho} \cong e\,n_h\,\mu_h$	$\sigma = \frac{1}{\rho} \cong e\,n_e\,\mu_e$

P-N Junction Diode as a Rectifier
Rectifier converts ac to dc. It is of
Half wave rectifier When the P-N junction diode rectifies half of the ac signal.
Efficiency $\%\eta = \frac{P_{out}}{P_{in}} \times 100 = \frac{40.6}{1+\frac{r_f}{R_L}}$
Form factor $= \frac{I_{rms}}{I_{dc}} = \frac{\pi}{2} = 1.57$
Ripple frequency (ω) for half wave rectifier is same as that of ac.
Full wave rectifier: It rectifies both halves of signal.

Difference Between Forward Bias and Reverse Bias

	Forward bias		Reverse bias
1.	Potential barrier reduces.	1.	Potential barrier increases.
2.	Width of depletion layer decreases.	2.	Width of depletion layer increases.
3.	P-N Jn. provide very small resistance.	3.	P-N Jn. provide high resistance.
4.	Forward current flow in circuit.	4.	Very small current flow in circuit.
5.	Order of forward current in milli amp.	5.	Order of current in micro amp.
6.	Mainly majority current flows.	6.	Mainly minority current flows.
7.	Forward characteristic curve 	7.	Reverse characteristic curve 
8.	Forward resistance $R_f = \frac{\Delta V_f}{\Delta I_f} \simeq 100\,\Omega$	8.	Reverse resistance $R_r = \frac{\Delta V_r}{\Delta I_r} \cong 10^6\,\Omega$
9.	Knee or cut voltage Ge $\to$ 0.3 V, Si $\to$ 0.7 V	9.	Breakdown voltage Ge $\to$ 25 V, Si $\to$ 35 V

Transistor
A three terminal semi-conductor device. n-p-n and p-n-p transistors CE, CC and CB configuration

P-n junction
An arrangement made by a close contact of n-type semiconductor and p-type semiconductor

Logic gates Digital circuit follows certain logical relationship between the input and output voltage

Inverter
Converts DC to AC

Zener diode
Used as a voltage regulator

Uses of transistor

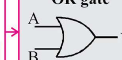
Switch
Transistor in cut off or saturation state

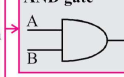
Oscillator frequency
$v = \frac{1}{2\pi\sqrt{LC}}$

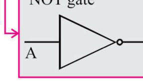
Amplifier
Used for increasing the amplitude of input signal

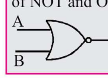
Forward and Reverse biasing : +(ve) terminal connected to p-side and –(ve) terminal. n-side in forward biasing. In reverse biasing +(ve) terminal connected to n-side and –(ve) terminal connected to P-side of diode

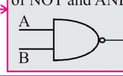
Potential barrier
Potential difference developed across depletion region i.e., region either side of junction free from charge carriers. V_B for silicon = 0.7 V and for germanium V_B = 0.3 V Width of depletion region is of the order of 10^{-6} m

OR gate


AND gate


NOT gate


NOR gate Combination of NOT and OR gate


NAND gate Combination of NOT and AND gate


Combination of Basic gates

Comparative study of CB, CE and CC amplifier:

	CB (Common Base)	CE (Common Emitter)	CC (Common Collector)
Input resistance	Low (100Ω)	High (750 Ω)	Very high = 750 kΩ
Output resistance	Very high	High	Low
Current gain	$\alpha_{dc} = \frac{I_c}{I_e} < 1$, $\alpha_{a.c} = \frac{\Delta I_c}{\Delta I_e}$	$\beta_{dc} = \frac{I_c}{I_b} > 1$, $\beta_{a.c} = \frac{\Delta I_c}{\Delta I_b}$	$\gamma = \frac{I_e}{I_b} > 1$
Voltage gain	$A_V = \frac{V_o}{V_i} = \frac{I_c R_L}{I_e R_i}$, $A_v = \alpha\frac{R_L}{R_i} \cong 150$	$A_V = \frac{V_o}{V_i} = \frac{I_c R_L}{I_b R_i}$, $A_v = \beta\frac{R_L}{R_i} \cong 500$	$A_V = \frac{V_o}{V_i} = \frac{I_e R_L}{I_b R_i}$, $A_v = \gamma\frac{R_L}{R_i}$; less than 1
Power gain	$A_p = \frac{P_o}{P_i}$, $A_p = \alpha^2\frac{R_L}{R_i}$	$A_p = \frac{P_o}{P_i}$, $A_p = \beta^2\frac{R_L}{R_i}$	$A_p = \frac{P_o}{P_i}$, $A_p = \gamma^2\frac{R_L}{R_i}$
Phase difference (between output and input)	Same phase	Opposite phase	Same phase
Application	For high frequency	For audioable frequency	For impedance matching

Relation between α, β and γ

α, β	β, γ	α, γ
$I_e = I_b + I_c$	$I_e = I_b + I_c$	$I_e = I_b + I_c$
divide by I_c	divide by I_b	divide by I_c
$\frac{I_e}{I_c} = \frac{I_b}{I_c} + 1$	$\frac{I_e}{I_b} = 1 + \frac{I_c}{I_b}$	$\frac{I_e}{I_e} = \frac{I_b}{I_e} + \frac{I_c}{I_e}$
$\alpha = \frac{\beta}{1+\beta}$,	$\gamma = 1 + \beta$	$\gamma = 1 + \frac{\alpha}{1-\alpha}$
$\beta = \frac{\alpha}{1-\alpha}$	$\gamma = \frac{1}{1-\alpha}$	

Mind Map-15

Communication Systems

Communication-act of transmission of information

Transmitter
Process and encode the information and make suitable for transmission

Transmitter consists of Transducer, modulator, amplifier and antenna.

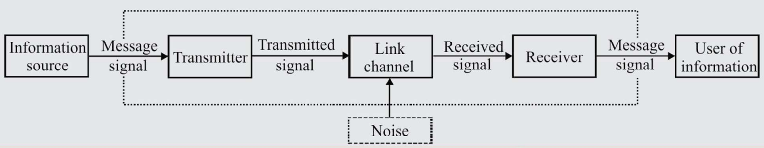
Communication channel
Medium through information propagate from transmitter to receiver

Elements of a communication system

Receiver
Receives and decode the signal received at the channel output

Receiver consists of Pickup antenna, demodulator, amplifier and transducer

Block diagram of communication system



Analog signal
Continuous variation of current or, voltage e.g., sound and picture signal in TV, voice signal in telephony

- Frequency of analog signal varies over a range 20 Hz to 20 kHz
- Complex analog signal consists of two or more waves of different frequencies

Signal
Information converted in electrical form and suitable for transmission

Digital signal
Which take only descrete stepwise values. 0 corresponds to low level 1 corresponds to high level of voltage or current

MODULATION

Continuous wave modulation

Amplitude modulation AM

Frequency modulation FM

Phase modulation PM

Pulse Amplitude modulation PAM

Pulse wave modulation

Pulse time modulation PTM

Pulse code modulation PCM

Basic modes of communication

Point-to-point mode
Between a single transmitter and a receiver e.g., telephony

Broadcast mode
Large number of receivers corresponding to a single transmitter e.g., radio and television

- Transducer- Converts one form of energy into another form e.g., microphone, photodetector etc.
- Modulator- Mixing audio electricsignal with high frequency radio waves
- Demodulator- To separate audio signal from modulated signal
- Amplifier- Boosting power of modulated signal
- Antenna- To pick and radiate the signal

Amplitude modulation
- Modulation index

Process of changing amplitude of a carrier wave in accordance with the amplitude of audio frequency signal.

$m_a = \frac{kE_m}{E_C}$

AM wave contains three frequencies f_c, $(f_c + f_m)$ USB frequency $(f_c - f_m)$ LSB frequency

Power in AM waves-carrier power, $\frac{\left(\frac{E_c}{2}\right)^2}{R} = \frac{E_c{}^2}{2R}$

- Total power of side bands $P_{sb} = \frac{\left(\frac{m_a E_c}{2\sqrt{2}}\right)^2}{R} + \frac{\left(\frac{m_a E_c}{2\sqrt{2}}\right)^2}{R} = \frac{m_a^2 E_c^2}{3R}$
- Total power of AM wave $P_{Total} = P_c + P_{sb} = \frac{E_c^2}{2R}\left(1 + \frac{m_a^2}{2}\right)$

$\frac{P_t}{P_c} = \left(1 + \frac{m_a^2}{2}\right)$ and $\frac{P_{sb}}{P_t} = \frac{m_a^2/2}{\left(1 + \frac{m_a^2}{2}\right)}$

- Maximum power in the AM (without distortion) when $m_a = 1$, i.e., $P_t = 1.5$, $P_c = 3\ P_{sb}$
- If I_c = Unmodulated current and I_t = total or modulated current

$\frac{P_t}{P_c} = \frac{I_t^2}{I_c^2} \Rightarrow \frac{I_t}{I_c} = \sqrt{\left(1 + \frac{m_a^2}{2}\right)}$

Limitation of amplitude modulation
(i) Noisy reception
(ii) Low efficiency
(iii) Small operating range
(iv) Power audio quality

Frequency Modulation (FM) Process of changing frequency of a carrier wave in accordance with the audio frequency. In FM overall amplitude of FM wave remains constant at all times. In FM total transmitted power remains constant.

Frequency deviation: Maximum change in frequency from mean value (v_c)

$\delta = (f_{max} - f_c) = f_c - f_{min} = k_f \cdot \frac{E_m}{2\pi}$

Carrier swing (CS): Total variation in frequency from the lowest to the highest.

$CS = 2 \times \Delta f = (f_{max} - f_{min})$

Frequency modulation Index (m_f): Ratio of maximum frequency deviation to the modulating frequency.

$m_f = \frac{\delta}{f_m} = \frac{f_{max} - f_c}{f_m} = \frac{f_c - f_{min}}{f_m} = \frac{k_f E_m}{f_m}$

Frequency spectrum:

$(f_c \pm f_m), (f_c \pm 2f_m), (f_c \pm 3f_m)$.......

The number of side bands depends on the modulation index m_f,

Bandwidth = $2n \times f_m$; where n = number of significant side band pairs

Bandwidth
Frequency range or portion of spectrum occupied by signal
- FM broadcast 88 – 108 MHZ
- Satellite communication 5.925 – 6.425 GHz Uplink 3.7 – 4.2 GHz Downlink
- Television 54 – 72 Hz – VHF 76 – 88 Hz – TV; 174 – 216 MHZ UHF; 420 – 890 Hz – TV
- Cellular mobile and radio 896 – 901 MHz Mobile to base station 840 – 935 MHz Base station to mobile

Propagation of Em waves

Space wave: Suitable for frequency 30 – 300 MHz Maximum (LOS) distance

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

R = Radius of earth
h_t = Height of transmitting antenna
h_R = Height of receiving antenna

Sky wave: Suitable for frequency 2 – 30 MHz

$V_{critical} = 9(N_{max})^{1/2}$

N_{max} = Maximum electron density of ionosphere per m^3

Ground wave
for local broadcast frequency upto 20MHz

S. No.	Transmission medium	Frequency band	Remarks
1.	Wire (most common)	750 MHz (Bandwidth) (coaxial cable)	Normally operated below 18 GHz
2.	Free space (radio waves)	540 kHz-4.2 GHz	
	(i) Standard AM broadcast	540-108 kHz	
	(ii) FM	88-108 kHz	
	(iii) Television	54-72 MHz 76-88 MHz	VHF (very high frequencies) TV
		174-216 MHz 420-890 MHz	UHF (ultra high frequency) TV
	(iv) Cellular mobile, radio	896-901 MHz	Mobile to base station
		840-935 MHz	Base station to mobile
	(v) Satellite communication	5.925-6.425 GHz	Uplink
		3.7 - 4.2 GHz	Downlink
3.	Optical communication using fibres	101 GHz-1000 GHz (microwaves, ultra-violet)	One single optical fibre offers bandwidth > 100 GHz