PHYSICS

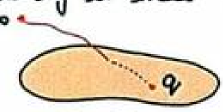
CLASS 12

C2

Electrostatic Potential

- Electric potential (V) at any point in a region with electric field is the work done in bringing a unit positive charge (without acceleration) from infinity to that point

$V_A = \frac{W}{q}$



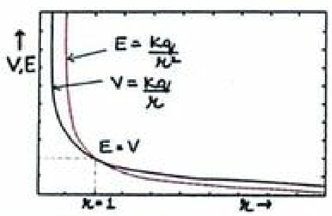
- SI Unit : Volt (V), $[V] = [ML^2T^{-3}A^{-1}]$
- Potential difference between two points A & B,

$V_B - V_A = \frac{W_{AB}}{q_0}$

Potential Due To A Point Charge

$V = \frac{Kq}{r} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$ $\left(V \propto \frac{1}{r}\right)$

- At $r = 1$, $V = E$



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Potential Due To An Electric Dipole

$V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{(r^2 - a^2\cos^2\theta)}$ (P = dipole moment = $q \cdot 2a$)

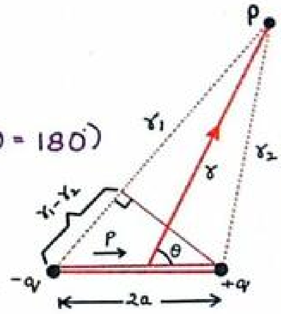
If $r >> a$, $V = \frac{kP\cos\theta}{r^2}$

- At axial point

$V = \pm\frac{1}{4\pi\varepsilon_0}\frac{P}{(r^2 - a^2)}$ ($\theta = 0°$ & $\theta = 180°$)

- At equitorial point

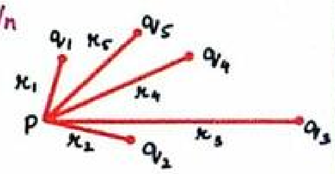
$V = 0$ ($\theta = 90°$)



Potential Due To A System Of Charges

$V = V_1 + V_2 + V_3 + \ldots + V_n$

$= \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{i=n}\frac{q_i}{r_i}$



$= \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + \cdots + \frac{q_n}{r_n}\right]$

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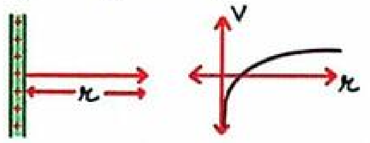
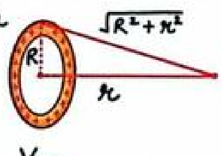
Potential Due To Uniformly Charged Thin Wire

$V = \frac{1}{4\pi\varepsilon_0} 2\lambda \ln(r)$



Potential Due To Uniformly Charged Ring

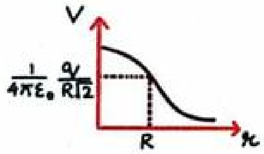
- At point P on axis at a distance r from centre,



$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{\sqrt{R^2+r^2}}$

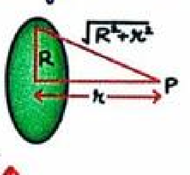
- At centre of ring,

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



Potential Due To Uniformly Charged Disc

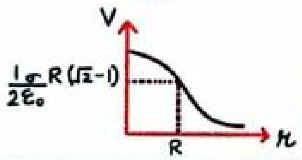
- At point P on axis at a distance r from centre,



$V = \frac{\sigma}{2\varepsilon_0}\left[\sqrt{R^2+r^2} - r\right]$

- At the centre $(x = 0)$,

$V = \frac{\sigma R}{2\varepsilon_0}$



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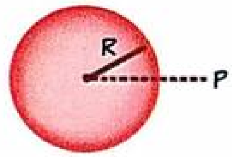
Potential Due To Uniformly Charged Spherical Shell / Conducting Solid Sphere

- Inside the shell $(r < R)$,

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

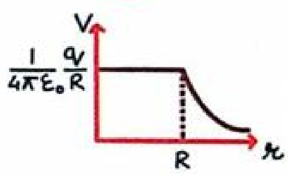


- At the surface $(r = R)$,

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

- Outside the shell $(r > R)$,

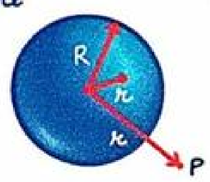
$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$



Potential Due To Uniformly Charged Non Conducting Solid Sphere

- Inside the sphere $(r < R)$

$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}\left[\frac{3}{2} - \frac{1}{2}\frac{r^2}{R^2}\right]$

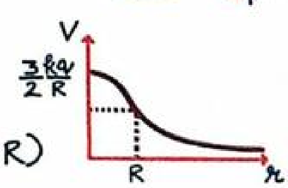


- At the surface $(r = R)$

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

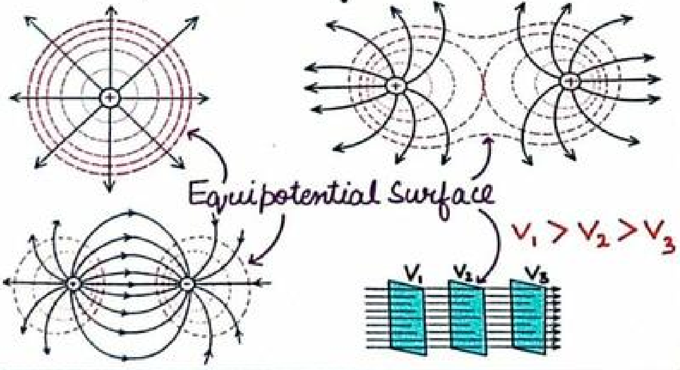
- Outside the sphere $(r > R)$

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

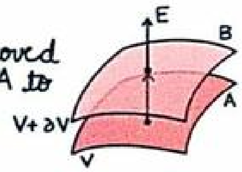


Equipotential Surface

- Surface having same potential at every point on the surface
- Between any two points on an equipotential surface, $\Delta V = 0$ & $W = 0$
- In a region of strong electric field, the equipotential surfaces are closer to each other
- No two equipotential surfaces can intersect each other
- Electric field lines are always normal to equipotential surface



Relation Between Electric Potential & Electric Field



- If a unit +ve charge is moved perpendicularly from surface A to B,

  $E = -\dfrac{\partial V}{\partial r}$

- In 3-D, $E = -\dfrac{\partial V}{\partial r} = -\left(\dfrac{\partial V}{\partial x}\hat{i} + \dfrac{\partial V}{\partial y}\hat{j} + \dfrac{\partial V}{\partial z}\hat{k}\right)$
- Electric field is in the direction in which the potential decreases the steepest
- Magnitude of electric field is given by change in magnitude of potential per unit displacement normal to equipotential surface
- When $\Delta U = 0 \Rightarrow E = 0$
- Example: $V = 3x + 4y - z$

  Find electric field strength.

  $\dfrac{\partial V}{\partial x} = \dfrac{\partial}{\partial x}(3x + 4y - z) = 3$

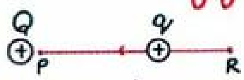
  $\dfrac{\partial V}{\partial y} = \dfrac{\partial}{\partial y}(3x + 4y - z) = 4$

  $\dfrac{\partial V}{\partial z} = \dfrac{\partial}{\partial z}(3x + 4y - z) = -1$

  $\Rightarrow E = 3\hat{i} + 4\hat{j} - 1\hat{k}$

Electric Potential Energy

Work Done



- Work done by the external forces in moving a charge q from R→P against the electrostatic repulsive force exerted by Q

  $W_{RP} = \int_R^P F_{ext} \cdot dr = -\int_R^P F_{Electrostatic} \cdot dr$

  $= U_P - U_R = \Delta U$

Potential Energy Of System Of Charges

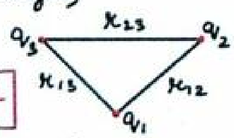
- For a system of two charges,

  $U = W_1 + W_2 = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r}$

- For a system of three charges,

  $U = W_1 + W_2 + W_3$

  $= \dfrac{1}{4\pi\varepsilon_0}\left[\dfrac{q_1 q_2}{r_{12}} + \dfrac{q_1 q_3}{r_{13}} + \dfrac{q_2 q_3}{r_{23}}\right]$



  $(W_1 = 0)$

- For n particle system,

  $U = \dfrac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\sum_{j=1}^{n}\dfrac{q_i q_j}{r_{ij}}$

Potential Energy Of Charges Placed In An Electric Field

- Potential energy of single charge

  $U = qV$

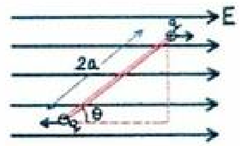
- Potential energy of two charges

  $U = W_1 + (W_2 + W_{12})$

  $= q_1 V_1 + \left(q_2 V_2 + \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r_{12}}\right)$

Potential Energy Of A Dipole

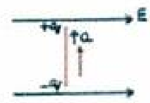
$U = -pE\cos\theta$



- $\theta = 0^\circ$, $U = -pE$

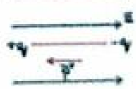
  (Stable equilibrium)

- $\theta = 90^\circ$, $U = 0$

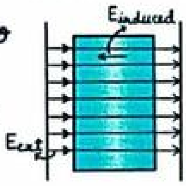


- $\theta = 180^\circ$, $U = +pE$

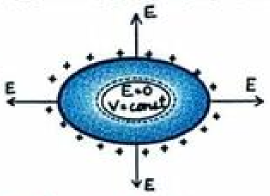
  (Unstable equilibrium)



Electrostatics Of Conductors



- E_{net} inside a conductor is zero ($E_{induced} = E_{external}$)
- $\vec{E}$ is normal to the surface of a charged conductor at every point on the surface
- Q_{net} inside = 0, charge resides on surface
- V is constant inside & has same values on the surface as inside



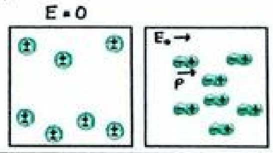
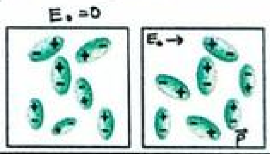
- Electric field at surface of a charged conductor,
  $E = \frac{\sigma}{\varepsilon_0}\hat{n}$
- Electrostatic pressure, $P = \frac{\sigma^2}{2\varepsilon_0} = \frac{1}{2}\varepsilon_0 E^2$

Electrostatic Shielding

- Method of making a region free from electric field
- Irrespective of the charge & field configuration outside the cavity, field inside it is always zero

Dielectrics & Polarisation

Dielectrics: Non conducting substances which can be polarised in presence of electric field

Non-Polar Dielectrics	Polar Dielectrics
Do not have inherent dipole moment	Have inherent dipole moment
When E ≠ 0, centres of +ve & -ve charges of molecules are displaced in opposite direction inducing net p in direction of E	When E ≠ 0, p of molecules align with the field creating net p in direction of E
Eg: H_2O, HCl etc.	Eg: O_2, H_2 etc.
	

Polarisation (P): Dipole moment per unit volume

- For linear isotropic dielectrics, $P = \chi_e E$
  (χ_e → Electric susceptibility of dielectric medium)

Capacitor & Capacitance

Capacitor

- A system of two conductors separated by an insultor
- If charge on conductors is -Q & +Q, potential difference, $V = V_1 - V_2$
- The total charge of a capacitor is zero

Capacitance (C)

- Ability of a capacitor to hold electric charge
  $C = \frac{Q}{V}$
- SI unit: Farad (F) & $[C] = [M L^{-2} T^4 A^2]$
  ($1\mu F = 10^{-6}F$, $1nF = 10^{-9}F$)
- C depends on,
  (i) Size & shape of conductor
  (ii) Separation between conductors
  (iii) Nature of medium in between
  (iv) Independent of the charge on the body

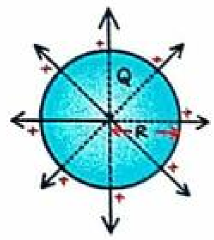
Dielectric Strength

- Maximum electric field that a dielectric medium can withstand without break down

Spherical Capacitor

$C = \frac{Q}{V} = 4\pi\varepsilon_0 R$

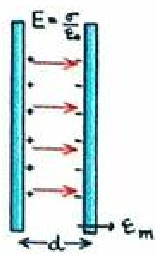
$\left[V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R}\right]$



Parallel Plate Capacitor

$C = \frac{\varepsilon_m A}{d} = \frac{\varepsilon_r \varepsilon_0 A}{d}$

(A → Area of plates
d → Distance between plates
ε_m → Permittivity of medium)



- Force acting between plates, $F = qE = \frac{Q^2}{2A\varepsilon_0}$

Energy Stored In A Capacitor

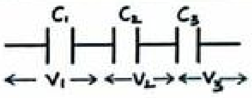
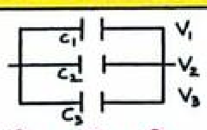
- Work done in moving charge Q from one plate to another is stored as energy

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

- Energy density,

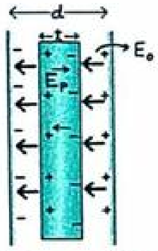
$u = \frac{U}{V} = \frac{1}{2}\varepsilon_0 E^2$ (V → Volume = Ad)

Combination Of Capacitors

Series Combination	Parallel Combination
	
$Q = Q_1 = Q_2 = Q_3$	$Q = Q_1 + Q_2 + Q_3$
$V = V_1 + V_2 + V_3$	$V = V_1 = V_2 = V_3$
$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$	$C_p = C_1 + C_2 + C_3$
For n identical capacitors, $C_s = \frac{C}{n}$	For n identical capacitors, $C_p = nC$
$U_{total} = U_1 + U_2 + \ldots + U_n$	$U_{total} = U_1 + U_2 + \ldots + U_n$

Capacitor With Dielectric Slab

- $E_{net} = E_0 - E_p = \frac{E_0}{K}$
- $V = E_0\left(d - t + \frac{t}{K}\right)$
- $C = \frac{\varepsilon_0 A}{\left(d - t + \frac{t}{K}\right)}$

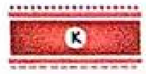


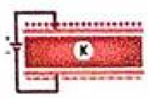
If dielectric is filled completely between plates

- $d = t$, $C' = K\frac{\varepsilon_0 A}{d} = KC$
- $C \propto K$, $\frac{C_1}{C_2} = \frac{K_1}{K_2}$

Effect Of Dielectric

	Battery Disconnected	Battery Kept Connected
Q'	Q	KQ
C'	KC	KC
V'	$\frac{V}{K}$	V
U'	$\frac{U}{K}$	KU
E'	$\frac{E}{K}$	E

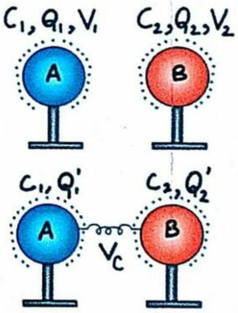




Redistribution Of Charge

- When two charged conductors are connected, charge flows from high to low potential conductor till potential of both becomes equal

Common Potential



- After redistribution,

$Q_1 + Q_2 = Q_1' + Q_2'$

$Q_1' = C_1 V_C$, $Q_2' = C_2 V_C$

$V_C = \frac{Q_1 + Q_2}{C_1 + C_2} = \frac{C_1 V_1 + C_2 V_2}{C_1 + C_2}$

Loss Of Energy

- Energy is lost in the form of heat due to flow of charge in wires

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

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Electric Current

- Rate of flow of charge through a conductor
- Current is a tensor quantity

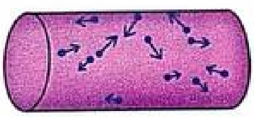
$I = \frac{Q}{t} = \frac{ne}{t}$, SI unit : Ampere

- Average current, $I_{avg} = \frac{\Delta Q}{\Delta t}$
- Instantaneous current, $I_{inst} = \frac{dQ}{dt}$ $[Q = f(t)]$

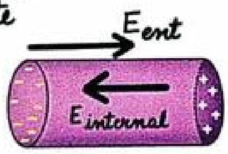
Electric Current In Conductors

- In absence of E_{ext}, electrons move in random directions
- Average velocity, $\vec{v}_{avg} = 0$

$\Rightarrow I_{net} = 0$



- In presence of E_{ext}, e^-s drift in direction opposite to electric field and hence, constitute an electric current



- Current flows until,

$E_{internal} = E_{ext}$

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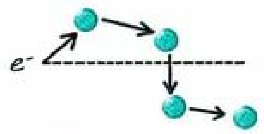
Drift Velocity



Average Relaxation Time (τ)

- Average time between two successive collisions of electrons

$\tau = \frac{\text{Mean Free Path of } e^-}{V_{rms}}$

Drift Velocity Of Electron

- Drift velocity, $\vec{V}_d = a\,\tau_{avg} = \frac{eE}{m_e}\tau$ $\left(a = \frac{eE}{m_e}\right)$
- In terms of potential (V), $v_d = \frac{eV}{m_e l}\tau$

m_e = mass of e^- = 9.11×10^{-31} Kg

- Relation between I & v_d, $I = neAv_d$ $\left(n = \frac{\text{No of } e^-s}{\text{Volume}}\right)$
- Relation between V & I, $V = \left(\frac{m_e l}{ne^2 A\tau}\right) I$
- $\left(\frac{ml}{ne^2 A\tau}\right) \rightarrow$ constant for a conductor with fixed length (l) & area (A)

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Current Density (j)

- Current density, $j = \frac{I}{A} = neV_d = \frac{ne^2E}{m}\tau$
- SI unit : Am^{-2}

Mobility (μ)

- Drift velocity acquired by charge carriers per unit electric field

$\mu = \frac{|V_d|}{E} = \frac{e\tau}{m_e}$

- SI unit : $m^2V^{-1}s^{-1}$
- Relation b/w I & μ, $I = neA\mu E$

Specific Resistance (ρ)

$\rho = \frac{E}{j} = R\frac{A}{l}$,

- SI unit : Ωm

Specific Conductance (σ)

$\sigma = \frac{1}{\rho} = \frac{j}{E}$ or $j = \sigma E$,

- SI unit : $\Omega^{-1} m^{-1}$

03

C3

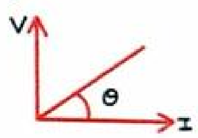
Ohm's Law

- Current flowing through the conductor is directly proportional to the potential difference

$V \propto I \Rightarrow V = RI$ (R = resistance)

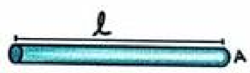
- Resistance is the ability of a conductor to resist the flow of charge

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



- SI unit : ohm (Ω)
- For a conductor,

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



- If a wire is stretched n times its length,

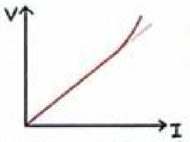
$R_f = n^2 R_i$

- By Ohm's Law,

$V = I\rho\frac{l}{A} = j\rho l$

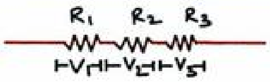
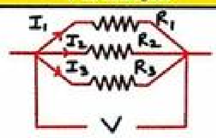
04

Limitations Of Ohm's Law



- For higher value of I, V varies non linearly
- Relation between V & I depends on sign of V
- Reversing the direction of V, keeping its magnitude same does not produce a current of same magnitude
  Example: characteristic curve of a diode
- Materials such as GaAs do not obey ohm's law

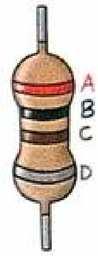
Combination Of Resistors

Series	Parallel
	
$I = I_1 = I_2 = I_3$	$I = I_1 + I_2 + I_3$
$V = V_1 + V_2 + V_3$	$V = V_1 = V_2 = V_3$
$R_s = R_1 + R_2 + R_3$	$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$
For n identical R, $R_s = nR$	For n identical R, $R_p = \frac{R}{n}$

Colour Code for Resistors

$R = (AB \times 10^C \pm D\%)$

Colour	Number (A,B)	Multiplier (C)
Black	0	10^0
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
Grey	8	10^8
White	9	10^9



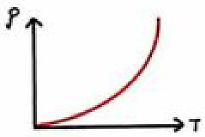
$R = 20 \times 10 \pm 10\%$

D (tolerance)	5%	10%	20%
Colour	Gold	Silver	No colour

Temperature Dependence Of Resistivity

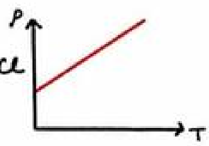
For Metals

- Over a limited range of temperature,
  $\rho_T = \rho_0(1+\alpha\Delta T)$
  $R_T = R_0(1+\alpha\Delta T)$
  {$\alpha \rightarrow$ temperature coefficient of resistivity}
- α is +ve for metals



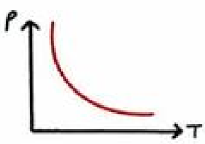
- Variation in ρ at lower temperature (<0°C) is non linear

For Alloys



- ρ has very weak dependence on temperature
- α is +ve
- ρ of magnanin & constantan is nearly independent of T

For Semiconductors



- ρ decreases as temperature increases
- α is −ve for semiconductors & insulators

Electrical Energy & Power

- Heat energy developed in a resistor,
  $E = Vq = VIt = I^2Rt = \frac{V^2}{R}t$, SI unit - Joules
- Electric power,
  $P = \frac{W}{t} = VI = I^2R = \frac{V^2}{R}$, SI unit = Watt (W)
- Power (P_c) dissipated in connecting wires having finite resistance R_c,
  $P_c = I^2R_c = \frac{P^2}{V^2}R_c$
  ($P \rightarrow$ Power delivered by connecting wires)
- To reduce the power wastage, connecting wires carry current at very high value of V (as $P_c \propto \frac{1}{V^2}$)
- For series combination of R, $P = \frac{V^2}{R}$
- For parallel combination of R, $P = I^2R$

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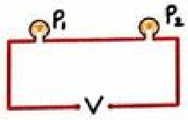
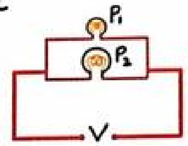
Power Consumption In Combination Of Bulbs



- In series, $\frac{1}{P_{eq}} = \frac{1}{P_1} + \frac{1}{P_2}$

  $P_{consumed}$ or Brightness $\propto V \propto \frac{1}{P_{rated}}$

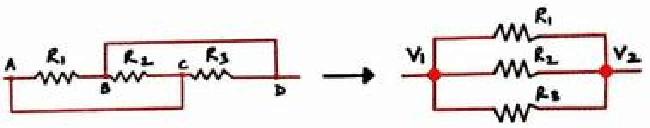


- In parallel, $P_{eq} = P_1 + P_2$

  $P_{consumed} \propto I \propto \frac{1}{R} \propto P_{rated}$

- P_{rated} → Power consumption at a voltage at which the appliance is designed to work

Special Arrangement Of R



- $V_A = V_C = V_1$, $V_B = V_D = V_2$ (as points A to B and C to D are joined by conducting wires)

C3

Cells, EMF & Internal R

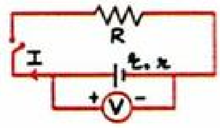
Electromotive Force (ε)

- The potential difference between positive & negative electrodes in an open circuit i.e. when no current is flowing through the cell

Terminal Potential Difference (V)

- Potential difference accross the terminals of a cell when current is drawn from it

$V = IR = \varepsilon - Ir$

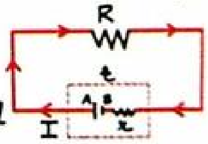


- When $R = 0$; $I_{max} = \frac{\varepsilon}{r}$

Internal Resistance (r)

- Resistance offered by the electrolyte of the cell

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



- If $\varepsilon >> Ir$, r can be ignored
- Dry cells have much higher value of r than common electrolytic cell

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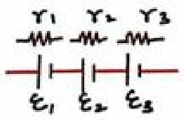
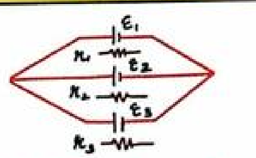
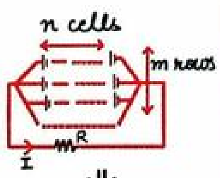
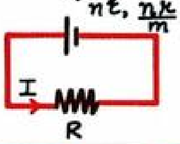
Combination Of Cells

Series	Parallel
	
$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3$	$\frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} + \frac{\varepsilon_3}{r_3}$
$r_{eq} = r_1 + r_2 + r_3$	$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$
For n identical cells,	For n identical cells,
$\varepsilon_{eq} = n\varepsilon$, $r_{eq} = nr$	$\varepsilon_{eq} = \varepsilon$, $r_{eq} = \frac{r}{n}$
Main Current, $I = \frac{n\varepsilon}{R + nr}$	Main Current, $I = \frac{\varepsilon}{R + \frac{r}{n}}$

Mixed Grouping Of Cells



- Total number of cells in one row = n
- Net emf, $\varepsilon_{net} = n\varepsilon$
- Total resistance, $R_{net} = R + \frac{nr}{m}$
- Net current, $I = \frac{mn\varepsilon}{mR + nr}$



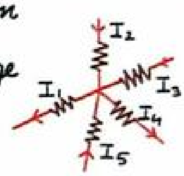
C3

Kirchhoff's Laws

Junction Rule

- At any junction, the sum of currents entering the junction is equal to the sum of currents leaving the junction
- Based on conservation of charge

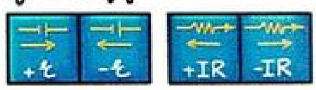
$I_1 + I_4 = I_2 + I_3 + I_5$



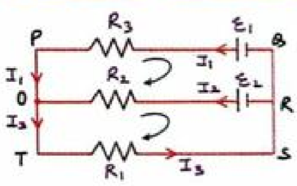
Loop Rule

- Algebric sum of potential changes around any closed loop involving resistors & cells is zero
- Based on conservation of energy

$\Sigma \Delta V = 0$



Example



- Using junction rule at O, $I_3 = I_1 + I_2$
- Using loop rule in,

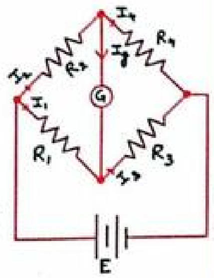
(i) PQROP → $-\varepsilon_1 + \varepsilon_2 - I_2R_2 + I_1R_3 = 0$

(ii) TORST → $-\varepsilon_2 + I_3R_1 + I_2R_2 = 0$

Wheatstone Bridge

- Used to determine value of one unknown resistor among the arrangement of resistors
- For a balanced bridge,

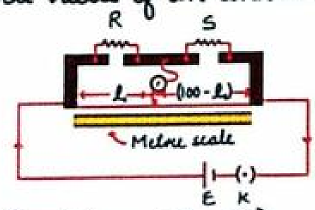
$\frac{R_1}{R_2} = \frac{R_3}{R_4}$ & $I_g = 0$



- Interchanging the positions of the galvanometer & cell does not affect the balanced condition

Meter Bridge

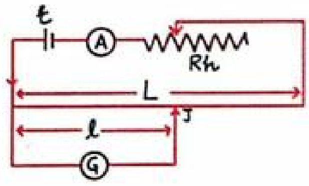
- It is based on Wheatstone bridge & is used to find value of an unknown resistance



- $\frac{R}{S} = \frac{l_1}{(100-l_1)}$ (resistance ∝ length)
- Length of wire = 1 m

Potentiometer

- Used to measure unknown emf or potential difference



- Potential drop across any length of wire of uniform cross section having constant current flow is directly proportional to that length

$V \propto l \Rightarrow V = Kl = \frac{\rho l}{A} I$ ($K \rightarrow$ potential gradient)

Applications

To Compare e.m.f Of Two Cells

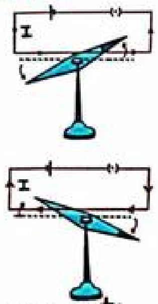
- $E_1 = Kl_1 = (x l_1) I$ & $E_2 = Kl_2 = (x l_2) I$
- $\frac{E_1}{E_2} = \frac{l_1}{l_2}$

To Measure Internal Resistance Of A Cell

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

C4

Oersted's Experiment



- Magnetic needle gets deflected when placed near a current carrying conductor
- On reversing the direction of current, needle gets deflected in opposite direction
- No deflection occurs in absence of current
- Proof that moving charges or currents produce a magnetic field in surrounding space

Magnetic Force

Sources & Fields

- Electric current or moving charges produce magnetic fields
- Vector quantity
- Obeys principle of superposition

Lorentz Force

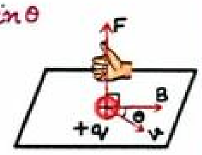
- Force on a charge moving in a region having both magnetic & electric field

$$\vec{F} = \vec{F}_e + \vec{F}_m = q(\vec{E} + \vec{v} \times \vec{B})$$

01

C4

- Force on a charge moving in a magnetic field, $F_m = q(\vec{v} \times \vec{B}) = qvB\sin\theta$

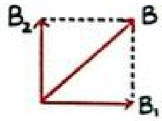


($B \rightarrow$ magnetic field
$\theta \rightarrow$ angle between v & B)

- If $\theta = 90°$, $F_m = qvB$
  $\theta = 0°$ or $180°$, $F_m = 0$
- For a charge at rest in a magnetic field, $F_m = 0$

Magnetic Field

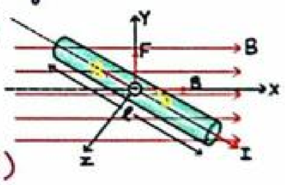
- $|B| = \frac{F}{qv}$, SI unit: Tesla (T)
  1 Tesla = 10^4 Gauss
- Resultant Magnetic Field



$$\vec{B} = \vec{B}_1 + \vec{B}_2 \quad \& \quad |B| = \sqrt{B_1^2 + B_2^2}$$

Force On Current Carrying Conductor

- $F = I(\vec{l} \times \vec{B}) = IlB\sin\theta$
  (direction of $\vec{l} = I$)
- For arbitrary shape of wire, $F_m = \sum I(d\vec{l} \times \vec{B})$



02

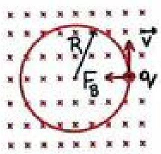
C4

Motion Of Charge In Uniform B

If $v \parallel B$, $\theta = 0°$ or $180°$: $F = 0$ (Straight line)

If $v \perp B$, $\theta = 90°$: $F = qvB = \frac{mv^2}{R}$
(Circular path)

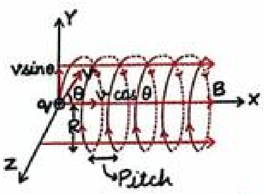
- Radius, $R = \frac{mv}{qB} = \frac{\sqrt{2mK}}{qB} = \frac{p}{qB}$



($p \rightarrow$ Momentum $K \rightarrow$ Kinetic Energy)

- Time Period, $T = \frac{2\pi R}{v} = \frac{2\pi m}{qB}$
- Angular speed, $\omega = \frac{2\pi}{T} = \frac{qB}{m}$
- Wavelength, $\lambda = \frac{h}{p} = \frac{h}{qBR}$ ($h \rightarrow$ Plank's constant)

If $0 < \theta < 90°$ (helical path)



- Radius, $R = \frac{mv\sin\theta}{qB}$
- Time Period, $T = \frac{2\pi m}{qB}$ & Frequency, $f = \frac{qB}{2\pi m}$
- Pitch of helix $= v\cos\theta\, T = \frac{2\pi mv\cos\theta}{qB}$

03

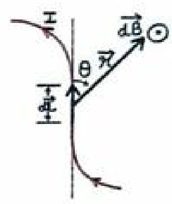
C4

Biot-Savart Law

$$dB \propto \frac{I(d\vec{l} \times \vec{r})}{r^3}, \quad dB = \frac{\mu_0}{4\pi}\frac{I(d\vec{l} \times \vec{r})}{r^3}$$

[μ_0 = permeability of free space = $4\pi \times 10^{-7}\ TmA^{-1}$]

- $B = \int dB = \frac{\mu_0}{4\pi}\int \frac{I\,dl}{r^2}\sin\theta$

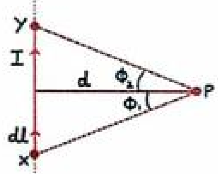


- If $\theta = 0°$ or $180°$, $B = 0$
- If $\theta = 90°$, $B = \frac{\mu_0}{4\pi}\int \frac{I\,dl}{r^2}$

Applications Of Biot Savart Law

B Due To Long Straight Wire

- For finite long wire,
  $B = \frac{\mu_0 I}{4\pi d}(\sin\phi_1 + \sin\phi_2)$



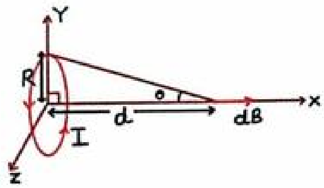
- For infinite long wire,
  $B = \frac{\mu_0 I}{2\pi d}$ ($\phi_1 = \phi_2 = 90°$)
- For semi infinite long wire,
  $B = \frac{\mu_0 I}{4\pi d}$ ($\phi_1 = 90°$ & $\phi_2 = 0°$)

04

B Due To A Circular Loop of N turns

- On the axis passing through centre,

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

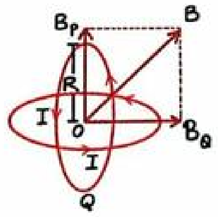


- At $d=0$, $\frac{\mu_0 N I}{2R}$
- At $d \gg R^2$, $\frac{\mu_0 N I R^2}{2d^3}$
- For a semicircular arc, $B = \frac{\mu_0 I}{4R}$ (at the centre, $d=0$)
- For a current carrying arc, $B = \frac{\mu_0 I}{2R}\left(\frac{\theta}{2\pi}\right)$ (at the centre, $d=0$)

B Due To Two Perpendicular Identical Circular Coils With Common Centre

- At centre O,

$B_P = \frac{\mu_0 I}{2R}$ & $B_Q = \frac{\mu_0 I}{2R}$



- Net magnetic field,

$$B_{net} = \sqrt{B_P^2 + B_Q^2} = \frac{\mu_0 I}{\sqrt{2} R}$$

Biot-Savart Law	Coulomb's Law
$dB \propto \frac{1}{r^2}$ (Long range force)	$F \propto \frac{1}{r^2}$ (Long range force)
Obeys superposition principle	Obeys superposition principle
Produced by a vector source ($I dl$)	Produced by a scalar source (q)
B is perpendicular to the plane containing r & $I.dl$	E is along the displacement vector r
Depends on angle b/w r & $I.dl$	No angle dependence

Relation Between ε_0, μ_0 & c

$\varepsilon_0 \mu_0 = \frac{1}{c^2}$ $\left\{ \begin{array}{l} c = \text{speed of light in vaccum} \\ \;\; = 3 \times 10^8\ ms^{-1} \end{array} \right\}$

Right Hand Thumb Rule

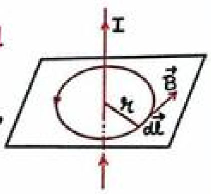
Thumb → Direction of magnetic field

Fingers → Curl of fingers gives the direction of I

Ampere's Circuital Law

- Line integral of magnetic field $\vec{B}$ along a closed path is equal to μ_0 times the total current passing through it

$$\int B.dl = \mu_0 I_{enclosed}$$

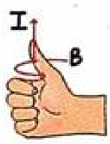


- For a loop of circumference $2\pi r$, to which B is tangential,

$$B(2\pi r) = \mu_0 I$$

- It is applicable only for steady currents

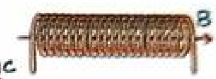
Right Hand Rule

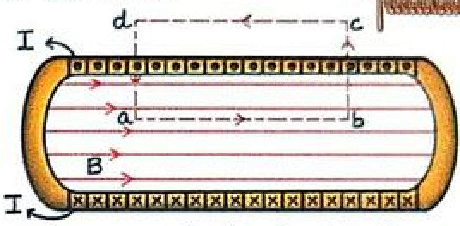


- Thumb → Direction of I
- Fingers → Curl of fingers gives the direction of magnetic field

Applications Of Ampere's Circuital Law

B Due To Solenoid



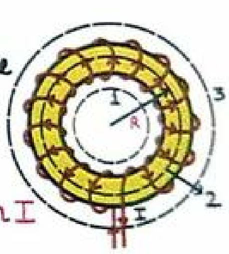


- A long wire wound closely in the form of helix
- Net magnetic field is vector sum of fields due to each turn

$$\int_b^c B.dl = \int_c^d B.dl = \int_d^a B.dl = 0$$

$$B = \int_a^b B.dl = \mu_0 n I \quad \left\{ n = \frac{N}{l} \right\}$$

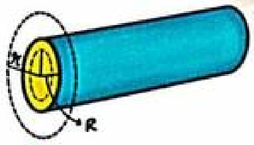
B Due To Toroid



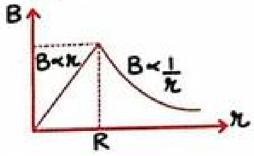
- A solenoid bent into a circle to form a closed ring
- For loop$_1$, $B=0$
- For loop$_2$, $B = \frac{\mu_0 N I}{2\pi R} = \mu_0 n I$
- For loop$_3$, $B=0$

B Due To Thick Wire

- For $r<R$, $B = \left(\frac{\mu_0 I}{2\pi R^2}\right) r$



- For $r>R$, $B = \frac{\mu_0 I}{2\pi r}$
- For $r=R$, $B = \frac{\mu_0 I}{2\pi R}$

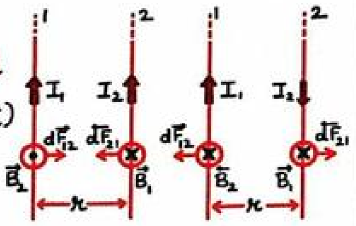


Force Between Two Parallel Current Carrying Conductors

- $F_{21} = I_2 l B_1 = \frac{\mu_0}{2\pi r} I_1 I_2 l$

($l \rightarrow$ length of segment)

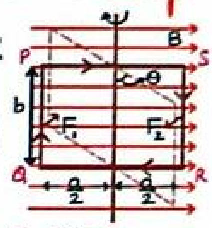
- $f = \frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$



- Parallel currents attract & antiparallel repel
- Ampere: Value of steady current which when maintained in each of the 2 long, straight, parallel conductors of negligible cross-section & placed one metre apart in vaccum would produce on each of these conductors a force equal to 2×10^{-7} N per metre of length

Torque On A Current Loop

- Net force on arms PS & QR is zero



- Force on arms PQ(F_1) & RS(F_2),

$\vec{F_1} = -\vec{F_2} = IbB$

- Torque, $\tau = F_1 \frac{a}{2}\sin\theta + F_2 \frac{a}{2}\sin\theta$

$= IabB\sin\theta = IAB\sin\theta$

($A = ab$ = area of loop)

- If $\theta = 0°$, $\tau = 0$
- If $\theta = 90°$, $\tau = IAB$
- For a loop having N turns, $\tau = NIAB\sin\theta$
- Magnetic Moment $(M) = NIA$ ($A \rightarrow$ Area of loop)
- Direction of $\vec{M}$ is normal to the plane of the loop
- Torque in terms of M, $\vec{\tau} = \vec{M}\times\vec{B} = MB\sin\theta$

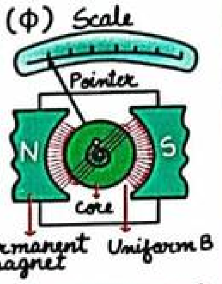
Circular Current Loop as Magnetic Dipole

- $B = \frac{\mu_0 I R^2}{2x^3} = \frac{\mu_0}{4\pi}\frac{2M}{x^3}$ (For $x \gg R$)
- $M = NIA = I\pi R^2$ ($N=1$ for single loop)

Moving Coil Galvanometer

Working Principle

- When a current carrying coil is placed in uniform B, it experiences a torque, producing angular deflection



τ due to $B = NIAB$

$\tau_{restoring}$ due to spring $= K\phi$ ($\phi \rightarrow$ deflection)

$\Rightarrow NIAB = K\phi \;\Rightarrow I = \underbrace{\left(\frac{K}{NAB}\right)}_{\text{Galvanometer constant}}\phi$

- Current Sensitivity, $I_s = \frac{\phi}{I} = \frac{NBA}{K}$
- Voltage Sensitivity, $V_s = \frac{\phi}{I} = \frac{NBA}{KR} = \frac{I_s}{R}$

- An increase in I_s may not necessarily increase V_s

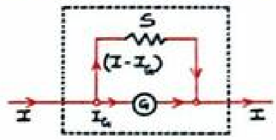
Eg: If no. of turns are doubled, $I_s' \rightarrow 2I_s$,

$R' \rightarrow 2R$ (as $R \propto l \propto N$),

V_s remains constant

Conversion Of Galvanometer

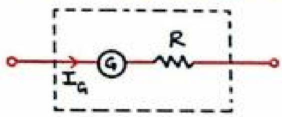
Into An Ammeter



- Shunt (low resistance coil) is connected in parallel
- Resistance of shunt, $S = \frac{I_G G}{(I-I_G)}$ (G → Resistance of Galvanometer)
- To increase range of ammeter n times,

$S = \frac{G}{n-1}$

Into A Voltmeter

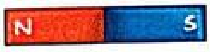


- High resistance coil is connected in series
- Resistance of coil, $R = \frac{V}{I_g} - G$

MAGNETISM

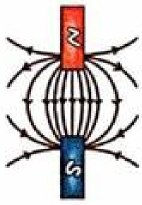
C5

Bar Magnet



- A bar magnet has two equal magnetic poles (North & South), which are non-separable
- Natural dipole, which produces magnetic field around it
- Poles: Ends of magnet where the magnetic force due to magnet is maximum
- Monopoles do not exist: If broken into pieces each behave as an individual magnet
- A freely suspended magnet always aligns in north-south direction

Magnetic Field Lines



- Closed continuous loops
- Tangent to magnetic field lines at any point gives direction of field at that point
- Higher the density of field lines, stronger the magnitude of magnetic field in that region
- Magnetic field lines do not intersect each other

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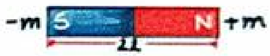
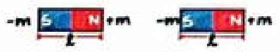
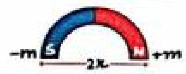
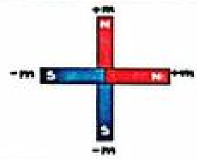
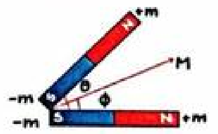
Magnetic Dipole Moment (M)

- $M = m(2l)$
  ($m \rightarrow$ pole strength)

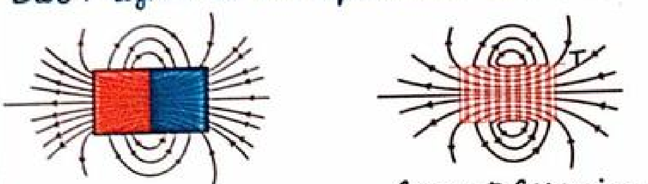


- SI unit: $A\text{-}m^2$
- Direction: South to North

Special Cases	Magnetic Dipole Moment
	$M' = \frac{M}{2}$, $m' = m$
	$M' = \frac{M}{2}$, $m' = \frac{m}{2}$
	$M' = \frac{2M}{\pi}$, $m' = m$
	$M' = \sqrt{2}M$, $m' = m$
	$\lvert M' \rvert = \sqrt{M_1^2 + M_2^2 + 2M_1M_2\cos\theta}$ $\tan\theta = \frac{M_2 \sin\theta}{M_1 + M_2\cos\theta}$

C5

Bar Magnet As An Equivalent Solenoid

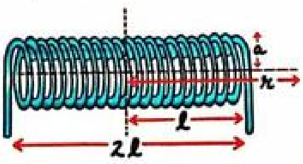


Bar Magnet Current Carrying Solenoid

- A bar magnet can be assumed as a solenoid due to resemblance of magnetic field lines
- Magnetic moment of a bar magnet is equal to the magnetic moment of an equivalent solenoid that produces same magnetic field

$M = NIA$
$= n(2l)I(\pi a^2)$

$\left(n = \frac{N}{2l} = \text{turns per unit length}, \; A = \pi a^2 \right)$



- Magnetic field at axial point ($r >> a$),
  $B = \frac{\mu_0}{4\pi} \frac{2M}{r^3}$
- Magnetic field at equitorial point,
  $B = \frac{\mu_0}{4\pi} \frac{M}{r^3}$

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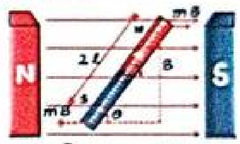
Bar Magnet In Uniform Magnetic Field



- Torque, $\tau = M \times B = MB\sin\theta$
- Potential energy (U) = Work Done (W) in rotating dipole by angle θ
  $= -M.B = -MB\cos\theta$
- If $\theta = 90^\circ$, $U = 0$ & $\theta = 0^\circ$, $U = MB$
- Work done in rotation, $W = MB(\cos\theta_1 - \cos\theta_2)$

Oscillation Of Freely Suspended Bar Magnet When Displaced By Small Angle θ

- Restoring Torque, $\tau = -MB\sin\theta \approx -MB\theta$
- Deflecting torque $\tau = I\alpha = I\frac{d^2\theta}{dt^2}$ ($I \rightarrow$ Moment Of Inertia)
- At equilibrium, $MB\sin\theta + I\frac{d^2\theta}{dt^2} = 0$ (S.H.M)
- Time period of oscillation, $T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{I}{MB}}$

C5

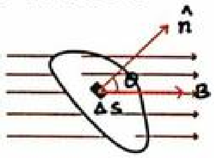
Analogy Between Electric & Magnetic Dipole

Parameters	Electrostatic	Magnetism
	$1/\varepsilon_0$	μ_0
Dipole moment	p	M
Equitorial field for a short dipole	$\frac{1}{4\pi\varepsilon_0}\frac{-p}{r^3}$	$\frac{\mu_0}{4\pi}\frac{-M}{r^3}$
Axial field for a short dipole	$\frac{1}{4\pi\varepsilon_0}\frac{-2p}{r^3}$	$\frac{\mu_0}{4\pi}\frac{2M}{r^3}$
Torque (In external field)	$p \times E$	$M \times B$
Energy (In external field)	$-p.E$	$-M.B$
Gauss Law	$\Phi_E = \frac{q}{\varepsilon_0}$	$\Phi_B = 0$

Magnetism & Gauss's Law

- Net magnetic flux through a closed surface is zero,

$$\Sigma \Delta\Phi_B = \oint B.ds = 0$$



- Incoming Φ_B = Outgoing Φ_B
- Magnetic flux, $\phi = B.A = BA\cos\theta$

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Magnetisation

Intensity Of Magnetisation (I)

- Magnetic moment developed per unit volume (V) in a material placed in a magnetising field

$I = \frac{M}{V} = \frac{m}{A}$, SI unit = Am^{-1}

Magnetic Intensity (H)

- Capability of magnetic field to magnetise a material

$H = \frac{B}{\mu_0} = nI$, SI unit = Am^{-1} ($n \to$ no. of turns per unit volume)

Magnetic Permeability (μ)

- Measure of extent to which the magnetic material can be penetrated by a magnetic field

$\mu = \frac{B}{H}$, SI unit - $Tm A^{-1}$

Magnetic Susceptibility (χ_m)

- Measure of how a magnetic material responds to an external field

$\chi_m = \frac{I}{H}$, χ_m has no units

C5

Relative Permeability (μ_r)

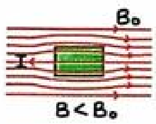
$$\mu_r = \frac{\mu\ \text{(medium)}}{\mu_0\ \text{(free space)}} = \frac{B\ \text{(internal field)}}{B_0\ \text{(external field)}}$$

- $\mu = \mu_0(1+\chi)$ or $\mu_r = 1+\chi$

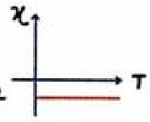
Magnetic Properties Of Materials

Diamagnetic Substances

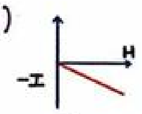
- Develop feeble magnetisation in opposite direction when placed in a magnetic field



- Spin motion of electrons get modified to produce magnetisation in opposite direction
- χ_m is independent of temperature



- χ_m & I for diamagnetic substances are small and negative ($-1 \le \chi_m < 0$)
- $0 < \mu_r < 1$ ($\mu < \mu_0$)



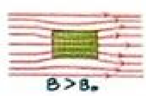
- Magnetic moment of a single atom is zero

Examples: Bi, Cu, Pb, Si, N (at STP), H_2O

C5

Paramagnetic Substances

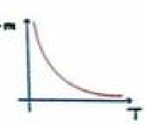
- Develop feeble magnetisation in same direction when placed in a magnetic field



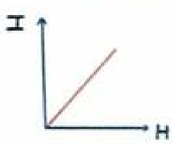
- Curie's Law: Magnetisation (M) of a paramagnetic material is inversely proportional to the absolute temperature

$M \propto \frac{1}{T} \Rightarrow M = C\frac{B_0}{T}$

$\chi_m = C\frac{\mu_0}{T}$ ($C \to$ Curie's Constant)



- χ_m & I for paramagnetic material are small & positive ($0 < \chi_m < \varepsilon$)
- On increasing B or decreasing T, magnetisation increases upto a saturation value (M_s), at which all the dipoles are aligned with the field, beyond this curie's law is not valid
- At a given temperature, $I \propto H$

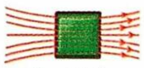


- $1 < \mu_r < (1+\varepsilon)$, $\mu > \mu_0$
- Each atom has permanent magnetic moment (M)

Examples: Al, Na, Ca, O (at STP), $CuCl_2$

Ferromagnetic Substances

- The dipole moment of individual atoms align in a common direction over a macroscopic volume called domain
- Develop strong magnetisation in same direction when placed in a magnetic field

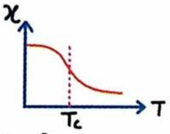


$B_m \gg B_o$

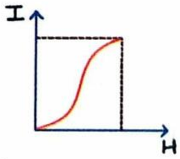
- Soft Ferromagnets: Magnetisation disappears on removal of external field
- Hard Ferromagnets: Magnetisation persists on removal of external field. They form permanent magnets.
- χ_m & I have large +ve values ($\chi_m >> 1$)

$\chi_m = \frac{C}{T - T_c}$ (Curie - Weiss Law) (for $T > T_c$)

($T_c \rightarrow$ Curie's Temperature)



- When temperature increases above T_c, a ferromagnet becomes a paramagnet
- $I \propto H$, only for small values
- $\mu_r >>> 1$ ($\mu >>> \mu_0$)
- Each atom has permanent magnetic moment



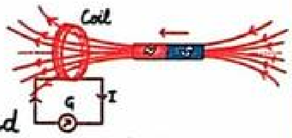
Examples: Co, Fe, Fe_2O_3, Ni, Gd

ELECTROMAGNETIC INDUCTION

C6

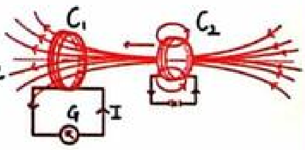
The Experiments Of Faraday & Henry

Experiment 1



- On pushing the bar magnet towards the coil deflection is observed in galvanometer & if bar magnet is pulled away deflection occurs in opposite direction
- The deflection indicates the presence of induced current
- The deflection lasts for as long as the bar magnet is in motion

Experiment 2

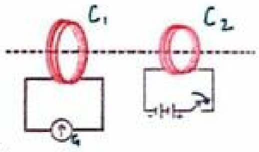


- A current in coil C_1 is induced due to relative motion between current carrying coils C_2 & C_1

01

C6

Experiment 3



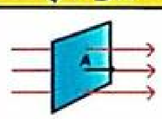
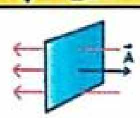
- A momentary deflection is observed in C_1 when key K is pressed
- If K is held pressed → no deflection
- If K is released → momentary deflection in opposite direction is observed

Electromagnetic Flux

- Total number of magnetic field lines passing normally through a surface

$$\phi_B = \vec{B}.\vec{A} = BA\cos\theta$$

- SI unit : $T\text{-}m^2$, Dimension : $[ML^2T^{-2}A^{-1}]$
- $\vec{A}$ is always perpendicular to the surface

$\theta = 0^\circ$, $\phi = BA$	$\theta = 90^\circ$, $\phi = 0$	$\theta = 180^\circ$, $\phi = -BA$
		

02

C6

Faraday's Laws

First Law

- E.M.F (ε) is induced whenever flux linked with the coil or circuit changes which lasts till the change in flux is taking place

Second Law

- The magnitude of induced emf in a coil or circuit is equal to the time rate of magnetic flux through the circuit or coil
- Induced emf, $\varepsilon = -N\frac{d\phi}{dt}$
- Induced current, $I = \frac{|\varepsilon|}{R} = \frac{1}{R}\left(N\frac{d\phi}{dt}\right)$

(N → No. of turns in coil, R → Resistance of coil, N=1, for a circuit)

- Induced charge, $dq = \frac{1}{R}d\phi$

Methods Of Generating Induced EMF

- By changing, (i) Magnetic field (ii) Orientation & shape of coil (iii) Area of cross section

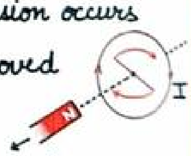
03

C6

Lenz's Law

- The polarity of induced emf is such that it tends to produce a current which opposes the change in magnetic flux which produces it
- The –ve sign in $\varepsilon = -\frac{d\phi}{dt}$ represents this effect
- Lenz's law is in accordance with the law of conservation of energy
- For continuous change in ϕ, some work is to be done (or some energy is to be spent) against the opposition offered by induced ε
- Energy spent by external source is converted into electrical energy appearing in the circuit
- When N pole of magnet is moved towards the coil
  - → I is induced in anticlockwise direction
  - → Coil develops N polarity & repulsion occurs

- When N-pole of magnet is moved away from the coil,
  - → I is induced in clockwise direction
  - → Coil develops S polarity & attraction occurs

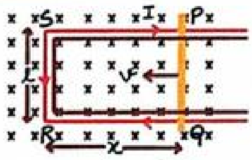


04

C6

Motional E.M.F

Conductor Moving Perpendicular To A Magnetic Field



- Free e^-s move from Q→P due to Lorentz force
- ϕ linked with the loop PQRS, $\phi_B = Blx$
- E.M.F induced, $\varepsilon = Blv$
- Charge induced, $\Delta q = \frac{\Delta \phi}{R}$
- Current induced, $I = \frac{\varepsilon}{R} = \frac{Blv}{R}$

(R→Resistance of the rod PQ)
- Force on rod PQ, $F = IlB = \frac{B^2 l^2 v}{R}$
- W in moving e^-(s) from Q→P, $W = qvBl$
- Power delivered by F_{ext}, $P = Fv = I^2R = \frac{B^2l^2v^2}{R}$

($P_{dissipated}$ as joules loss = $P_{delivered}$ by F_{ext})

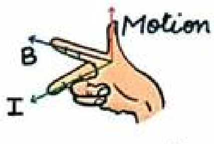
C6

Metallic Rod Rotated In Uniform Magnetic Field

- Free e^-s move from P→Q due to Lorentz force
- Change in flux in one revolution, $\Delta\phi = B\pi L^2$
- Induced e.m.f, $\varepsilon = \frac{1}{2} B\omega L^2$
- Charge induced, $Q = \frac{B\pi L^2}{R}$ (R→ Resistance of Rod)
- Current through AB, $I = \frac{1}{2}\frac{BL^2\omega}{R}$
- Work done (W), in moving the rod PQ, with constant v or ω is converted into electrical energy
- Same amount of P will be lost from the circuit in the form of heat

C6

Fleming's Right Hand Rule

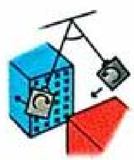


- Thumb → Motion of conductor
- Forefinger → Direction of B
- Central finger → Direction of induced current

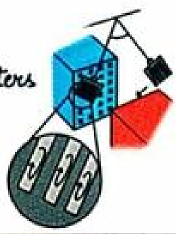
Eddy Currents

- Induced current produced in a conductor when the magnetic flux linked with the conductor changes
- Eddy currents produce both heating & magnetic effects

Applications



- Magnetic breaking in trains
- Electromagnetic damping
- Induction furnace
- Electric power metres, speedometers



Method To Minimize Eddy Currents

- Lamination of core

C6

Inductance

- Ratio of flux linkage to current
- Scalar quantity
- SI unit : Henry (H)
- Dimensions : $[ML^2T^{-2}A^{-2}]$
- Current can be induced in a coil by change in flux produced by another coil in its vicinity or flux change produced by same coil
- Flux produced by a coil ($N\phi$) $\propto$ Current (I)
- The proportionality constant appearing is called inductance
- Inductance depends on the geometry of coil & intrinsic properties of material

Self Inductance (L)

- Measure of inertia of the coil against the change of current through it
- It is electromagnetic analogue of mass
- Change in current in coil induces an EMF in the coil called induced emf or back emf
- Flux through a coil, $N\phi_B \propto I \Rightarrow N\phi_B = LI$
- Self-inductance, $L = \frac{N\phi_B}{I} = \frac{\varepsilon}{dI/dt} = \frac{NBA}{I}$
- SI unit : Henry, $[L] = [ML^2T^{-2}A^{-2}]$
- EMF induced, $\varepsilon = -L\frac{dI}{dt}$ (L→Self Inductance)
- L of a coil depends on its geometry & the permeability of the medium

Long Solenoid

$N\phi_B = \frac{\mu_r \mu_0 N^2 A I}{\ell}$ (A → Area of cross section, μ_r → Relative permeability)

$L = \frac{\mu_r \mu_0 N^2 A}{\ell} = \mu_r \mu_0 n^2 V$ (Volume → $V = A\ell$)

(n → Number of turns per unit length)

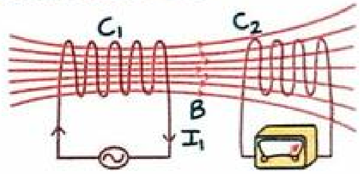
Energy Stored In An Inductor

Energy required to build up the current I,

$$U = L\int_0^I I\,dI = \frac{1}{2}LI^2$$

Energy density, $u = \frac{U}{V} = \frac{1}{2}\frac{B^2}{\mu_0}$

Mutual Inductance (M)

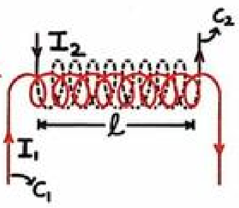


- EMF is induced in coil (C_2) due to change in current in neighbouring coil (C_1)
- Flux through the coil, $N_2\phi_2 \propto I_1$
  $\Rightarrow N_2\phi_2 = M_{21}I_1$
- EMF induced, $\varepsilon_2 = -M_{21}\frac{dI_1}{dt}$

(M_{21} → Mutual inductance of coil 2 w.r.t coil 1)
($M_{21} = M_{12} = M$)

- Mutual Inductance, $M_{21} = \frac{\varepsilon_2}{dI_1/dt}$
- $M_{21} = \frac{N_2\phi_2}{I_1} = \frac{N_2B_1A_2}{I_1}$ & $M_{12} = \frac{N_1\phi_1}{I_2} = \frac{N_1B_2A_1}{I_2}$
- SI unit : Henry (H), $[M] = [ML^2T^{-2}A^{-2}]$
- Mutual Inductance depends on separation between coil & relative orientation

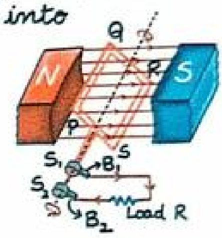
Co-axial Solenoid



- Flux through coil 1,
  $N_2\phi_2 = B_1A_2N_2 = \mu_0\frac{N_1}{\ell}I_1A_2N_2$
- Mutual Inductance,
  $M_{21} = \frac{\mu_r\mu_0N_1N_2A_2}{\ell}$
- If separation between C_1 & C_2 is increased, M decreases
- If primary coil C_1 envelopes secondary coil C_2 completely, M is maximum (The entire flux produced by C_1 is linked with C_2)
- If C_1 & C_2 are perpendicular to each other, M is minimum

A.C. Generator

- Device that produces a current whose direction changes periodically (a.c.) and converts mechanical energy into electrical energy



Principle

- Electromagnetic induction

Construction

- Armature: Coil having large no. of turns
- Slip Rings: Coaxial rings, S_1 & S_2, are used to rotate the coil
- Brushes: Graphite or metallic rods, B_1 & B_2, are used to feed current in external circuit
- For a coil of N turns & area A rotating with a constant angular speed ω and angle θ between B and A then,

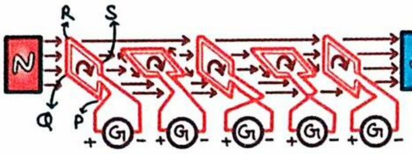
$$\phi = NBA\cos\theta = NBA\cos\omega t$$

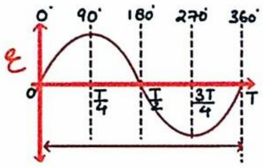
$\Rightarrow \varepsilon = NBA\omega\sin\omega t = \varepsilon_0\sin\omega t = \varepsilon_0\sin 2\pi\nu t$

(ν = frequency of rotation of the coil)

$\Rightarrow I = \frac{\varepsilon_0\sin\omega t}{R} = I_0\sin\omega t$ (I_0 → Peak value of I, ε_0 → Peak value of ε)

Working





First Half Rotation

- Direction of current, P→Q→R→S (clockwise)
- When $\theta = 0$, $\mathcal{E} = 0$ $(\sin\omega t = 0)$
- When $\theta = 90^\circ$, $\mathcal{E} = \mathcal{E}_0 = NBA\omega$ $(\sin\omega t = 1)$

Second Half Rotation

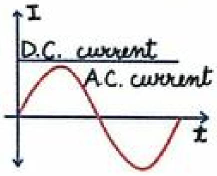
- Direction of current, Q→P→S→R (anticlockwise)
- When $\theta = 180^\circ$, $\mathcal{E} = 0$ $(\sin 180^\circ = 0)$
- When $\theta = 270^\circ$, $\mathcal{E} = -\mathcal{E}_0$ $(\sin 270^\circ = -1)$
- When $\theta = 360^\circ$, $\mathcal{E} = 0$ $(\sin 360^\circ = 0)$

C7

Alternating Current

Alternating Current

Current whose magnitude & direction changes periodically



Direct Current

Current whose direction remains constant with time

- Voltage & current varying sinusoidally,

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

(I, V = Instantaneous value of current & emf
I_0, V_0 = Peak value of current & emf)

ω = angular frequency $= \frac{2\pi}{T}$

Average Value Of A.C.

- Over a complete cycle $(0 \to T)$, $I_{avg} = 0$
- Over a half cycle $(0 \to \frac{T}{2})$,

$$I_{avg} = \frac{2}{\pi} I_0 = 0.637\, I_0$$

$$V_{avg} = \frac{2}{\pi} V_0 = 0.637\, V_0$$

C7

R.M.S Value (Effective Value)

- $I_{rms} = \frac{I_0}{\sqrt{2}} = 0.707\, I_0$ & $V_{rms} = \frac{V_0}{\sqrt{2}} = 0.707\, V_0$
- Example:

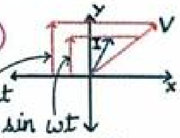
Rating of household supply is 220V

R.M.S. value = 220V & Peak Value $= \sqrt{2} \times 220 \approx 311$V

Phasors (Rotating Vectors)

- Vector which rotates about the origin with angular speed ω
- Let alternating voltage & current be,

$V = V_0 \sin \omega t$ & $I = I_0 \sin(\omega t + \phi)$
($\phi \to$ phase difference between V & I)



- I leads V or V lags I
I reaches max value before V

Example: $V = V_0 \sin \omega t$ & $I = I_0 \sin(\omega t + \phi)$

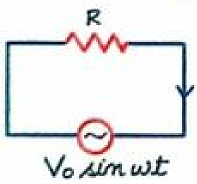
- I lags V or V leads I
I reaches max value after V

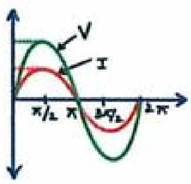
Example: $V = V_0 \sin \omega t$ & $I = I_0 \sin(\omega t - \phi)$

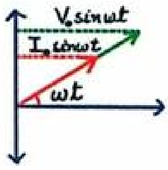
C7

A.C. Voltage Applied To Circuit Elements & Their Combination

Resistor Only Circuit



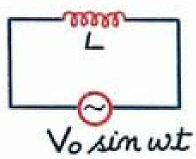


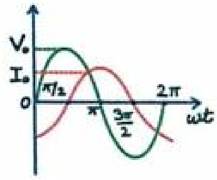


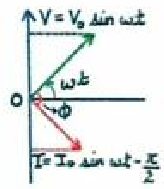
- $V = V_0 \sin \omega t = IR$
- $I = I_0 \sin \omega t$ $\left(I_0 = \frac{V_0}{R}\right)$
- Impedance, $X = R$
- $P_{avg} = \frac{1}{2} I_0^2 R = I_{rms}^2 R = \frac{V_{rms}^2}{R}$
- $P_{inst} = I^2 R = I_0^2 R \sin^2 \omega t$
- Current & voltage are in same phase

C7

Inductor Only Circuit



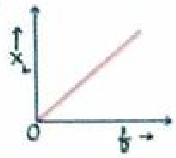




- Net instantaneous e.m.f, $\Sigma V(t) = 0$

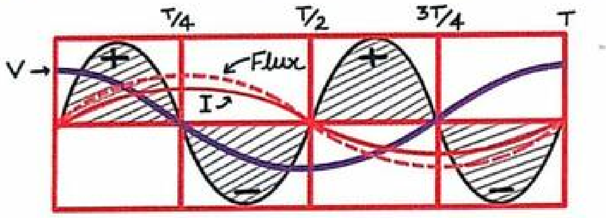
$\Rightarrow V - L\frac{dI}{dt} = 0$ or $V = L\frac{dI}{dt} = V_0 \sin \omega t$

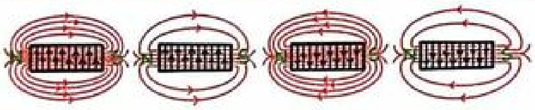
- $I = I_0 \sin(\omega t - \frac{\pi}{2})$ $\left[I_0 = \frac{V_0}{\omega L}\right]$
- Impedance, $X = X_L = \omega L = 2\pi \nu L$
- $P_{avg} = 0$
- $P_{inst} = IV = -\frac{I_0 V_0}{2} \sin 2\omega t$



- I lags behind V by $\frac{\pi}{2}$
- At $t = 0$, $X_L = \infty$, inductor is discharged & acts as an open switch

Magnetisation & Demagnetisation Of Inductor



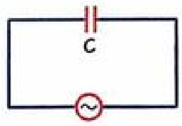


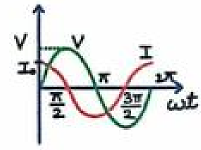
Time Period	I	V	P	Core	Energy
$0 \to \frac{T}{4}$	+ve	+ve	+ve	Magnetised	Absorbed from source
$\frac{T}{4} \to \frac{T}{2}$	+ve	−ve	−ve	Demagnetised	Released to source
$\frac{T}{4} \to \frac{3T}{4}$	−ve	−ve	+ve	Magnetised	Absorbed from source
$\frac{3T}{4} \to T$	−ve	+ve	−ve	Demagnetised	Released to source

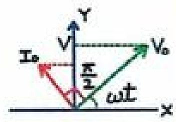
- Over a complete cycle (0→T), net energy absorbed is zero

Capacitor Only Circuit

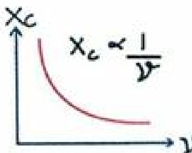
- When a capacitor is connected to a d.c. source, it gets fully charged & stops the flow of current
- When a capacitor is attached to an a.c. source, it gets alternatively charged and discharged



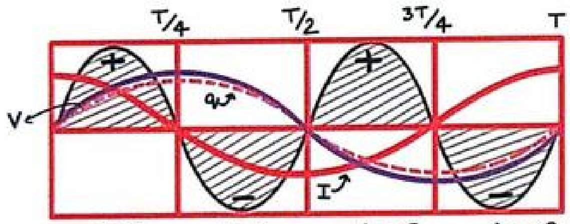


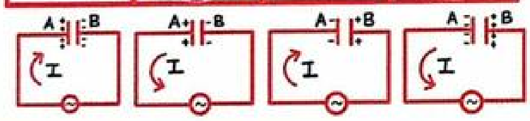


- $V = \frac{q}{C} = V_0 \sin\omega t$
- $I = I_0 \sin(\omega t + \frac{\pi}{2})$ $\left[I_0 = \frac{V_0}{(1/\omega C)}\right]$
- Impedance, $X = X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C}$
- $P_{avg} = 0$ (for $t_0 = 0 \to T$)
- $P_{inst} = \frac{I_0 V_0}{2} \sin 2\omega t$
- I leads V by $\frac{\pi}{2}$



Charging & Discharging Of A Capacitor

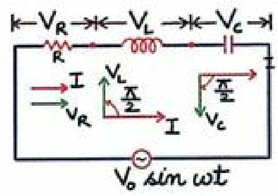


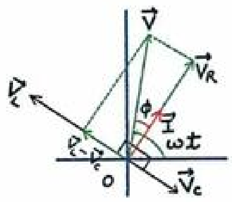


Time Period	I	V	P	Capacitor	Energy
$0 \to \frac{T}{4}$	+ve	+ve	+ve	Charged	Absorbed from source
$\frac{T}{4} \to \frac{T}{2}$	−ve	+ve	−ve	Discharged	Released to source
$\frac{T}{4} \to \frac{3T}{4}$	−ve	−ve	+ve	Charged	Absorbed from source
$\frac{3T}{4} \to T$	+ve	−ve	−ve	Discharged	Released to source

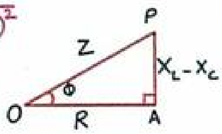
- Over a complete cycle, net energy absorbed is zero

LCR Circuit





- $\vec{V} = \vec{V_L} + \vec{V_R} + \vec{V_C} = L\frac{dI}{dt} + IR + \frac{q}{C} = V_0 \sin\omega t$
- $V_0 = \sqrt{V_{R_0}^2 + (V_{L_0} - V_{C_0})^2} = I_0\sqrt{R^2 + (X_L - X_C)^2}$
- Impedance, $X = \sqrt{R^2 + (X_L - X_C)^2}$
- $\tan\phi = \left(\frac{X_L - X_C}{R}\right) = \left(\frac{V_L - V_C}{R}\right)$



- If $X_L > X_C$, ϕ is +ve

  ⇒ Circuit is inductive & I lags V
- If $X_L < X_C$, ϕ is −ve

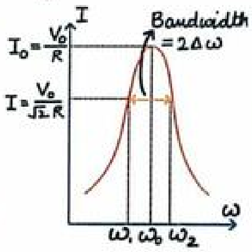
  ⇒ Circuit is capacitive & I leads V

Resonance Condition

- When current through LCR circuit becomes maximum & Z is minimum
  At $X_L = X_C$, $Z = R$ & $I \rightarrow max$
- Current, $I_0 = \frac{V_0}{R}$
- Resonant angular frequency, $\omega_0 = \frac{1}{\sqrt{LC}}$ $rad\,s^{-1}$
- Resonant frequency, $\nu_0 = \frac{1}{2\pi\sqrt{LC}}$ Hz

Quality Factor (Q)

- Measure of sharpness of the resonance of an LCR circuit
- $Q = \frac{\omega_0}{\omega_2 - \omega_1} = \frac{\omega_0}{2\Delta\omega} = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{\omega_0 L}{R}$
  $(\Delta\omega = \omega_0 - \omega_1 = \omega_2 - \omega_0)$
- $2\Delta\omega = \omega_2 - \omega_1 = \frac{R}{L}$
  ($2\Delta\omega$ = bandwidth of the circuit)
- $\omega_1 = \omega_0 - \frac{R}{2L}$, $\omega_2 = \omega_0 + \frac{R}{2L}$



- Half Power Frequency: Values of ω at which power input is half of its max value

Power In A.C. Circuit

- Instantaneous power,
  $P = V_0 I_0 \sin\omega t \sin(\omega t - \phi)$
- Average power,
  $P_{av} = V_{rms} I_{rms} \cos\phi = I_{rms}^2 Z \cos\phi$
  $= \frac{1}{2} V_0 I_0 \cos\phi$ $\left(\cos\phi = \text{Power Factor} = \frac{R}{Z}\right)$

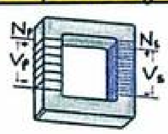
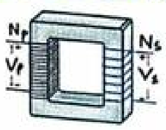
Circuit	$\cos\phi$	$P_{instantaneous}$	$P_{average}$
R - only	1	$I_0^2 R \sin^2\omega t$	$\frac{1}{2} V_0 I_0$
L - only	0	$-\frac{I_0 V_0}{2} \sin 2\omega t$	0
C - only	0	$\frac{I_0 V_0}{2} \sin 2\omega t$	0
LCR (At resonance)	1	$\frac{I_0 V_0}{2} \sin^2\omega t$	$\frac{1}{2} V_0 I_0$

Wattless Current

The current in a.c. circuit when average power consumed in the circuit is zero

Transformer

- Device used for converting low alternating V to a high alternating V & vice-versa
- Principle: Based on mutual induction
- When an A.C. is passed through one coil an emf is induced in the other
- Does not work in case of D.C. source as no emf is induced

Step Up Transformer	Step Down Transformer
	
$N_s > N_p \Rightarrow V_s > V_p$	$N_p > N_s \Rightarrow V_p > V_s$
Converts low V to high V	Converts high V to low V

- For an ideal transformer,
  Output Power = Input Power
  $\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$ = Transformation ratio (K)
- Efficiency, $\eta = \frac{\text{Output Power}}{\text{Input Power}} = \frac{V_s I_s}{V_p I_p} \times 100\%$

Types Of Energy Loss In Transformer

1. Resistance Of Windings
   - Energy is lost due to heat produced in wire (I^2R)
   - Can be reduced by using thick wire in case of high I & low V windings
2. Eddy Current Loss
   - Changing magnetic flux induces eddy currents in the iron core & causes heating
   - Can be reduced by using laminated core
3. Hysteresis Loss
   - Work done in cycles of magnetisation & demagnetisation is lost in form of heat
   - Can be reduced by using magnetic materials which have low hysteresis loss
4. Flux Leakage
   - Magnetic flux produced gets leaked due to poor design of core
   - Can be reduced by winding the primary & secondary coils one over the other

Electron, Photon, Photo Electric Effect

C11

Electron Emission

- Phenomenon of emission of free electron from surface of a metal

Work Function (W_0)

- Minimum amount of energy required by a free electron to just escape the metal surface
- W_0 depends on (a) Nature of the surface (b) Properties of the metal
- SI unit of W_0 = J
  Other units : eV (electron volt), $1 eV = 1.6 \times 10^{-19} J$
- Lowest W_0 → Cesium (Cs) [2.14eV]
  Highest W_0 → Platinum (Pt) [5.65eV]
- Condition for electron emission,
  Energy of $e^- \geq W_0$

Emission	Energy Supply
Thermionic Emission	Heating
Field Emission	Electric Field
Photoelectric Emission	Light Radiations

01

C11

Photelectric Effect

The phenomenon of electron emission from metal surface when light of suitable frequency is incident on it

Hertz Observation

- Voltage sparks across detector loop increased when UV light was incident on emitter plate

Hallwachs' & Lenard's Observation

1. When UV radiations are allowed to fall on emitter plate of an evacuated glass tube enclosing two electrodes (metal plates) current flows in the circuit
2. Variation of charge on zinc plate when illuminated by UV light

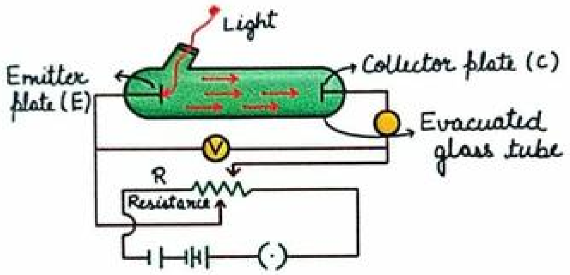
Initial	Final
Negatively charged	Neutral
Uncharged	Positively charged
Positively charged	More positively charged

3. Only light of certain minimum frequency (threshold frequency) ejected the electron

02

C11

Experimental Study Of Photoelectric Effect



- When light of sufficient frequency ($\nu > \nu_0$) falls on E → photoelectrons are emitted
- When C is kept +ve & E is kept -ve then e⁻(s) travel in evacuated tube & reach C & produce photocurrent I_p
- $I_p \propto$ Number of e⁻(s) emitted by E
- The photocurrent can be increased or decreased by varying the potential between C & E
- On reversing the polarity of E & C, electric field is set in the direction of motion of e⁻ causing the photoelectric current to decrease

03

C11

Photoelectrons

- Electrons ejected when light is incident on metal surface

Quanta Of Light

- Smallest discrete amount of light
- 1 quantum of light radiation → Photon

Threshold Frequency (ν_0)

- Minimum frequency of light required for photoelectric emission

Photocurrent (i_p)

- Current produced due to electrons ejected when light is incident on the surface

Saturation Current (I_s)

- Maximum value of photoelectric current when light of fixed intensity is incident on a metal surface

Cut Off or Stopping Potential (V_0)

- Value of negative potential at which the photocurrent becomes zero

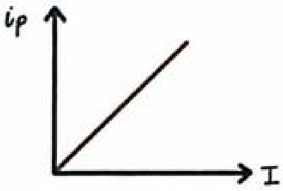
04

Observations From The Experiment

Effect Of Intensity Of Light (I) On Photocurrent

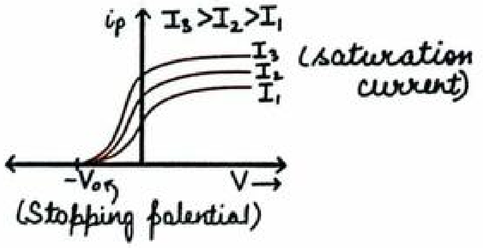
- For fixed frequency of incident radiation and constant potential,

$I \propto i_p$



Effect Of Potential On Photocurrent

- For a fixed value of I and ν of incident radiation, i_p increases with increase in potential and becomes maximum

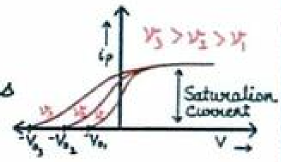


Effect Of Frequency Of Incident Radiation On Stopping Potential

- For radiation with different frequency but same I, stopping potential is different for different ν (more negative for higher incident frequency)

Maximum K.E., $K_{max} = eV_0$

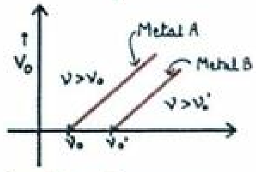
- K_{max} of photoelectron varies linearly with ν of incident light, but it is independent of I



Effect Of Frequency Of Incident Radiation On Stopping Potential

- Saturation current is same for all incident radiations as intensity remains the same
- For a photosensitive material,

$V_0 \propto \nu$



- There is a minimum cut-off frequency for which stopping potential is zero below which no emission is possible even if I is large

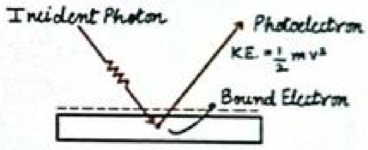
Wave Theory

Light is an electromagnetic wave consisting of electric and magnetic fields with continuous distribution of energy over the region of space over which the wave is extended

Failures Of Wave Theory

Wave Theory	Experimental Fact
As I of radiation increases, KE_{max} of photoelectron increases	KE_{max} is independent of I
Ejection of e⁻ depends on I of radiation imparted over sufficient time & independent of ν of incident radiation	Ejection of e⁻ occurs at or above threshold frequency
Absorbtion of energy by e⁻ takes place over the entire wavefront of radiation. Since, energy absorbed per e⁻ per unit time is small, e⁻ emission should require a finite time.	Photoelectron emission is an instantaneous process

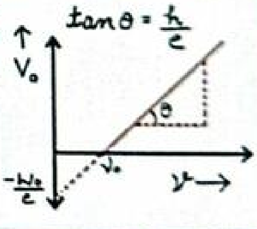
Einstien's Photelectric Equation



$$KE_{max} = \underbrace{\frac{1}{2}mv^2_{max}}_{\text{Maximum kinetic energy that can be possessed by emitted } e^-} = \underbrace{h\nu}_{\text{Energy of incident photons}} - \underbrace{W_0}_{\text{Energy required to overcame work function}}$$

- As K.E. $\neq$ -ve, $h\nu > W_0$ or $\nu > \nu_0$
  $\Rightarrow$ Threshold frequency, $\nu_0 = \frac{W_0}{h}$
- $W_0 = \frac{19.878 \times 10^{-26}}{\lambda_0} J = \frac{12400}{\lambda_0} eV$
  ($\lambda_0 \rightarrow$ Threshold wavelength [in Å])
- $K.E. = h(\nu - \nu_0) = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$
- $K.E. = eV_0 = h\nu - W_0$
  ($V_0 \rightarrow$ Stopping potential)
- $V_0 = \left(\frac{h}{e}\right)\nu - \frac{W_0}{e}$
  (Y→ intercept → $\frac{W_0}{e} = \frac{h\nu_0}{e}$)

$\tan\theta = \frac{h}{e}$



Particle Nature Of Light

- In interaction of radiation with matter it behaves as if it is made up of particles called photons
- Energy of each photon, $E = h\nu$ and
  Momentum of each photon, $p = \frac{h\nu}{c} = \frac{h}{\lambda}$
  and, Speed c = speed of light
- Photons are electrically neutral & are not deflected by electric & magnetic fields
- In photon particle collision, the total energy & total momentum are conserved. However, the number of photons may not be conserved in a collision (photons may be absorbed or new photon may be created)
- All photons of light of a particular ν & λ, have the same energy and momentum, independent of I of radiation

Wave Nature Of Matter (de Broglie Wave)

- Material particles in motion have wave like properties. It is based on 2 considerations
  (a) Nature loves symmetry & matter and energy must have symmetrical characters
  Energy mass relation, $E = mc^2$
  (b) If radiation shows dual nature, so should matter
- de Broglie wavelength (λ associated with de Broglie) $\lambda = \frac{h}{p} = \frac{h}{mv}$
- If velocity $v = 0$, $\lambda = \infty \Rightarrow$ wave nature is not associated with particles at rest
- de Broglie waves can not be electromagnetic
- Also called matter waves

For a Charged Particle

- $p = \sqrt{2mK} = \sqrt{2meV}$ [K - Kinetic energy, V - Potential]
  $\lambda = \frac{h}{\sqrt{2mK}} = \frac{h}{\sqrt{2meV}}$
  ($h = 6.636 \times 10^{-34}$ Js, $e = 1.6 \times 10^{-19}$ C)
- For an e^-, $\lambda = \frac{12.27}{\sqrt{V}}$ Å

Special Cases

Case 1: If an e^- with initial velocity V_0 is accelerated in an electric field E_0, then at time t,

$$\lambda = \frac{h}{m\left(V_0 + \frac{eE_0}{m}\right)t}$$

Case 2: de-Broglie wavelength of a neutron in thermal equilibrium at temperature T,

$$\lambda = \frac{h}{\sqrt{3mK_BT}}$$ ($K_B \rightarrow$ Boltzmann's Constant)

Case 3: Ratio of wavelength of an e^- & a photon of same energy E

$$\lambda_p \propto \lambda_e^2$$

Heisenberg Uncertainity Principle

It is not possible to measure both position & momentum of an e^- or any other particle at the same instant of time

$$\Delta x . \Delta p \geq \frac{h}{4\pi}$$

ATOMIC & NUCLEAR PHYSICS

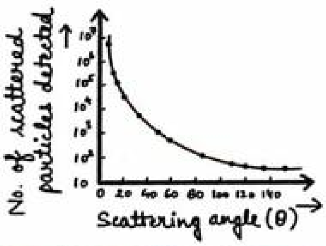
C12

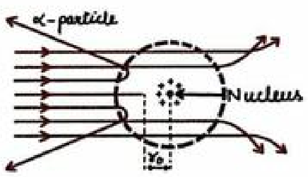
Alpha Particle Scattering Experiment

- Beam of α-particles (He^{+2}) is allowed to fall on a thin gold foil
- Scattered α-particles produced tiny flash on zinc sulphide screen

Observations

- Most of the α-particles passed undeflected or suffered small deflections
- 1 out of every 8000 particles got deflected by an angle more than $90°$
- Only few particles retraced their paths





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Rutherford's Model

- Most of the space inside an atom is empty
- Most of the mass of an atom & all of the positive charge are concentrated in the nucleus with electrons some distance away
- Electrons revolve around the nucleus & atom as whole is electrically neutral
- Size of the nucleus ($10^{-15}-10^{-14}$m) is very small as compared to the size of an atom ($\sim 10^{-10}$m)

Drawbacks of Rutherford Model

- Not able to explain the stability of atom
- Accelerated charged particles radiate energy, hence energy of revolving e^- must decrease & e^- should spiral inwards & fall into the nucleus
- Not able to explain line spectrum
- As e^- spiral inwards, it would emit a continuous spectrum which would contradict the line spectrum actually observed

02

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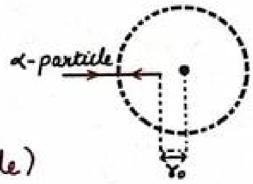
Distance Of Closest Approach (r_o)

- Least distance from the nucleus at which α-particle comes momentarily at rest

$$r_o = \frac{K(2e)(Ze)}{K.E_\alpha}$$



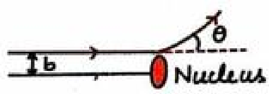
($K.E_\alpha \rightarrow$ Kinetic energy of incident α-particle)

$$\left(K = \frac{1}{4\pi\varepsilon_0}\right)$$

Impact Parameter (b)

- Perpendicular distance of velocity vector of α-particle about the centre of the nucleus

$$b = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2 \cot\theta/2}{K.E_\alpha}$$



- If b is large, α-particle passes with no or small deflection
- If $b=0$, particle retraces its path ($\theta = 180°$)

03

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Electron Orbits (For H-atom)

- $F_e = F_{centripetal} \Rightarrow \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} = \frac{mv^2}{r}$

($F_e \rightarrow$ electrostatic force b/w revolving e^- & nucleus)

- Orbital radius, $r = \frac{e^2}{4\pi\varepsilon_0 mv^2}$
- Total energy, $E = K + U = \frac{e^2}{8\pi\varepsilon_0 r} - \frac{e^2}{4\pi\varepsilon_0 r} = \frac{-e^2}{8\pi\varepsilon_0 r}$

$$\left(K = -E = -\frac{U}{2}\right)$$

- As E is negative, electron is bound to the nucleus, else it will not follow closed orbit around the nucleus

Atomic Spectra

- Atomic gas or vapour excited at low pressure by passing an electric current through it emits radiation
- The radiation emitted by atomic gases has spectrum of specific wavelength
- Line Spectrum: The set of isolated parallel lines in a spectrum

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- **Emission Spectrum:** A spectrum of discrete bright lines on a dark background
- **Absorption Spectrum:** A spectrum of discrete dark line on a bright background
- **Spectral Series:** Certain sets of spectrum in which spacing between lines decrease in a regular way
- For spectral series, $\frac{1}{\lambda} = Z^2 R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$

(Z → Atomic number
R → Rydberg constant ($R = 1.097 \times 10^7 m^{-1}$)
n_2 & n_1 → Final & initial energy orbitals)

- For spectral series of hydrogen,

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) \quad (\because Z = 1)$$

- Frequency of spectrum, $\nu = RC\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$
- Energy, $E = hCR\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) = 13.6\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) eV$
- For last line (shortest λ & highest ν), $n_i \to \infty$
- For first line (longest λ & lowest ν), $n_i \to n_f + 1$

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Hydrogen Spectrum

$\frac{1}{\lambda}$	Shortest λ	Longest λ	Region
Lyman Series $[n_i = 1, n_f = 2, 3, 4, 5, 6 \ldots]$			
$R\left(1 - \frac{1}{n_i^2}\right)$	$\frac{1}{R}$	$\frac{4}{3R}$	Ultraviolet
Balmer series $[n_i = 2, n_f = 3, 4, 5, 6 \ldots]$			
$R\left(\frac{1}{2^2} - \frac{1}{n_i^2}\right)$	$\frac{4}{R}$	$\frac{36}{5R}$	Visible region
Paschen series $[n_i = 3, n_f = 4, 5, 6 \ldots]$			
$R\left(\frac{1}{3^2} - \frac{1}{n_i^2}\right)$	$\frac{9}{R}$	$\frac{144}{7R}$	Infrared
Brackett series $[n_i = 4, n_f = 5, 6, 7 \ldots]$			
$R\left(\frac{1}{4^2} - \frac{1}{n_i^2}\right)$	$\frac{16}{R}$	$\frac{400}{9R}$	Infrared
Pfund series $[n_i = 5, n_f = 6, 7, 8 \ldots]$			
$R\left(\frac{1}{5^2} - \frac{1}{n_i^2}\right)$	$\frac{25}{R}$	$\frac{900}{11R}$	Infrared

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Bohr's Model Of H-Atom

Bohr's Postulates

1. Electron in an atom could revolve in certain stable orbit without radiating energy
2. Electron revolves around the nucleus only in those orbits for which an angular momentum (L) is some integral multiple of $\frac{h}{2\pi}$

$\Rightarrow L$ is quantised, $L = \frac{nh}{2\pi}$

(where n = 1, 2, 3...... is principle quantum no.)

3. An electron might make a transition from a higher energy orbit to a lower energy orbit & emit a photon having energy equal to the difference between the orbital energies

The frequency of the emitted photon,

$$\nu = \frac{E_2 - E_1}{h}$$

$$(h = 6.63 \times 10^{-34} Js)$$

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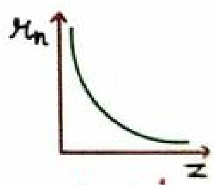
Terms	For Any H-like Atom	H-Atom
Radii	$\frac{h^2}{4\pi^2 mKZe^2} n^2 = 0.53 \frac{n^2}{Z}$ Å	$0.53 n^2$ Å
Velocity	$\frac{2\pi KZe^2}{h} \frac{1}{n} = 2.2 \times 10^6 \frac{Z}{n} ms^{-1}$	$\frac{1}{137} \cdot \frac{c}{n}$
Total Energy	$\left(\frac{-me^4}{8h^2 \varepsilon_0^2}\right)\frac{Z^2}{n^2} = -13.6 \frac{Z^2}{n^2} eV$	$\frac{-13.6}{n^2} eV$
Time Period	$\frac{2\pi r_n}{v_n} = \frac{4\varepsilon_0^2 h^3}{me^4} \frac{n^3}{Z^2} = 1.5 \times 10^{-16} \frac{n^3}{Z^2}$	$\frac{4\varepsilon_0^2 h^3 n^3}{me^4}$ second

- Total no of emissions from n^{th} state to ground state,

$$N = \frac{n(n-1)}{2}$$

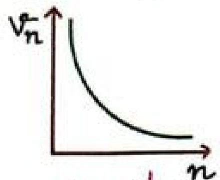
Variation Of r_n with n & Z

$r_n \propto n^2$

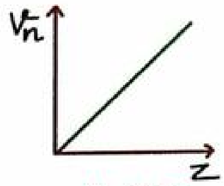


$r_n \propto \frac{1}{Z}$

Variation Of v_n with n & Z

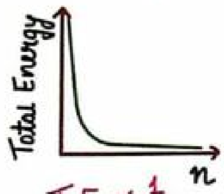


$v_n \propto \frac{1}{n}$

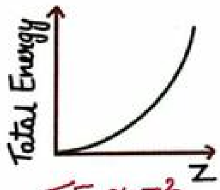


$v_n \propto Z$

Variation Of Total Energy with n & Z



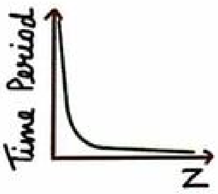
$T.E. \propto \frac{1}{n^2}$



$T.E. \propto Z^2$

Variation Of Time Period with n & Z

Time period $\propto n^3$



Time period $\propto \frac{1}{Z^2}$

Energy Levels Of H-atom

- Ground State : The lowest state of an atom or orbital with the lowest energy
- Bohr Radius : Radius of the ground state
- Ionisation Energy : Minimum energy required to free an e^- from ground state
  I.E. For H-atom = 13.6 eV
- Ionisation Potential : Ionisation energy per unit charge
  For H-atom, V = 13.6 V
- Excitation Energy : Energy required to take an atom from ground to excited state

Line Spectra Of H-atom

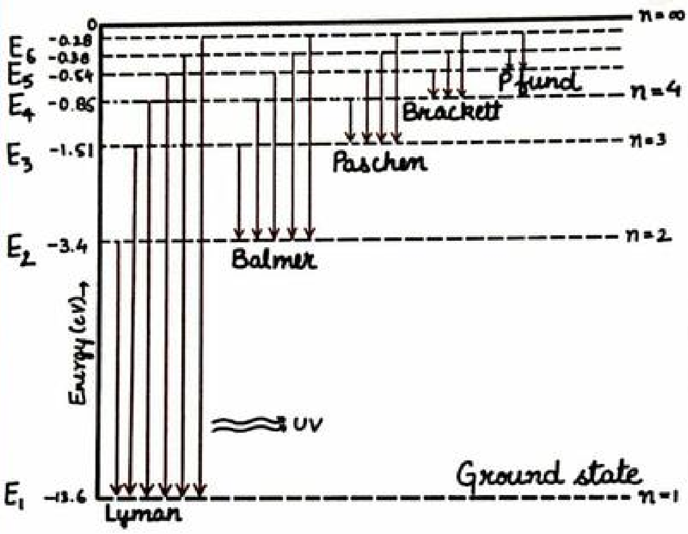
- Electron falls back from an excited state to a lower energy state by emitting a photon of energy, $E = h\nu$
- $h\nu = E_i - E_f = \Delta E = \frac{hc}{\lambda}$

$$\frac{1}{\lambda} = \frac{me^4}{8\varepsilon_0^2 h^3 c}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

(Rydberg constant, $R = \frac{mc^4}{8\varepsilon_0^2 h^3 c} = 1.03 \times 10^7 \, m^{-1}$

$Rhc = 13.6 \text{ eV}$)

$$\lambda = \frac{12400}{\Delta E(\text{eV})} \text{Å}$$



Example: Wavelength of photon emitted when H-atom transitions from $n = 3$ to $n = 2$ energy level

$$\lambda = \frac{12400}{\Delta E_{32}(\text{eV})}$$

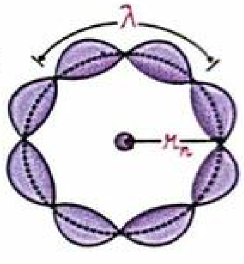
$$\Delta E_{32} = E_3 - E_2 = -1.51 + 3.4 = 1.89 \text{ eV}$$

$$\lambda = \frac{12400}{1.89} = 6561 \text{ Å}$$

de Broglie Explanation Of Bohr's 2nd Postulate

- A stationary orbit is that which contains an integral number of de Broglie wave associated with the revolving electron
- For electron revolving in n^{th} circular orbit of radius r_n,

Total distance covered is the circumference of orbit,



$$\Rightarrow 2\pi r_n = n\lambda$$

de Broglie wavelength of n^{th} orbit,

$$\lambda = \frac{h}{P_n} = \frac{h}{mv_n}$$

$$\Rightarrow 2\pi r_n = \frac{nh}{mv_n} \text{ or } mv_n r_n = n\left(\frac{h}{2\pi}\right)$$

Limitation Of Bohr's Model

- Only applicable to H-like atoms (He^+, Li^{+2} etc)
- Unable to explain the relative intensities of the frequencies in spectrum

C13

The Nucleus

Atomic Mass Unit

- One atomic mass unit is defined as $\frac{1}{12}$th of the mass of C-12 atom
- Unit : u or a.m.u ($1u = 1.6605 \times 10^{-27}$ Kg)

Composition Of Nucleus

- Nucleus is composed of protons & neutrons (protons + neutrons = nucleons)
- Neutron is the particle present in a nucleus having mass almost equal to proton
- Mass number (A) = $N_p + N_n$
  ($N_p \rightarrow$ Number of protons, $N_n \rightarrow$ Number of neutrons)
- Atomic no (Z) = N_p
- Represtation of a nucleus = ${}^{A}_{Z}X$
  ($X \rightarrow$ chemical symbol of species/element)
- Total charge of nucleus = $+Ze$

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Particle	Proton	Electron	Neutron
Charge (C) (in C)	$+1.6 \times 10^{-19}$	-1.6×10^{-19}	Neutral
Mass (M) (in kg)	1.6726×10^{-27}	9.11×10^{-31}	1.6749×10^{-27}

Isotopes	Isobar	Isotone
Atoms of an element having same atomic no. & different atomic mass	Atoms of different elements having different atomic no. & same atomic mass	Atoms of different elements having same no. of neutrons but differt atomic no.
Eg: ${}^{1}_{1}H, {}^{2}_{1}H, {}^{3}_{1}H$, ${}^{6}_{3}Li, {}^{7}_{3}Li$	Eg: ${}^{3}_{1}H, {}^{3}_{2}He$, ${}^{40}_{18}Ar, {}^{40}_{19}K, {}^{40}_{20}Ca$	Eg: ${}^{36}_{16}S, {}^{37}_{17}Cl, {}^{39}_{19}K$, ${}^{14}_{6}C, {}^{15}_{7}N, {}^{16}_{8}O$

Nuclear Size & Density

- Volume of nucleus, $V\left(\frac{4}{3}\pi R^3\right) \propto A$
  $\Rightarrow$ Radius, $R = R_0 A^{1/3}$ ($R_0 = 1.2 \times 10^{-15}$ m $= 1.2$ fm)
- Density of nucleus,
  $$\rho = \frac{\text{Mass of nucleus}}{\text{Volume of nucleus}} = \frac{A \times m}{\frac{4}{3}\pi A R_0^3} = \frac{3m}{4\pi R_0^3} = 2.3 \times 10^{17}\,\text{Kg m}^{-3}$$
  (m = average mass of 1 nucleon $= 1.66 \times 10^{-27}$ kg)
- ρ is independent of A and same for all nuclei

02

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Mass-Energy Relation

- $E = mc^2$ ($c = 3 \times 10^8\,ms^{-1}$), $E = m \times 931$ MeV (m is in u)
- According to the theory proposed by Einstien (theory of special relativity), mass is another form of energy i.e mass can be converted into energy

Nuclear Binding Energy

- $Zp + (A-Z)n \longrightarrow {}_{Z}X^{A}$ + Binding Energy

Mass Defect

- Difference between rest mass of nucleus & the total rest mass of protons & neutrons
- $\Delta m = Zm_p + (A-Z)m_n - M$
  ($m_p \rightarrow$ mass of proton, $m_n \rightarrow$ mass of neutron, $M \rightarrow$ mass of nucleus)
- Rest mass of protons + neutrons > rest mass of nucleus

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Binding Energy (E_b)

- Energy released when certain number of neutrons & protons are brought together to form a nucleus of a certain charge and mass

$$E_b = \Delta mc^2$$
$$E_b = [Z m_p + (A-Z)m_n - m]c^2$$
$$E_b \text{ for } \Delta m = 1u = 931.5 \text{ MeV}$$

Binding Energy Per Nucleon (E_{bn})

$$E_{bn} = \frac{E_b}{A}$$

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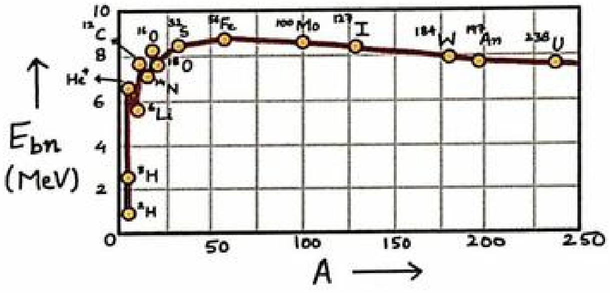
Binding Energy Curve (E_{bn} vs A)



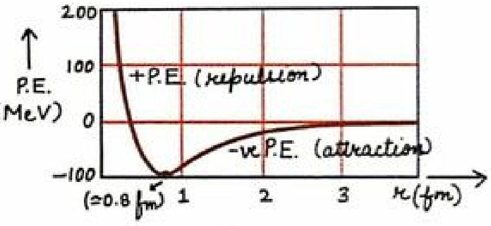
- The local maxima for ^4_2He, $^{12}_6C$ & $^{16}_8O$ indicates greater stability
- The local minima of ^6_3Li, $^{10}_5B$ & $^{14}_7N$ indicates lower stability
- ^{56}Fe has highest value of E_{bn} (8.75 MeV) & is most stable nuclei
- Nuclei with very low or very high mass numbers have lesser E_{bn} & are less stable
- Nuclei with A>170, i.e., very high mass favours nuclear fission reaction
- Nuclei with A<10, i.e., very less mass favours nuclear fusion reaction

Nuclear Force

- Strong attractive force which binds protons & neutrons together inside the nucleus

Properties Of Nuclear Force

- Strongest forces acting over short ranges (acts upto a distance of 10^{-15}m)
- At $r \approx 0.8$ fm the potential energy is minimum i.e. above 0.8 fm force is attractive & below 0.8 fm its repulsive



- The nuclear forces between proton-proton, proton-neutron & neutron-neutron is approximately same

$$F_{pp} = F_{pn} = F_{nn}$$

- Nuclear force doesn't depend on charge

Radioactivity

Radioactive Decay

- A nuclear phenomenon in which an unstable nucleus undergoes a decay

Radioactive Elements

- Elements which show radioactivity

Law of Radioactive Decay

$$\underbrace{\frac{dN}{dt}}_{\text{Rate of disintegration}} \propto N \rightarrow \text{Number of undecayed nuclei in sample}$$

$$N = N_0 e^{-\lambda t} \quad (N_0 = N_{at\ t=0})$$

($\lambda \rightarrow$ decay constant)

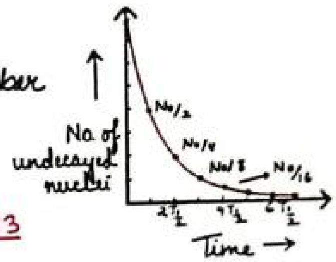
- If $t = \lambda$, N = 36.8% of N_0

Activity, $R = -\frac{dN}{dt} = \lambda N = R_0 e^{-\lambda t}$ $\left(R_0 = R_{at\ t=0} = \lambda N_0\right)$

- SI unit of R: Becquerrel (Bq), 1 Bq = 1 decay/s
- Traditional unit, 1 curie (ci) = 3.7×10^{10} Bq

Half Life ($T_{1/2}$)

- Time in which number of nuclei in a sample reduce to half



$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$

- No. of nuclei left after n half lives,

$$N = \frac{N_0}{2^n} = \frac{N}{2^{t/T_{1/2}}} \quad (t = n \times T_{\frac{1}{2}})$$

Mean Half Life (τ)

- Average time for which a radioctive nuclei exists

$$\tau = \frac{1}{\lambda} = \frac{T_{\frac{1}{2}}}{0.693} = 1.44\, T_{\frac{1}{2}}$$

- Number of nuclei decayed in $\Delta t = t_2 - t_1$ is,

$$\Delta N = N_2 - N_1 = \frac{1}{\lambda}(R_1 - R_2) \left[\begin{matrix} \text{at } t = t_1,\ R_1 \rightarrow R\ \& \\ t = t_2,\ R_2 \rightarrow R \end{matrix}\right]$$

Types Of Radioactive Decay

1. **Alpha Decay**: A process in which an unstable nucleus decays by emission of an alpha particle (^4_2He)

- $^A_ZX \rightarrow {}^{A-4}_{Z-2}Y + {}^4_2He + Q$ (energy is released)
- Eg: $^{208}_{84}Po \rightarrow {}^{204}_{82}Pb + {}^4_2He + Q$
- Q value = $(m_X - m_Y - m_{He})c^2$
  (Q value → difference between initial & total mass energy of decay products)

2. **Beta Decay**: A process in which a nucleus decays by emission of e^- or e^+ but mass number (A) remains same

- β^- Decay (neutron converts into proton)
  $n \longrightarrow p + e^- + \bar{\nu}$
  $^A_ZX \rightarrow {}^A_{Z+1}Y + e^- + \bar{\nu}$ ($\bar{\nu}$ → antineutrino)
  Eg: $^{14}_6C \longrightarrow {}^{14}_7N + e^- + \bar{\nu}$
- β^+ Decay (conversion of proton to neutron)
  $p \longrightarrow n + e^- + \bar{\nu}$
  $^A_ZX \rightarrow {}^A_{Z-1}Y + e^+ + \nu$ (ν → neutrino)
  Eg: $^{22}_{11}Na \longrightarrow {}^{22}_{10}Ne + e^- + \bar{\nu}$
- Neutrino is a neutral particle with very small mass ($m_\nu \approx 0$) as compared to e^-

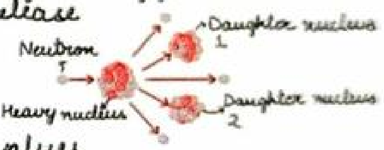
3. **Gamma Decay**: A process in which a nucleus decays from its excited state to its ground state by emitting a photon

- Energy of photon is equal to the difference in the two energy levels
- Penetrating power & velocity of particles
  $\gamma > \beta > \alpha$

Nuclear Energy

- Whenever a lighter nuclei (A<30) or a heavy nuclei (A>170) with binding energy less than 8 MeV transforms into a nuclei with greater binding energy, there will be a net energy release

Nuclear Fission



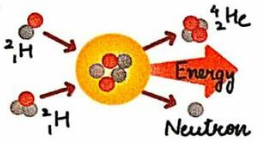
- Heavy nuclei having low E_{bn} values splits into lighter nuclei by releasing energy
- The disintegration energy appears as kinetic energy of fragments & neutrons & is then transfered to surrounding matter appearing as heat
- On average 2 or 3 extra neutrons are released per fission which can initiate fission

- Used in nuclear reactors for controlled supply of energy & in atom bombs for sudden supply of energy
- **Example**: When $^{235}_{92}U$ is bombarded with a neutron
- $^1_0n + {}^{235}_{92}U \rightarrow {}^{236}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + {}^1_0n$

Nuclear Fusion

- Lighter nuclei having less value of E_{bn} combines to form heavy stable nuclei by releasing energy
- For fusion to occur, nuclei must come close enough so that nuclear force can act & have enough energy to overcome coulomb barrier

Thermonuclear Fusion



- Fusion achieved by raising the temperature of system in order to provide sufficient K.E. to overcome coulomb repulsive forces
- **Example**: Two protons combine to form a deutron
- $^1_1H + {}^1_1H \rightarrow {}^2_1H + e^+ + \nu + 0.42$ MeV

C14

Classification Of Solids

On The Basis Of Conductivity

- Metals: High conductivity ($\sigma \sim 10^2 - 10^8\ Sm^{-1}$) & low resistivity ($\rho \sim 10^{-2} - 10^{-8}\ \Omega m$)
- Semiconductors: Moderate conductivity & resistivity ($\sigma \sim 10^5 - 10^{-6}\ Sm^{-1}$ & $\rho \sim 10^{-5} - 10^6\ \Omega m$)
- Some examples of semiconductors
  - Elemental semiconductors: Silicon & Germanium
  - Compound semiconductors,
    - (a) Inorganic: CdS, GaAs, CdSe etc
    - (b) Organic Polymers: Polypyrrole & Polyaniline
- Insulators: High resistivity ($\sigma \sim 10^{11} - 10^{19}\ \Omega m$) & low conductivity ($\sigma \sim 10^{-11} - 10^{-19}\ Sm^{-1}$)

01

C14

On The Basis Of Energy Bands

- Energy Bands: Different energy levels with continuous energy variation form

Valence Band (VB)	Conduction Band (CB)
Contains valence e^-	Usually empty
Lower energy level of e^-	Higher energy level of e^-
Partially or completely filled	Empty or partially filled
e^-s of this band do not contribute in electric current	Free e^-s in this band contribute in electric current

- Forbidden Energy Gap: Energy gap between VB & CB

$$E_g = E_{CB} - E_{VB}$$

- No e^- can exist in this gap

02

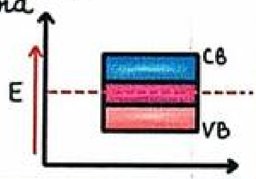
C14

Metals

Conduction band is partially filled or overlapping the valence band

Energy gap (E_g) ≈ 0

Eg: Fe, Cu, Al etc.

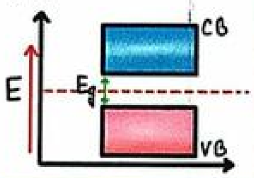


Insulator

Valence band is completely filled & conduction band is completely empty

E_g is large > 3eV

Eg: Rubber, glass

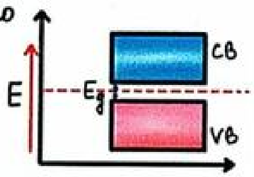


Semiconductor

Valence band is filled & conduction band is empty at absolute zero

E_g is small < 3eV

Eg: Si, Ge etc.



03

C14

Fermi Energy: The maximum possible energy possessed by free e^- at T = 0K (absolute zero)

- At T = 0K, semiconductors behave as perfect insulators

Charge Carriers

- Electrons (e^-) → –ve charge carriers
- Holes (Vacancy of e^-) → +ve charge carrier

Intrinsic Semiconductor

- Pure semiconductors having no external impurities
- $n_e = n_h = n_i$ & $n_i^2 = n_e n_h$

  (n_e & n_h → number of free e^- & holes per unit volume; n_i → intrinsic carrier concentration)

- At T > 0K, some e^-s gain sufficient thermal energy & jump from VB to CB
- Electrical conductivity depends on temperature as T↑, n_e & n_h↑
- In presence of external electric field, e^- & holes move in opposite direction

  ⇒ Total current, $I = I_e + I_h$

04

Extrinsic Semiconductor

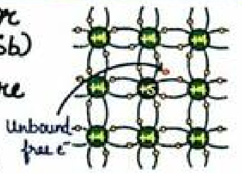
A semiconductor mixed with a suitable impurity of different valency

Doping: Deliberate addition of a desirable impurity to intrinsic semiconductor

Dopant: Impurity atoms used for doping

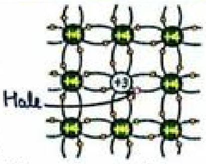
n-Type Semiconductor

- Doping → Pentavalent donor impurities (As, P, Sb)
- Majority charge carriers are e^- ($n_e >> n_h$) ⇒ $I_{total} \cong I_e$
- Conductivity is due to e^-s
- Each pentavalent impurity (donor) donates one extra e^-



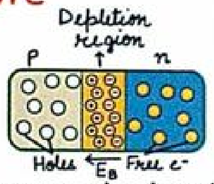
p-Type Semiconductor

- Doping → Trivalent (Al, B)
- Majority charge carriers are holes ($n_h >> n_e$) ⇒ $I_{total} \cong I_{holes}$
- Conductivity is due to holes
- Each trivalent impurity acceptor creates a hole



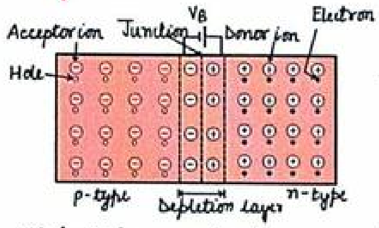
p-n Junction

- During formation of p-n junction holes diffuse from p → n & e⁻ from n → p



- Near the junction -ve charges are developed on p-side and +ve charges on n-side
- Electric field is set up from n → p side

p-n Junction Diode



- Metallic contacts are provided at the ends of p-n junction for application of external voltage

Depletion Region

- The region on either side of a pn junction
- It is free from charge carriers

Barrier Potential (V_B)

- A potential opposing further diffusion of electrons & holes develops near junction
- V_B depends on the type of semiconductor & on the amount of doping and temperature
- To cross barrier, energy of $e^- = eV_B$

Diffusion Current

- Current due to flow of majority charge carriers
- Direction of current is from p → n

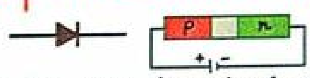
Drift Current

- Current due to barrier field i.e. due to flow of minority charge carriers
- Direction of current is from n → p
- In steady state, $I_{diff} = I_{drift}$

  or $I_{net} = 0$

Biasing Of p-n Junction

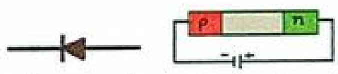
Forward Biasing



- p-side is connected to +ve terminal of battery & n-side to -ve terminal
- Potential barrier decreases

- Width of depletion layer decreases
- Effective resistance across junction decreases
- At, $V > V_B$ majority charge carriers flow easily

Reverse Biasing



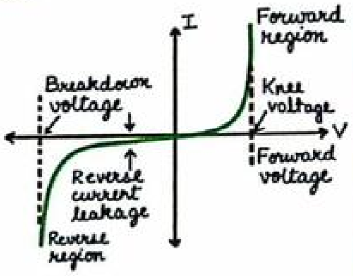
- p-side is connected to -ve terminal of battery & n-side to +ve terminal
- Potential barrier increases

- Width of depletion layer increases
- Effective resistance across junction becomes very large
- Current due to majority charge carriers is zero, small current flows due to minority charge carriers

V-I Characteristics

- $V_{out} = V_{in} - V_B$
- Dynamic resistance,

  $r_d = \frac{\Delta V}{\Delta I}$



- As Temperature increases, number of e⁻-hole pairs increases, hence, overall resistance decreases

Threshold / Knee / Cut Off Voltage

- Forward voltage above which the current flow increases exponentially

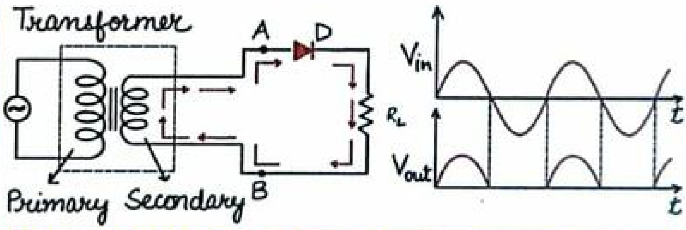
Breakdown Voltage

- Value of voltage in reverse condition above which the value of reverse current suddenly increases

Junction Diode As Rectifier

- Rectifier is a device which converts AC voltage to DC voltage
- When an alternating voltage is passed through diode, current in cycle only passes when diode is forward biased
- To protect diode from reverse breakdown, Reverse breakdown voltage of diode > peak A.C. voltage at the secondary coil of the transformer

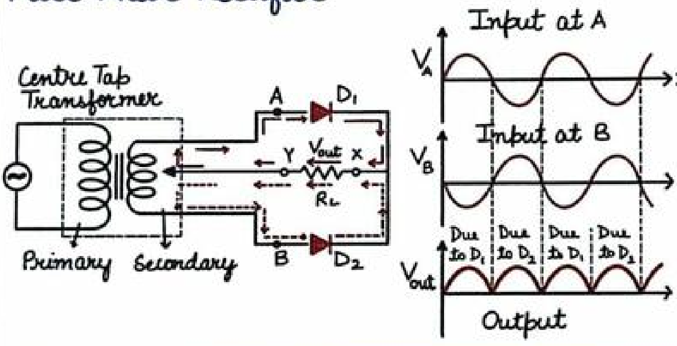
Half-wave Rectifier



Half Cycle (A.C.)	A	B	Diode
+ve	+	−	Forward biased
−ve	−	+	Reverse biased

- In +ve half cycle, input resistance at the junction is low & current flows through R_L (+ve output)
- In −ve half cycle, input resistance at junction is high & no current flows through R_L (no output)

Full Wave Rectifier



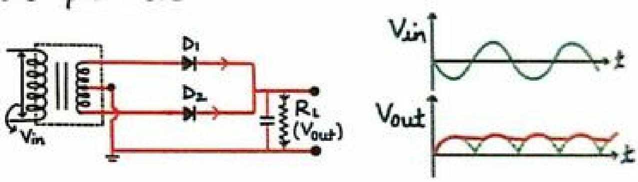
Half Cycle	A	B	D_1	D_2
+ve	+	−	Forward biased	Reverse biased
−ve	−	+	Reverse biased	Forward biased

- Rectifies both halves of the input A.C. signal

- In +ve half cycle, resistance at junction of D_1 is low & current flows through R_L (+ve output)
- In −ve half cycle, resistance at junction of D_2 is low & D_1 is high and current flows through R_L (+ve output)
- Output frequency (ν_o) = 2 × input frequency (ν_i)

Filters

- Additional circuit which filter out the A.C ripple to give a steady value of dc i.e. pure dc



- Capacitor is connected across the terminals in full wave rectifier parallel to the load (R_L)
- The output thus obtained by using capacitor input filter is nearer to the peak voltage of rectified voltage

Special Purpose Diodes

Light Emitting Diode

- LED is a heavily doped p-n junction diode in forward biased condition

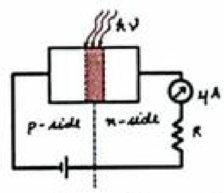
Working

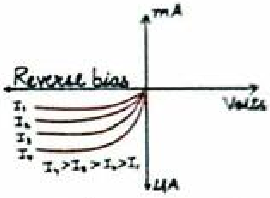
- Electron move from N→P where they recombine with holes & release energy in form of photons
- Energy of photons ≤ band gap (E_g)
- $\lambda_{emitted} = \frac{12400 Å}{E_g}$ (colour of light depends on band gap)
- Reverse breakdown voltage is very low (~5 V)
- Intensity of light is determined by the forward current conducted by junction
- GaAsP is used to make LED's of different colours & GaAs is used to make IR LEDs

Advantages Over Conventional Incandescent Low Power Lamps

- Low operational voltage & less power
- No warm up time required
- Light emitted is nearly monochromatic
- Long life & ruggedness

Photodiode



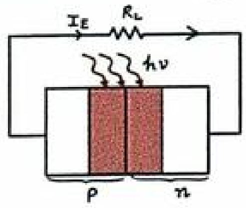


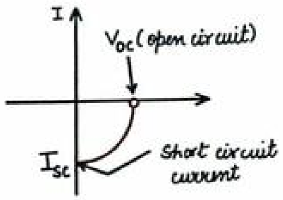
- p-n junction diode under reverse biasing fabricated by a photosensitive material
- Light energy is converted into electrical energy
- Electron hole pairs are generated when light ($h\nu > E_g$) falls on a depletion layer
- A reverse current is produced & conductivity of semiconductor increases
- The magnitude of photocurrent depends on intensity of incident light (i), $I \propto i$

Uses

- Detection of optical signals
- In light operating switches

Solar Cell





- Unbiased p-n junction diode used to convert solar energy into electrical energy
- Junction area is kept large to generate more power
- When light falls on it emf is generated
  - Generation of e-hole pair occurs
  - e's are swept to n-side & holes to p-side
  - p-side becomes +ve & n-side negative which develops photovoltage

Selection Criteria Of Material

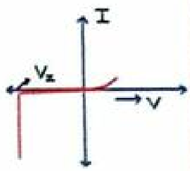
- Band gap → 1.0 eV → 8.0 eV
- High optical absorption → ~10^4 cm^{-1}
- Electrical conductivity

Zener Diode

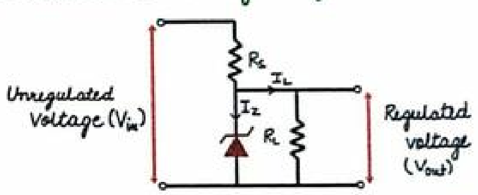
- A heavily doped p-n junction diode operating in reverse breakdown region
- Depletion region formed is very thin

I-V Characteristics

- When reverse bias voltage (V) equals zener breakdown voltage (V_z), large current can be produced by very small change in V



Zener Diode As Voltage Regulator



- In reverse breakdown region, voltage across the diode remains almost the same even for a large change in the reverse current
- As V_{input} ↑, current through R_s & Zener diode increases but V_z & V_{out} remains constant in the breakdown region

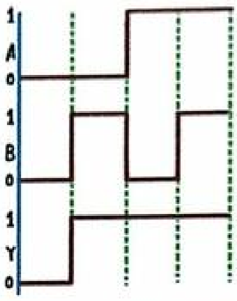
C14

Logic Gates

OR Gate

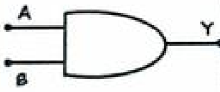
$Y = A + B$

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

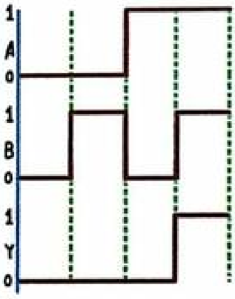


AND Gate

$Y = A.B$

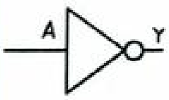


A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

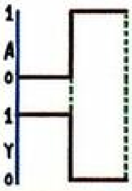


NOT Gate (invertor)

$Y = \bar{A}$



A	X
0	1
1	0



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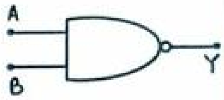
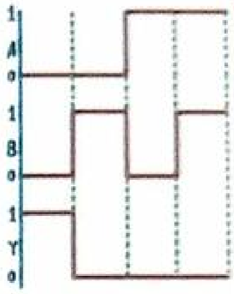
NAND Gate (AND + NOT)

$Y = \overline{A.B}$

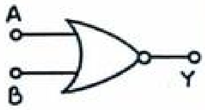


A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

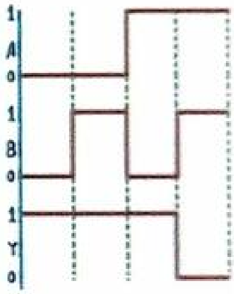


NOR Gate (AND + NOT)

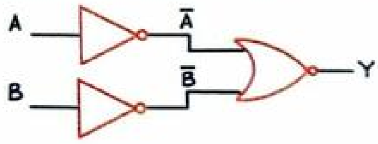
$Y = \overline{A+B}$



A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0



Example For Combination Of Gates



A	B	X
0	0	0
0	1	0
1	0	0
1	1	1

$Y = \overline{\bar{A} + \bar{B}} = \bar{\bar{A}}.\bar{\bar{B}} = A.B$ (AND Gate)

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Some Useful Results

- $A + A.B = A$
- $A.(A+B) = A$
- $\overline{A+B} = \bar{A}.\bar{B}$
- $\overline{A.B} = \bar{A} + \bar{B}$

[De Morgan's theorem]

- $A.0 = 0$
- $A.1 = A$
- $A.A = A$
- $A.\bar{A} = 0$

[AND Laws]

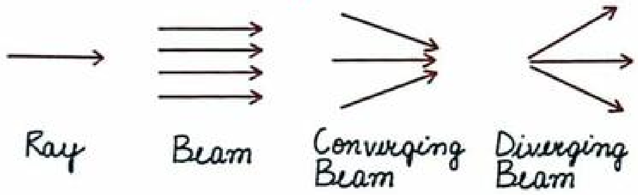
- $A + 0 = A$
- $A + 1 = 1$
- $A + A = A$
- $A + \bar{A} = 1$

[OR Laws]

- $C + AD = (C + A).(C + D)$

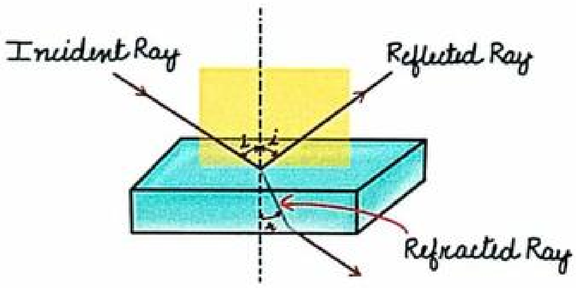
RAY OPTICS

Light



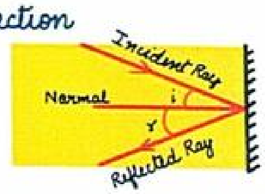
- Light is an electromagnetic wave & travels with a speed of $3 \times 10^8\ ms^{-1}$
- Light travels in straight line
- Light can undergo these three effects,

1. Reflection 2. Refraction 3. Absorption



Reflection

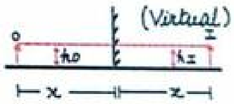
Laws Of Reflection



- Angle of incidence = Angle of reflection
- Incident ray, reflected ray & normal to the reflecting surface at the point of incidence all lie in same plane

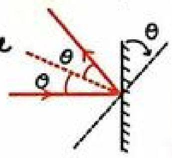
Plane Mirror

- Image is formed behind the mirror & $h_I = h_o$
- Image is always virtual



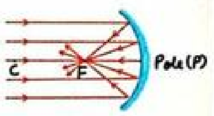
Special Cases

- If mirror is rotated by angle θ, ray is rotated by angle 2θ
- If light falls normally on the surface the reflected light traces the same path

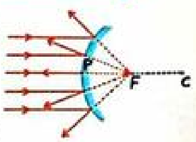


Spherical Mirrors

Concave Mirror : Mirrors having reflecting surface towards the centre of sphere

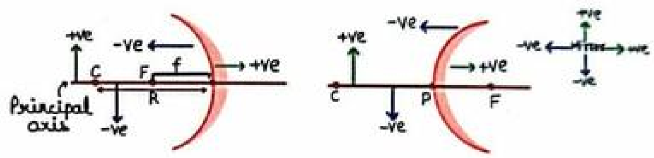


Convex Mirror : Mirrors having reflecting surface away from the centre of sphere



- Pole (P): Mid point of the mirror
- Centre of curvature (C): Centre of the sphere of which the mirror is a part
- Principal axis: Line joining P & C
- Principal focus (F): Point on the principal axis at which the rays coming parallel to principal axis meet or appear to meet after reflection
- Focal length (f): Distance between P & F

Sign Convention



- $f_{concave} \rightarrow -ve$, $f_{convex} \rightarrow +ve$ (f = focal length)
- Radius of Curvature, R = 2f

Mirror Formula

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

(v → distance of image from pole
u → distance of object from pole)

Linear Magnification

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

(h_I → height of image
h_o → height of object)

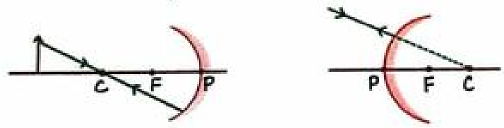
m	Image
+ve	virtual & erect
-ve	real & inverted
>1	magnified
<1	diminished
=1	same size as of object

Conditions Of Reflection By Mirror

Incident Ray: Parallel to the principal axis
Reflected Ray: Through the focus

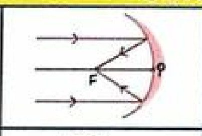
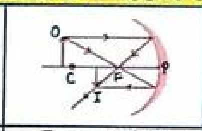
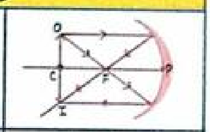
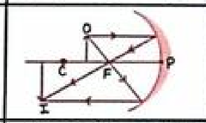
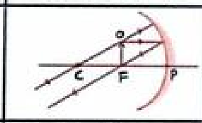
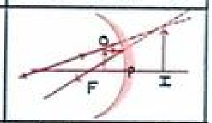
Incident Ray: Through the focus
Reflected Ray: Parallel to the principal axis

Incident Ray: Incident at P at an angle
Reflected Ray: Reflected by the same angle

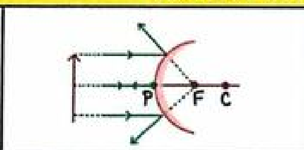
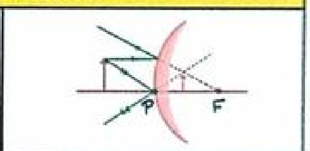


Incident Ray: Passing through C
Reflected Ray: Retraces the same path

Concave Mirror

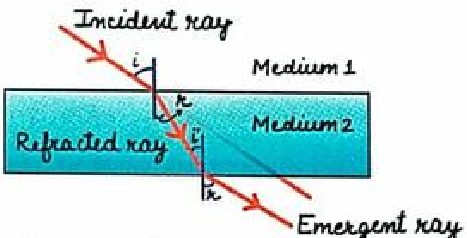
			
u	∞	Beyond C	At C
v	F	Between F & C	At C
I	Real & Inverted	Real & Inverted	Real & Inverted
m	$\lvert m \rvert < 1$ & $-ve$	$\lvert m \rvert < 1$ & $-ve$	$\lvert m \rvert = 1$ & $-ve$
			
u	Between C & F	At F	Between F & P
v	Beyond C	At ∞	Behind Mirror
I	Real & Inverted	Real & Inverted	Virtual & Erect
m	$\lvert m \rvert > 1$ & $-ve$	$\lvert m \rvert > 1$ & $-ve$	$\lvert m \rvert > 1$ & $+ve$

Convex Mirror

		
u	At ∞	Between ∞ & P
v	At F	Behind Mirror b/w P & F
I	Virtual & Erect	Virtual & Erect
m	$\lvert m \rvert < 1$ & $+ve$	$\lvert m \rvert < 1$ & $+ve$

Refraction

Bending of light when it passes obliquely from one medium to another



- If ray travels from rarer to denser medium, velocity↓, & it bends towards the normal
- If ray travels from denser to rarer medium, velocity↑, & it bends away from the normal

Laws Of Refraction

- Snell's Law: $\frac{\sin i}{\sin r} = \text{constant} = n_{21}$

(n_{21} → Refractive index of medium 2 w.r.t 1)

$$n_1 \sin i = n_2 \sin r$$

- Incident ray, refracted ray & normal to the interface at the point of incidence, all three lie in same plane

Refractive Index

- Ratio of speed of light in vacuum to speed of light in a medium

$$n = \frac{c}{v} = \frac{\lambda_{vacuum}}{\lambda_{medium}}$$

- n depends on nature of medium, wavelength of light & temperature of medium
- n is independent of angle of incidence

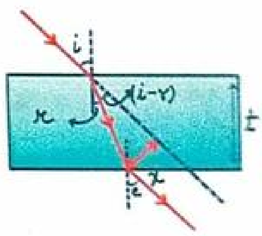
Medium	Vacuum	Air	Water	Glass	Diamond
n	1	1.0003	1.33	1.5	2.42

Refraction Through A Glass Slab

Lateral Shift

- Perpendicular distance between the incident & emergent ray

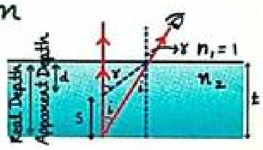
$$x = \frac{t \sin(i-r)}{\cos r}$$



Real Depth & Apparent Depth

Object In Denser Medium

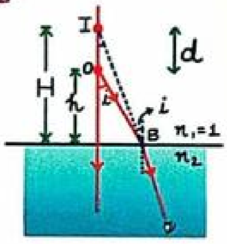
- $n_2 = \frac{\text{Real Depth}}{\text{Apparent Depth}} = \frac{t}{d}$



- Normal Shift, $s = t\left(1 - \frac{1}{n_2}\right)$

Object In Rarer Medium

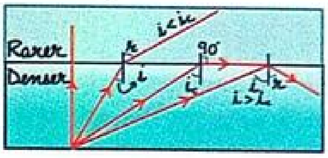
- $n_2 = \frac{\text{Apparent hieght}}{\text{Real height}} = \frac{H}{h}$
- Normal Shift, $d = (n_2 - 1)h$



Advanced Sunrise And Delayed Sunset

- It is due to atmospheric refraction
- $n = 1.00029$ for air w.r.t vacuum
- Sun appears to rise early & set late by 2 minutes
- Due to refraction sun appears flattened during sunset & sunrise

Total Internal Reflection (TIR)



Critical Angle (i_c)

Angle of incidence in denser medium for which the angle of refraction is 90° in rarer medium

TIR

Light travelling through denser medium gets completelely reflected back when angle of incidence $i > i_c$

If rarer medium is air, $n_2 = 1$ then, $i_c = \sin^{-1}\left(\frac{1}{n_1}\right)$

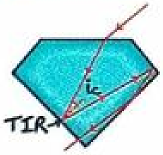
and for TIR, $n_1 \geqslant \frac{1}{\sin i_c}$

Applications Of TIR

1. Mirage

An optical illusion seen in desert or over hot surfaces due to which observer sees a pool of water

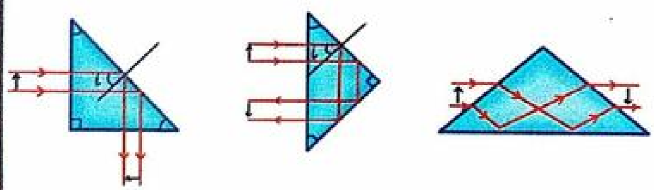
2. Brilliance Of Diamond



- Beam of light enters a diamond, undergoes TIR inside repeatedly & emerges only from few of its faces
- Intensity of emergent ray > intensity of incident ray
- For diamond, $n = 2.47$ & $i_c = 24.4°$

3. Total Reflecting Prisms

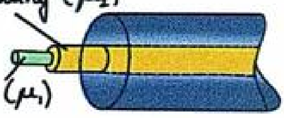
- Right angle isosceles prisms (45°-90°-45°) are used to turn rays or images by 90° or 180°



4. Optical Fibres

- Used for transmitting audio & video signals through long distances
- Used for transmitting & receiving electrical signals & transmission of optical signals
- Minimal loss in the intensity of light or signals due to TIR

Cladding (μ_2)



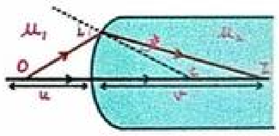
Core (μ_1)

$\mu_2 < \mu_1$

Refraction At Spherical Surface

- $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$
- For a plane surface, $R = \infty$

$\Rightarrow \frac{\mu_2}{v} - \frac{\mu_1}{u} = 0$



Refraction By A Lens

Lens Makers Formula

- $\frac{1}{f} = \left[\frac{\mu_2 - \mu_1}{\mu_1}\right]\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$

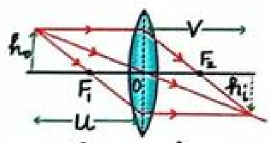
  ($\mu_2 \rightarrow \mu$ of material of lens; $\mu_1 \rightarrow \mu$ of the medium) $\mu_1 = 1$ (air)

Thin Lens Formula

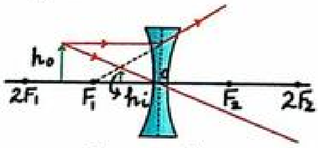
- $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ ($v \rightarrow$ distance of image from O; $u \rightarrow$ distance of object from O)

Conditions Of Refraction By A Lens

- A ray parallel to principal axis of the lens after refraction passes through F_2 or appears to pass through F_1 (for convex lens)
- A ray passing through O emerges without deviation after refraction
- A ray passing through F_1 emerges parallel to principal axis after refraction



Convex lens



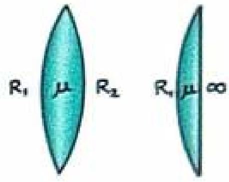
Concave lens

Magnification Of A Lens

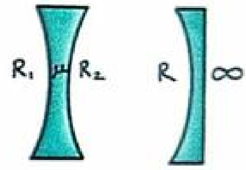
$$m = \frac{v}{u} = \frac{f}{f+u} = \frac{f-v}{f}$$

Focal Length Of Different Lenses

- Equi-biconvex lens, $R_1 = +R$, $R_2 = -R \Rightarrow \frac{1}{f} = \frac{R}{2(\mu-1)}$
- Equi-biconcave lens, $R_1 = -R$, $R_2 = +R \Rightarrow \frac{1}{f} = \frac{-R}{2(\mu-1)}$

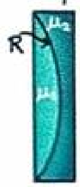


- Plano-convex lens $R_1 = R$, $R_2 = \infty \Rightarrow \frac{1}{f} = \frac{R}{(\mu-1)}$
- Plano-concave lens $R_1 = -R$, $R_2 = \infty \Rightarrow \frac{1}{f} = \frac{-R}{(\mu-1)}$



- For combination of plano-convex & plano-concave lens

  $f = \frac{R}{\mu_1 - \mu_2}$



Power Of A Lens

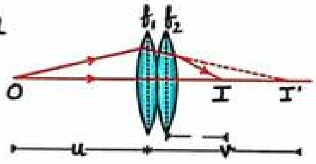
- Measure of the convergence or divergence which a lens introduces in the light falling on it

  $P = \frac{1}{f} = (\mu-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ SI unit : Dioptre (D) $1D = 1m^{-1}$

- Intensity of image $\propto$ area of lens exposed by the incident ray

Combination Of Lenses In Contact

- For combination of n lenses,

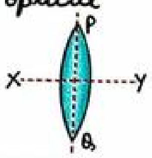


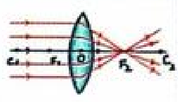
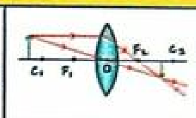
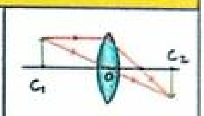
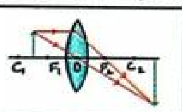
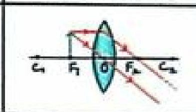
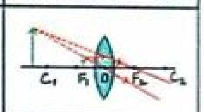
$$\frac{1}{f_{eff}} = \frac{1}{f_1} + \frac{1}{f_2} + \ldots\ldots + \frac{1}{f_n}$$

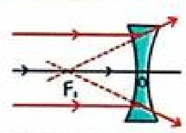
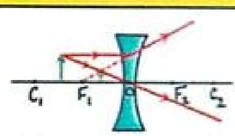
$$P_{total} = P_1 + P_2 + \ldots\ldots + P_n$$

$$m_{total} = m_1 \times m_2 \times \ldots + m_n$$

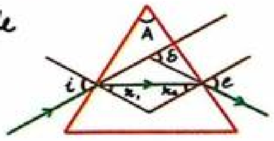
- System of combination of lenses is used in designing lens for cameras, microscopes, telescopes & other optical instruments
- By cutting lens, 'f' of each half, in XY axis $\rightarrow$ remains same in PQ axis $\rightarrow$ 2f



Convex Lens			
			
u	At ∞	Beyond C_1	At C_1
v	At F_2	Between C_2 & F_2	At C_2
I	Real & Inverted	Real & Inverted	Real & Inverted
m	$\lvert m \rvert < 1$ & -ve	$\lvert m \rvert < 1$ & -ve	$\lvert m \rvert = 1$ & -ve
			
u	Between C_1 & F_1	At F_1	Between F_1 & O
v	Beyond C_2	At ∞	Behind the object
I	Real & Inverted	Real & Inverted	Virtual & erect
m	$\lvert m \rvert > 1$ & -ve	$\lvert m \rvert > 1$ & -ve	$\lvert m \rvert > 1$ & +ve

Concave Lens		
		
u	At ∞	Between ∞ & O
v	At f	Between O & F_1
I	Virtual & Erect	Virtual & Erect
m	$\lvert m \rvert < 1$ & +ve	$\lvert m \rvert < 1$ & +ve

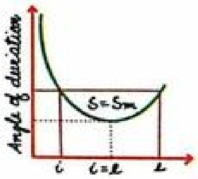
Refraction Through A Prism



- Angle of Prism (A): Angle between two plane surfaces of prism
- For equiangular prism $A = 60^\circ$
- Angle of deviation (δ): Angle between the emergent ray & the incident ray

$\delta = i + e - A$ & $A = r_1 + r_2$
(e → angle of emergence)

- Angle Of Minimum Deviation (δ_m): Smallest angle at which light is bent by the prism
- At $i = e$, $r_1 = r_2 = r$ $(A = 2r)$



$\delta = \delta_m = 2i - A = 2i - 2r$

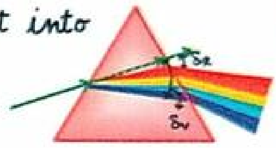
$i = \dfrac{A + \delta_m}{2}$ & $r = \dfrac{A}{2}$

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

- For a small angle prism, $\mu = \dfrac{A + \delta_m}{A}$
$\Rightarrow \delta_m = (\mu - 1)A$

Dispersion Of White Light

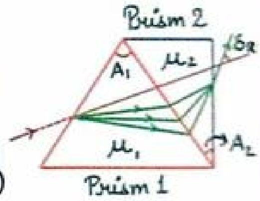
- Splitting of white light into its constituent colours



n & $\delta \propto \dfrac{1}{\lambda}$

- $\lambda_{red} \rightarrow$ max $\Rightarrow \delta_{red} \rightarrow$ min
- $\lambda_{red} \rightarrow$ min $\Rightarrow \delta_{violet} \rightarrow$ max

Combination Of Prism



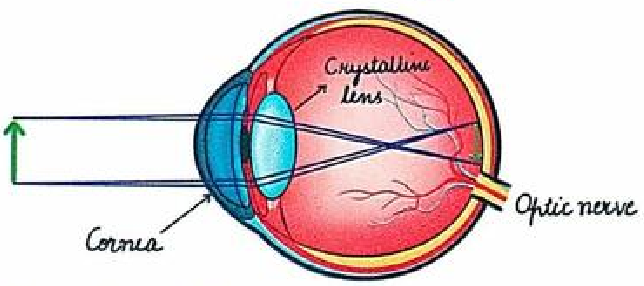
- Deviation produced by two prisms,

$\delta_1 = (\mu_1 - 1)A$ (For Prism 1)
$\delta_2 = (\mu_2 - 1)A$ (For Prism 2)

- Resultant deviation, $\delta_R = \delta_1 - \delta_2$
- For dispersion without deviation, $\delta_R = 0$

$$\frac{A_1}{A_2} = \frac{\mu_2 - 1}{\mu_1 - 1}$$

Human Eye



Near Point (D): Nearest point from an eye at which any object can be seen clearly & distinctly. D = 25cm
- Image formed is real & inverted

Defects In Human Eye

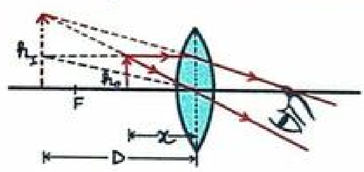
Myopia – Near Sightedness
- Image of farther object is formed in front of the retina
- Correction : Concave Lens

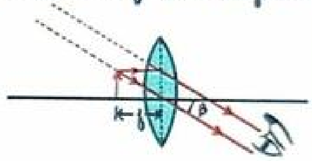
Hypermetropia – Farsightedness
- Image of nearby object is formed behind the retina
- Correction : Convex Lens

Optical Instruments

Simple Microscope

- A convex lens of small focal length
- Used to see very small objects
- Nature of image : Erect, virtual, enlarged & at same side of the object





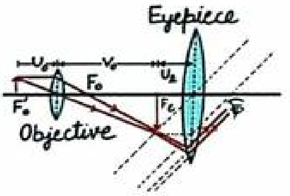
- Used to see very small objects

Object	b/w O & F	At F
Image	At D	At ∞
m	$1 + \dfrac{D}{f}$	$\dfrac{D}{f}$

- Limited maximum magnification (≤ 9) for realistic focal length

Compound Microscope

- Consists of 2 convex lenses,
  1. Eyepiece → larger aperture & focal length
  2. Objective → smaller aperture & focal length
- Used for large magnification
- Nature of image: virtual, enlarged, inverted
- Tube length: Distance b/w two lenses



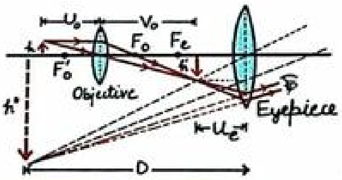
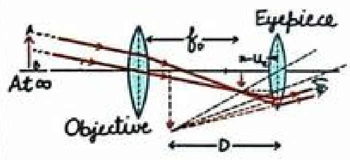


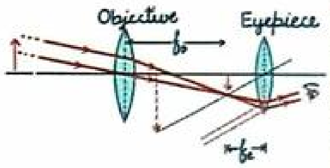
Image	$\lvert m\rvert = m_o m_e$	Length
D	$\frac{v_o}{u_o}\left(1+\frac{D}{f_e}\right)$	$v_o + u_e$
∞	$\frac{L}{f_o}\left(\frac{D}{f_e}\right)$	$v_o + f_e$

Astronomical Telescope

(a) Refracting Type Telescope

- Consists of two convex lenses
  1. Eyepiece → smaller aperture & focal length
  2. Objective → larger aperture & focal length
- Used to provide angular magnification of distant object

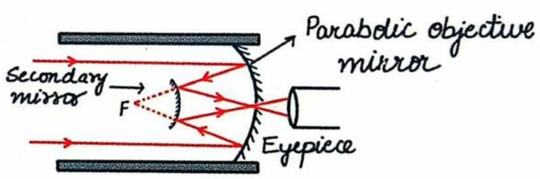




Object	Image	$\lvert m\rvert$	Length
At ∞	D	$\frac{f_o}{f_e}\left(1+\frac{f_e}{D}\right)$	$f_o + u_e$
At ∞	∞	$\frac{f_o}{f_e}$	$f_o + f_e$

(b) Reflecting Type Telescope

- Objective is replaced by a concave mirror of large aperture & large focal length
- It has large resolving & light gathering power
- Small convex lens is used as eyepiece
- Also called Cassegrain Telescope



Object	Image	m
At ∞	D	$\frac{f_o}{f_e}\left(1+f_e/D\right)$
At ∞	∞	$\frac{f_o}{f_e} = \frac{R/2}{f_e}$

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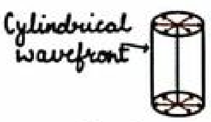
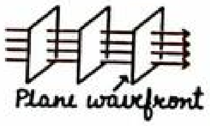
Wavefront

- Locus of points oscillating in phase (a surface of constant phase)
- Speed of Wave: The speed with which the wavefront moves outwards from the source
- Energy of the wave travels in a direction perpendicular to the wavefront
- A point source produces spherical wavefronts (SF)

- A line source produces cylindrical wavefronts



- A parallel beam produces plane wavefronts



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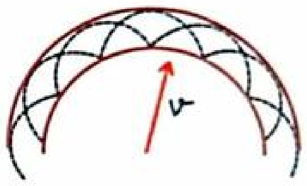
Huygen's Principle

- It is essentially a geometrical construction, which given the shape of the wavefront at any time allows to determine the shape of the wavefront at a later time

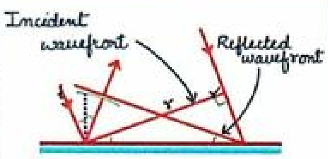


- Each point on wavefront acts as a fresh source of secondary disturbances called secondary wavelets
- A common tangent to all the wavelets emanating from the same wavefront gives the new position and shape of wavefront at that time
- λ & v of the secondary wave is same as the original wave but has reduced intensity

C10

Reflection & Refraction Of Plane Wave

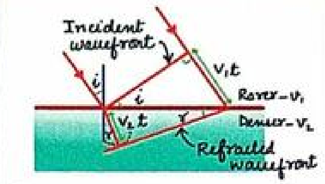
Reflection



Obeys law of reflection

$\angle i = \angle r$

Refraction

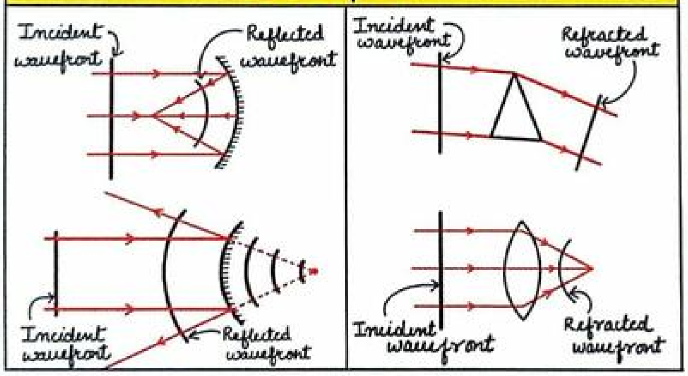


Obeys Snell's law

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}^1\mu_2 = \frac{\lambda_1}{\lambda_2}$$

- λ & v decrease
- ν remains same

Examples



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Coherent And Incoherent Addition Of Waves

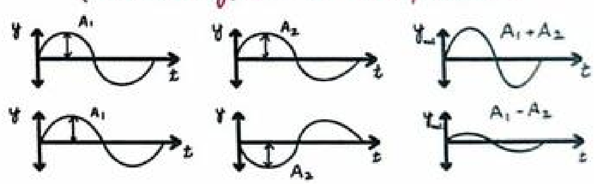
Coherent Sources: Two sources which emit waves of same ν with a zero or constant phase difference

Incoherent Sources: Two sources which do not emit waves with constant phase difference

Superposition Principle: Resultant displacement, $\vec{y}_{net} = \vec{y}_1 + \vec{y}_2 + \vec{y}_3 + \dots\dots + y_n$

Interference Of Light: When two waves having constant or zero phase difference & same frequency travelling in same direction superpose, the intensity gets redistributed becoming maximum at some points & minimum at other.

(Intensity) $I \propto A^2$ (Amplitude)



On superposition of two coherent waves

- $y = y_1 + y_2 = a_1 \cos \omega t + a_2 \cos(\omega t + \phi)$
$$= A \cos(\omega t + \theta)$$
- $A^2 = a_1^2 + a_2^2 + 2 a_1 a_2 \cos\phi$
- $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos\phi$
- If $I_1 = I_2 = I_0$, $I = 4 I_0 \cos^2 \frac{\phi}{2}$

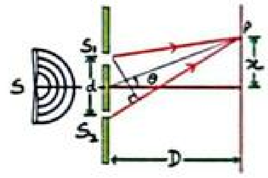
Constructive Interference	Destructive Interference
$\cos\phi = 1$ ($\phi = 0, \pm 2\pi \ldots$) path difference, $\Delta x = n\lambda$ $I = (\sqrt{I_1} + \sqrt{I_2})^2$ $I_{max} = 4 I_0$	$\cos\phi = -1$ ($\phi = \pm\pi, \pm 3\pi, \pm 5\pi$) $\Delta x = (2n+1)\frac{\lambda}{2}$ $I = (\sqrt{I_1} - \sqrt{I_2})^2$ $I_{min} = 0$

- $\frac{I_{max}}{I_{min}} = \left(\frac{a_1 + a_2}{a_1 - a_2}\right)^2 = \left(\frac{\sqrt{I_1} + \sqrt{I_2}}{\sqrt{I_1} - \sqrt{I_2}}\right)^2$
- $I \propto$ width of the slit (w)
- $\frac{I_1}{I_2} = \frac{W_1}{W_2} = \frac{a_1^2}{a_2^2}$

YDSE

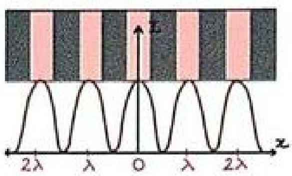
- Monochromatic light from a narrow slit S falls on slits S_1 & S_2
- S_1 & S_2 are very close to each other & at equal distance from S and behave like two coherent sources
- Waves emanating from S_1 & S_2 spread into region beyond S_1 & S_2
- Waves interfere in a region where they overlap and form alternate bright & dark fringes on screen with equal spacing in between

Path Difference



- $\Delta x = S_2P - S_1P = \frac{xd}{D}$
- In terms of phase difference $\Delta\phi$,
$$\Delta x = \frac{\lambda}{2\pi} \Delta\phi$$
- Infront of one of the slits,
$$\Delta x = \frac{d^2}{2D} \quad \left(x = \frac{d}{2}\right)$$

- For bright fringe,
$$\Delta x = d \sin\theta = n\lambda$$
$\Rightarrow$ Position, $x_b = n \frac{D\lambda}{d}$



- For dark fringe,
$$\Delta x = (2n+1)\frac{\lambda}{2}$$
$\Rightarrow$ Position, $x_d = (2n+1) \frac{D\lambda}{d}$

($n = 0, \pm 1, \pm 2, \ldots$ for both x_b and x_d)

- Intensity of all bright fringes are equal

Fringe Width

- Distance between two consecutive bright & dark fringes
$$\beta = x_{n+1} - x_n = \frac{\lambda D}{d}$$
- Angular width, $\theta = \frac{\beta}{D} = \frac{\lambda}{d}$
- If apparatus is completely immersed in a liquid of refractive index n,
$$\beta' = \frac{\beta}{n} = \frac{D\lambda}{nd} \qquad \lambda' = \frac{\lambda}{n}$$

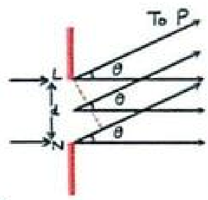
Diffraction

- Bending of light around the corners of an obstacle of the size of wavelength

- Amount of bending depends on the size of aperture of the obstacle & λ of the wave

Diffraction By Single Slit

- Path Difference
$$\Delta x = NP - LP = d \sin\theta \simeq d\theta$$
(for smaller angles)



- Δx b/w mid point & edge of slit, $\Delta x = \lambda/2$

Dark Fringe (Secondary minima)

- $d \sin\theta = n\lambda$
$\Rightarrow$ Angular position, $\theta = \frac{n\lambda}{d}$ ($\sin\theta = \theta$)
- Position of n^{th} minima, $x = n \frac{\lambda D}{d}$

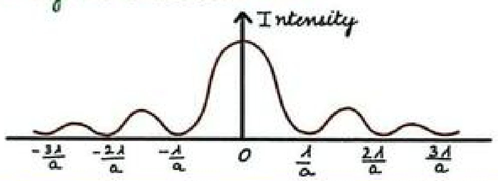
Bright Fringe (Secondary maxima)

- $d \sin\theta = (2n+1)\frac{\lambda}{2}$
$\Rightarrow$ Angular position, $\theta = (2n+1)\frac{\lambda}{2}$ ($\sin\theta \simeq \theta$)
- Position of n^{th} maxima, $x = (2n+1)\frac{\lambda D}{2d}$

Width Of Central Maxima

- Linear width, $\beta = \frac{2D\lambda}{d}$; Angular width, $\theta = \frac{2\lambda}{d}$

Intensity Distribution Curve



Interference	Diffraction
Result of superposition of secondary waves from two different wavefronts from two coherent sources	Result of superposition of wavelets from different parts of same wavefront
All bright & dark fringes are of equal width	The width of central bright fringe is twice the width of any secondary maximum
All bright fringes are of same intensity	Intensity of bright fringe decreases with increase in order of maxima
Number of bands are large	No of bands are small

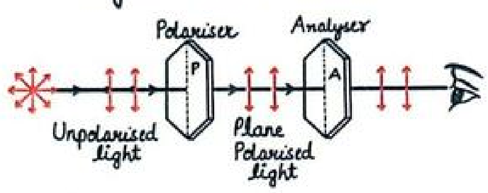
Polarisation

- The process of restricting the oscillation of a wave to just one direction in a transverse plane
- Only transverse wave exhibit polarisation
- Unpolarised Wave: A transverse wave in which vibrations are present in all direction in a plane perpendicular to the direction of propagation
- Polarised Wave: Transverse wave in which vibrations are present in one direction in a plane perpendicular to the direction of propagation

Polaroids

- Thin film of microscopic crystals aligned in a particular direction
- Converts unpolarised wave to a polarised wave
- Uses: In sun glasses, headlights of automobile, 3 D movies, LCD's etc

- Polariser: Polaroid on which unpolarised light is incident
- Analyser: Polaroid on which polarised light is incident

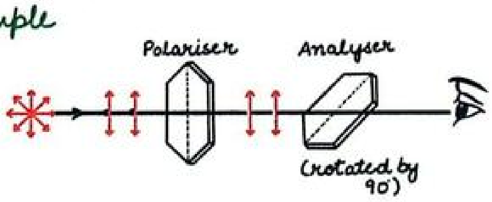


Law Of Malus

- When plane polarised light is passed through analyser its intensity,

$$I = I_0 \cos^2 \theta$$

- Example

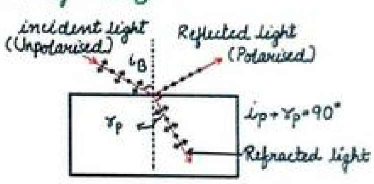


- If $\theta = 90°$, intensity of light transmitted by analyser is zero

Polarisation By Reflection

- When an unpolarised light is incident on a boundary between two transparent media, the reflected light is polarised with its electric vector perpendicular to the plane of incidence when refracted & reflected rays make a right angle with each other

Brewster Angle (i_B)



- Angle of incidence at which beam of unpolarised light falling on a transparent surface is reflected as a beam of completely plane polarised light
- At i_B, reflected & refracted light are perpendicular to each other

Brewster Law

- $\mu = \tan i_B$
- At $i \neq i_B$, the reflected light will be partially polarised

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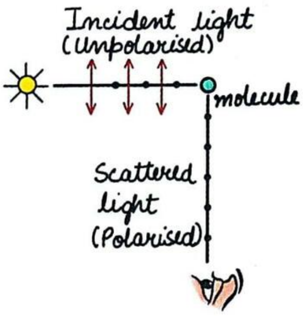
Polarisation By Scattering



- Phenomenon in which a beam of white light passes through a medium consisting of small particles of the order of wavelength of light when seen in a direction perpendicular to the incident beam appears bluish
- Light scattered in direction perpendicular to the incident light is plane polarised
- Scatterers : The particles of medium scattering the light
- The scatterers absorb & re-radiate the light during scattering