केंद्रीय विद्यालय संगठन
KENDRIYA VIDYALAYA SANGATHAN
मुंबई संभाग   MUMBAI REGION

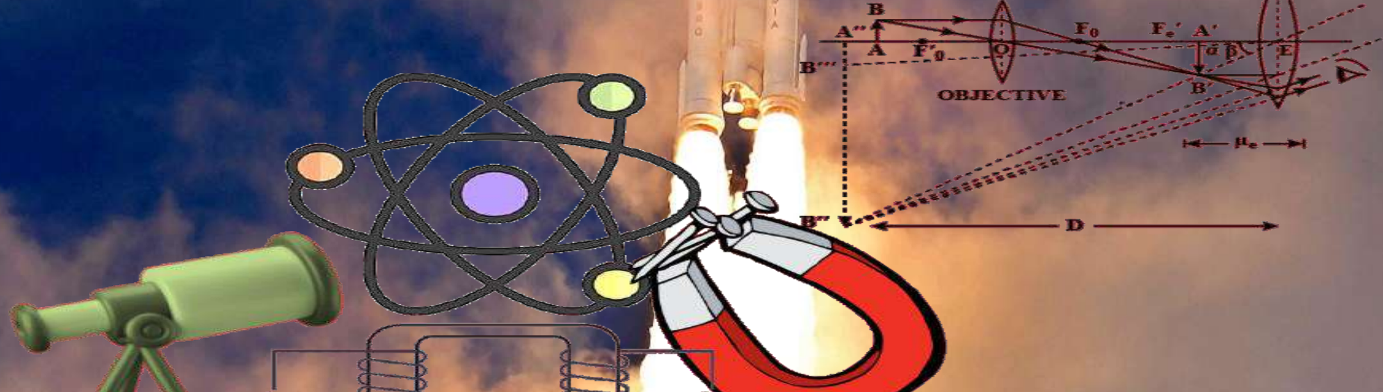
G20 भारत 2023 INDIA

तत् त्वं पूषन् अपावृणु
केन्द्रीय विद्यालय संगठन

आज़ादी का अमृत महोत्सव

कक्षा - बारहवीं
CLASS -XII

सत्र / SESSION-
2023-2024



A sure way to achieve the Goal

अध्ययन सामग्री–भौतिक विज्ञान
STUDY MATERIAL - PHYSICS

केंद्रीय विद्यालय संगठन, मुंबई संभाग
Kendriya Vidyalaya Sangathan, Regional Office, Mumbai
आई आई टी कैंपस , पवई , मुंबई IIT Campus, Powai, Mumbai-400076
दूरभाष Tel:-(022) 2572 8060 , 2572 2328,2572 1614
वेबसाइट Website- https://romumbai.kvs.gov.in

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REVIEW, EDITING & COMPILATION

समग्र समीक्षक का नाम NAME OF OVERALL REVIEWER	पद DESIGNATION	केंद्रीय विद्यालय का नाम NAME OF KV
Mr. M.GOPALA REDDY	PGT PHYSICS	KV RHE PUNE

सामग्री CONTENT	संपादक/ संकलक का नाम एवं पद NAME AND DESIGNATION OF EDITOR/ COMPILER	केंद्रीय विद्यालय का नाम NAME OF KV
STUDY MATERIAL & MASTER CARD	Mr. PREM PRAKASH SINGH PGT PHYSICS	KVIIT POWAI, MUMBAI
COVER PAGE DESIGN		

संकुल वॉर अध्ययन सामग्री निर्माता टीम
CLUSTER WISE TEAM OF PREPARERES

पाठ Ch. No.	पाठ का नाम NAME OF CHAPTER	कोर सदस्य का नाम NAME OF CORE MEMBER	संकुल का नाम NAME OF CLUSTER
1. 2.	ELECTRIC CHARGES AND FIELDS ELECTRIC POTENTIAL AND CAPACITANCE	Mr. VILAS PAWAR PGT PHYSICS K. V. No. 2, AFS Pune	PUNE-2

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CLUSTER WISE TEAM OF PREPARERES

पाठ Ch. No.	पाठ का नाम NAME OF CHAPTER	कोर सदस्य का नाम NAME OF CORE MEMBER	संकुल का नाम NAME OF CLUSTER
3.	CURRENT ELECTRICITY	Mr. M.GOPALA REDDY PGT PHYSICS KV RHE PUNE	PUNE-1

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पाठ Ch. No.	पाठ का नाम NAME OF CHAPTER	कोर सदस्य का नाम NAME OF CORE MEMBER	संकुल का नाम NAME OF CLUSTER
4. 5.	MOVING CHARGES AND MAGNETISM MAGNETISM AND MATTER	Dr. RAVINDRA KAMBALE PGT PHYSICS K. V. KOLIWADA	MUMBAI -1

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पाठ Ch. No.	पाठ का नाम NAME OF CHAPTER	कोर सदस्य का नाम NAME OF CORE MEMBER	संकुल का नाम NAME OF CLUSTER
6. 7.	ELECTROMAGNETIC INDUCTION ALTENATING CURRENT	Mr. SANTOSH V. SONTAKKE PGT PHYSICS KV AJNI NAGPUR	NAGPUR

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पाठ Ch. No.	पाठ का नाम NAME OF CHAPTER	कोर सदस्य का नाम NAME OF CORE MEMBER	संकुल का नाम NAME OF CLUSTER
8. 11.	ELECTROMAGNETIC WAVES DUAL NATURE OF RADIATION AND MATTER	Ms. NEHA SHARMA PGT PHYSICS KV INS MANDOVI ,GOA	GOA

क्र. सं S. No.	सदस्य का नाम NAME OF MEMBERS	पद DESIGNATION	केंद्रीय विद्यालय का नाम NAME OF KV
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CLUSTER WISE TEAM OF PREPARERES

पाठ Ch. No.	पाठ का नाम NAME OF CHAPTER	कोर सदस्य का नाम NAME OF CORE MEMBER	संकुल का नाम NAME OF CLUSTER
9. 10.	RAY OPTICS AND OPTICAL INSTRUMENTS WAVE OPTICS	Mr. GANESH AHIRRAO PGT PHYSICS KV ONGC PANVEL	MUMBAI -2

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पाठ Ch. No.	पाठ का नाम NAME OF CHAPTER	कोर सदस्य का नाम NAME OF CORE MEMBER	संकुल का नाम NAME OF CLUSTER
12. 13.	ATOMS NUCLEI	Mr. SUNIL JADHAV PGT PHYSICS KV Cantt. Aurangabad	AHMEDNAGAR

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CLUSTER WISE TEAM OF PREPARERES

पाठ Ch. No.	पाठ का नाम NAME OF CHAPTER	कोर सदस्य का नाम NAME OF CORE MEMBER	संकुल का नाम NAME OF CLUSTER
14.	SEMICONDUCTOR MATERIAL: ELECTRONIC DEVICES	Mr. ASHOK KUMAR PGT PHYSICS KV OF VARANGAON BHUSAWAL	NASHIK

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UNIT WISE TEAM OF REVIEW TEAM

इकाई सं. **Unit No.**	इकाई का नाम **Name of the Unit**	अध्ययन सामग्री निर्माता संकुल **Name of the Cluster material prepared**	अध्ययन सामग्री समिक्षकर्ता संकुल **Name of the cluster reviewing the material**	संकुल के प्रभारी का नाम **Name of the core in charge**
1	Electrostatics	Pune – 2	Nashik Mr Ashok Kumar	Mr. Vilas Pawar (KV No.2 AFS)
2	Current Electricity	Pune – 1	Goa Ms Neha Sharma	Mr. M G Reddy (KV RHE)
3	Magnetic Effects of Current and Magnetism	Mumbai - 1	Pune – 2 Mr. Vilas Pawar	Mr. Ravindra Kamble (KVKoliwada)
4	Electromagnetic Induction and Alternating Currents	Nagpur	Mumbai –2 Mr. Ganesh Ahirrao	Mr. Santosh V Sontakke (KV Ajni Nagpur)
5	Electromagnetic waves	Goa	Ahmednagar Mr. Sunil Jadhav	Ms. Neha Sharma (KV INS Mandovi)
6	Optics	Mumbai - 2	Nagpur Mr. Santosh V Sontakke	Mr. Ganesh Ahirrao (KV ONGC Panvel)
7	Dual Nature of Radiation and Matter	Goa	Ahmednagar Mr. Sunil Jadhav	Ms. Neha Sharma (KV INS Mandovi)
8	Atoms and Nuclei	Ahmednagar	Mumbai – 1 Mr. Ravindra Kamble	Mr. Sunil Jadhav (KV CANT Aurangabad)
9	Electronic Devices	Nashik	Pune – 1 M.G Reddy	Mr. Ashok Kumar (KV OF Varangaon)

विषय सूची
INDEX

CLASS XII (2023-24) PHYSICS (THEORY)

Time: 3 hrs. **Max Marks: 70**

		No. of Periods	Marks
Unit–I	**Electrostatics**	**26**	**16**
	Chapter–1: Electric Charges and Fields		
	Chapter–2: Electrostatic Potential and Capacitance		
Unit-II	**Current Electricity**	**16**	
	Chapter–3: Current Electricity		
Unit-III	**Magnetic Effects of Current and Magnetism**	**25**	**17**
	Chapter–4: Moving Charges and Magnetism		
	Chapter–5: Magnetism and Matter		
Unit-IV	**Electromagnetic Induction and Alternating Currents**	**24**	
	Chapter–6: Electromagnetic Induction		
	Chapter–7: Alternating Current		
Unit–V	**Electromagnetic Waves**	**04**	**18**
	Chapter–8: Electromagnetic Waves		
Unit–VI	**Optics**	**30**	
	Chapter–9: Ray Optics and Optical Instruments		
	Chapter–10: Wave Optics		
Unit–VII	**Dual Nature of Radiation and Matter**	**8**	**12**
	Chapter–11: Dual Nature of Radiation and Matter		
Unit–VIII	**Atoms and Nuclei**	**15**	
	Chapter–12: Atoms		
	Chapter–13: Nuclei		
Unit–IX	**Electronic Devices**	**10**	**7**
	Chapter–14: Semiconductor Electronics: Materials, Devices and Simple Circuits		
	Total	**160**	**70**

COURSE STRUCTURE 2023-2024

Unit I: Electrostatics **26 Periods**

Chapter–1: Electric Charges and Fields

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

Chapter–2: Electrostatic Potential and Capacitance

Electric potential, potential difference, electric potential due to a point charge, a dipole and system of charges; equipotential surfaces, electrical potential energy of a system of two-point charges and of electric dipole in an electrostatic field. Conductors and insulators, free charges and bound charges inside a conductor. Dielectrics and electric polarization, capacitors and capacitance, combination of capacitors in series and in parallel, capacitance of a parallel plate capacitor with and without dielectric medium between the plates, energy stored in a capacitor (no derivation, formulae only).

Unit II: Current Electricity **18 Periods**

Chapter–3: Current Electricity

Electric current, flow of electric charges in a metallic conductor, drift velocity, mobility and their relation with electric current; Ohm's law, V-I characteristics (linear and non-linear), electrical energy and power, electrical resistivity and conductivity, temperature dependence of resistance, Internal resistance of a cell, potential difference and emf of a cell, combination of cells in series and in parallel, Kirchhoff's rules, Wheatstone bridge.

Unit III: Magnetic Effects of Current and Magnetism **25 Periods**

Chapter–4: Moving Charges and Magnetism

Concept of magnetic field, Oersted's experiment. Biot - Savart law and its application to current carrying circular loop. Ampere's law and its applications to infinitely long straight wire. Straight solenoid (only qualitative treatment), force on a moving charge in uniform magnetic and electric fields. Force on a current-carrying conductor in a uniform magnetic field, force between two parallel current-carrying conductors-definition of ampere, torque experienced by a current loop in uniform magnetic field; Current loop as a magnetic dipole and its magnetic dipole moment, moving coil galvanometer- its current sensitivity and conversion to ammeter and voltmeter.

Chapter–5: Magnetism and Matter

Bar magnet, bar magnet as an equivalent solenoid (qualitative treatment only), magnetic field intensity due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis (qualitative treatment only), torque on a magnetic dipole (bar magnet) in a uniform magnetic field (qualitative treatment only), magnetic field lines. Magnetic properties of materials- Para-, dia- and ferro - magnetic substances with examples, Magnetization of materials, effect of temperature on magnetic properties.

Unit IV: Electromagnetic Induction and Alternating Currents **24 Periods**

Chapter–6: Electromagnetic Induction

Electromagnetic induction; Faraday's laws, induced EMF and current; Lenz's Law, Self and mutual induction.

Chapter–7: Alternating Current
Alternating currents, peak and RMS value of alternating current/voltage; reactance and impedance; LCR series circuit (phasors only), resonance, power in AC circuits, power factor, wattless current. AC generator, Transformer.

Unit V: Electromagnetic waves 04 Periods
Chapter–8: Electromagnetic Waves
Basic idea of displacement current, Electromagnetic waves, their characteristics, their transverse nature (qualitative idea only). Electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays) including elementary facts about their uses.

Unit VI: Optics 30 Periods
Chapter–9: Ray Optics and Optical Instruments
Ray Optics: Reflection of light, spherical mirrors, mirror formula, refraction of light, total internal reflection and optical fibers, refraction at spherical surfaces, lenses, thin lens formula, lens maker's formula, magnification, power of a lens, combination of thin lenses in contact, refraction of light through a prism. Optical instruments: Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers.

Chapter–10: Wave Optics
Wave optics: Wave front and Huygen's principle, reflection and refraction of plane wave at a plane surface using wave fronts. Proof of laws of reflection and refraction using Huygen's principle. Interference, Young's double slit experiment and expression for fringe width (No derivation final expression only), coherent sources and sustained interference of light, diffraction due to a single slit, width of central maxima (qualitative treatment only).

Unit VII: Dual Nature of Radiation and Matter 08 Periods
Chapter–11: Dual Nature of Radiation and Matter
Dual nature of radiation, Photoelectric effect, Hertz and Lenard's observations; Einstein's photoelectric equation-particle nature of light. Experimental study of photoelectric effect Matter waves-wave nature of particles, de-Broglie relation.

Unit VIII: Atoms and Nuclei 15 Periods
Chapter–12: Atoms
Alpha-particle scattering experiment; Rutherford's model of atom; Bohr model of hydrogen atom, Expression for radius of nth possible orbit, velocity and energy of electron in nth orbit, hydrogen line spectra (qualitative treatment only).
Chapter–13: Nuclei
Composition and size of nucleus, nuclear force Mass-energy relation, mass defect; binding energy per nucleon and its variation with mass number; nuclear fission, nuclear fusion.

Unit IX: Electronic Devices 10 Periods
Chapter–14: Semiconductor Electronics:
Materials, Devices and Simple Circuits Energy bands in conductors, semiconductors and insulators (qualitative ideas only) Intrinsic and extrinsic semiconductors- p and n type, p-n junction Semiconductor diode - I-V characteristics in forward and reverse bias, application of junction diode -diode as a rectifier

Unit I: Electrostatics

CHAPTER–1: ELECTRIC CHARGES AND FIELDS

GIST OF THE CHAPTER:

Electric charges, Conservation of charge, Coulomb's law-force between two-point charges, forces between multiple charges; superposition principle and continuous charge distribution.

Electric field, electric field due to a point charge, electric field lines, electric dipole, electric field due to a dipole, torque on a dipole in uniform electric field.
Electric flux, statement of Gauss's theorem and its applications to find field due to infinitely long straight wire, uniformly charged infinite plane sheet and uniformly charged thin spherical shell (field inside and outside).

DEFINITIONS & CONCEPTS:-

1. Charge : Charge is an intrinsic property of elementary particles of matter which gives rise to electric force between various objects.

2. Two types of charges: Positive and negative.

3. Transference of electrons is the cause of frictional electricity.

4. Basic properties of electric charge :

i) Additivity of charges : Total charge is the algebraic sum of individual charges.

ii) Conservation of charges : The total charge of an isolated system is always conserved.

iii) Quantisation of charges : Charge of an object is always in the form of integral multiple of electronic charge and never its fraction.

5. Coulomb's Law : It states that electrostatic force of attraction or repulsion between two stationary point charges kept in free space is given by:

$F = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_2}{r^2}\right)$ where 'q_1' and 'q_2' are the stationary point charges and 'r' is the separation between them.

ε_0 = permittivity of free space = 8.85 x 10^{-12} C^2/Nm^2

$\frac{1}{4\pi\varepsilon_0}$ = 9 x 10^9 Nm^2/C^2

It states that electrostatic force of attraction or repulsion between two stationary point charges kept in medium is given by:

$F = \frac{1}{4\pi\varepsilon}\left(\frac{q_1 q_2}{r^2}\right)$ where 'q_1' and 'q_2' are the stationary point charges and 'r' is the separation between them. $\varepsilon =$ absolute permittivity of medium.

In vector form

$$\vec{F} = \frac{1}{4\pi\varepsilon}\left(\frac{q_1 q_2}{r^2}\right)\hat{r}$$

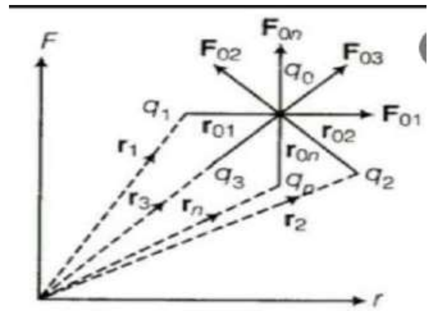
(charge) $q_1 \xrightarrow[\vec{r}]{\hspace{3cm}} q_2$ (another charge) $\longrightarrow \vec{F}$

6. Dielectric constant = The ratio of force between two charges in vacuum to the force acting between when they are shifted in a medium is called relative permittivity or dielectric constant of the medium.

$K = \dfrac{\varepsilon}{\varepsilon_0}$ Where K is also called the relative permittivity and ε is the permittivity of medium.

7. Principle of Superposition of Electrostatic Forces:
This principle states that the net electric force experienced by a given charge particle q_o due to a system of charged particles is equal to the vector sum of the forces exerted on it due to all the other charged particles of the system.

i.e. $\mathbf{F_0} = \mathbf{F_{01}} + \mathbf{F_{02}} + \mathbf{F_{03}} \ldots\ldots + \mathbf{F_{0N}}$



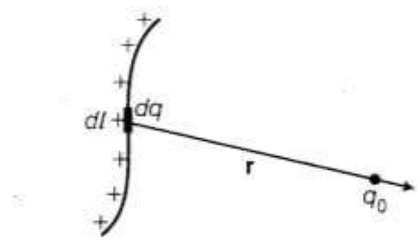
Superposition of electrostatic forces

8. Electrostatic force due to continuous charge distribution:

i) linear charge distribution(λ):

λ= Charge/Length =C/m

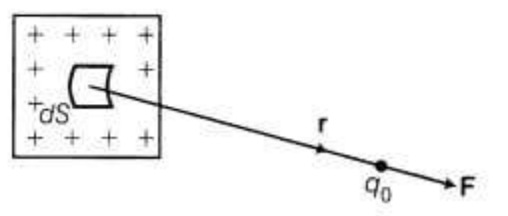
$$\lambda = \frac{dq}{dl}$$



ii) Surface charge distribution(σ):

σ= Charge/Area = Cm^{-2}

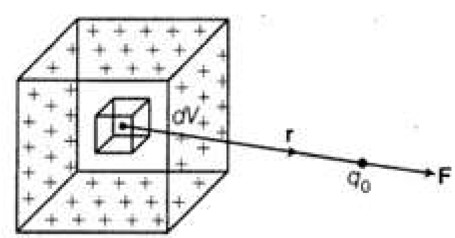
$$\sigma = \frac{dq}{dS}$$



iii) Volume charge distribution(ρ) :

ρ = Charge/ Volume = Cm^{-3}

$$\rho = \frac{dq}{dV}$$



UNITS OF CHARGE

(i) SI unit coulomb (C)
(ii) CGS system

(a) Electrostatic unit, esu of charge or stat-coulomb (stat-C)
(b) Electromagnetic unit, emu of charge or ab-C (ab-coulomb) 1 ab-C = 10 C, 1 C = 3 x 10^9 stat-C

Relationship of k to ε_0: $\quad \boldsymbol{k = \frac{1}{4\pi\varepsilon_0} = 9X\ 10^9\ Nm^2C^2}$

$\boldsymbol{\varepsilon_0}$= permittivity of free space = 8.85 X $10^{-12}\ C^2N^{-1}m^{-2}$

Force on a point charge in an electric field: $\vec{F} = q\,\vec{E}$

Electric Field ($\vec{E}$) :

It may be defined as the space surrounding the electric charge where another charge felt a force of attraction or repulsion.

Q - q_0 ⟶

(Source charge) $\quad \vec{r} \quad$ (Test charge) $\quad \vec{E}$

Electric field produced by the charge Q at a distance $\vec{r}$

$\vec{E} = \dfrac{\vec{F}}{q_0}$ Where $\vec{E}$ = electric field; q_0 = Test charge; $\vec{F}$ = Electrostatic force

Electric field lines radiate outwards from positive charges. The net electric field is zero inside a conductor.

Electric field due to point charge

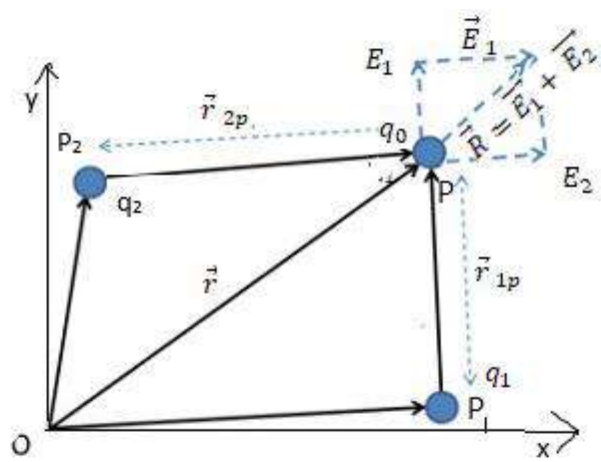
$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{r^2}\right)\hat{r}$$

(Note that Derivation is available in textbook)

Field due to system of charge (Multiple Charges):

$\vec{E} = E_1 + E_2 + \ldots E_n \quad = \frac{1}{4\pi\varepsilon_0}\sum_{i=0}^{n}(q_i\ /r_i^2)\hat{r_i}$

(Note that Derivation is available in textbook)



NOTES:-

Note1 Electric field is a vector quantity. It takes the direction of force.
Note2 If q_0 is negative, then direction of $\vec{E}$ will be in the opposite direction of force.
Note3 SI unit of $\vec{E}$ =newton/coulomb (N/C) or (N/C^{-1})
Note4 If q_0 =1 (unity), then electric field is the force that a unit positive charge would experience if placed at that point.

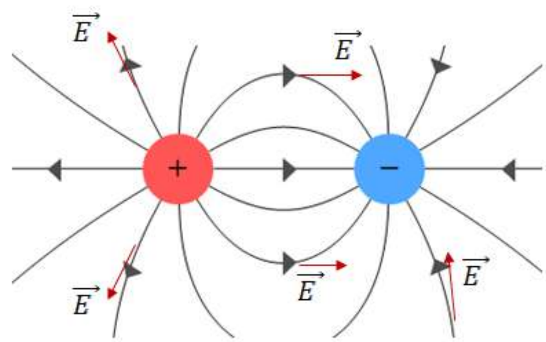
GRAPH for Electric field due to a point charge

Note : Graph of electric field with distance r

Electric Field lines: It is defined as the path pull over by moving test charges. To visualise electric field due to a system of charge, an imaginary field lines are draw.

Properties:

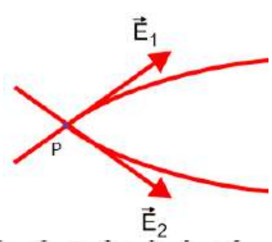
1. Field lines from a positive charge to negative charge



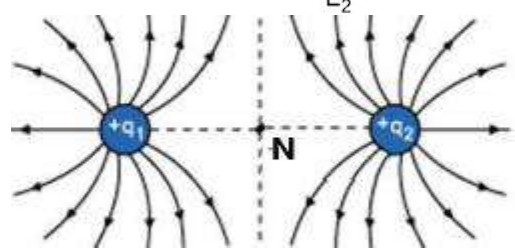
2. Direction of filed lines shown by the tangent to the field lines.
3. Electric field lines emerge normal from positive charge and terminate at negative charge.

4. They never interest each other.

   This can be explained by method of contradiction at two field lines E_1 & E_2 interest at P as shown in the figure. Then there may be two tangents at E_1 and $E_{2.}$ Which is not possible. Since one and only one tangent can be drawn. Therefore, our assumption is wrong.

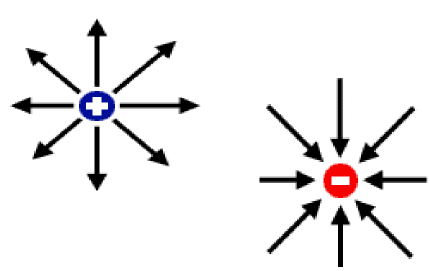


5. Electric field contract in length which shows that opposite charges attract.

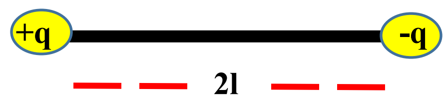


6. Electric field lines exert lateral pressure which shows that like charges repel. N is a point which shows field intensity is zero called neutral point.
7. Closer field lines indicate the stronger region and rarer field lines shows weaker region.
8. Single positive charge radiates field lines radially outward (q > 0).

9. Single negative charge radiates field lines radially inward (q < 0).



<u>**ELECTRIC DIPOLE:**</u>

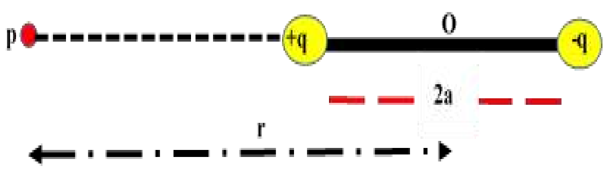


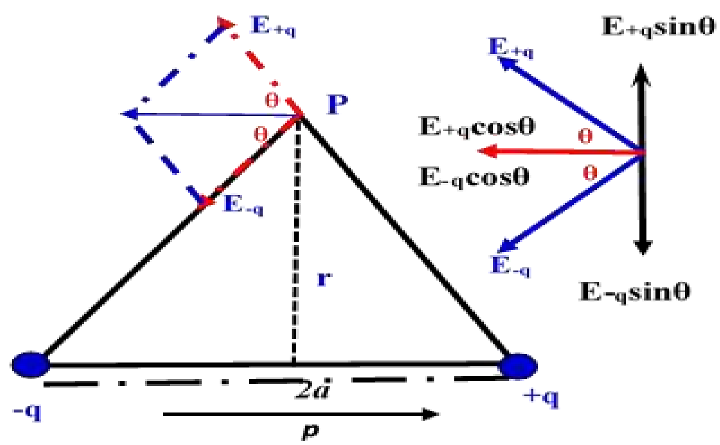
- **Two equal and opposite charges separated by small distance forms dipole**
- **Dipole moment is a vector quantity with direction from negative to positive charge.**
  Dipole Moment: $\vec{p} = (q \times 2a)$
- **Electric field intensity due to dipole can be calculated at axial as well as equatorial point.**

Electric Field Intensity (Axial point): $E_{Axial} = \frac{1}{4\pi\varepsilon_0}\left[\frac{2p}{r^3}\right]$

Electric Field Intensity (equatorial line): $E_{equat} = -\frac{1}{4\pi\varepsilon_0}\left[\frac{p}{r^3}\right]$

i) Axial Point **ii) Equatorial point**





<u>**Electric Dipole in a Uniform Electric Field:**</u>

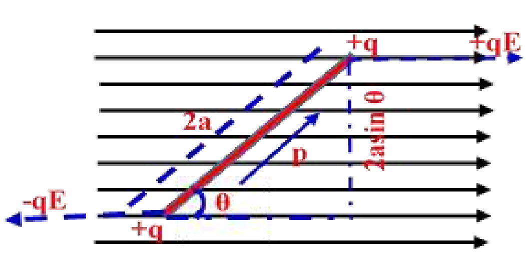
- **Electric dipole is placed in a uniform electric field, it experiences torque**

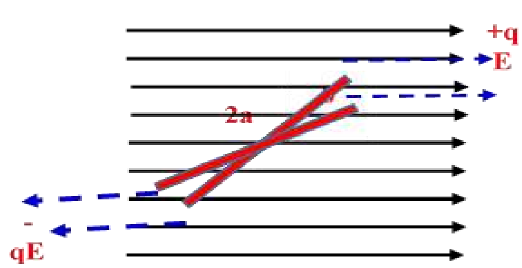
i)Torque on an Electric Dipole: $\tau = q\,E\,(2a \sin\theta) = p\,E \sin\theta$, $\tau = \vec{p} \times \vec{E}$

ii) Work done On an Electric Dipole: $W = p\,E\,(\cos\theta_1 - \cos\theta_2)$

iii) Potential Energy: $U = -\,p\,E\cos\theta$

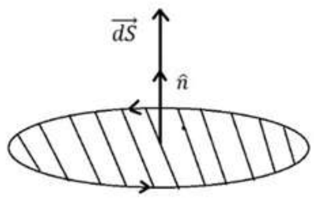
- **Potential Energy can be taken zero arbitrarily at any position of the dipole.**



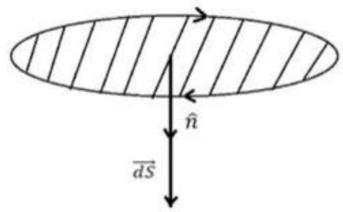


Electric Flux, Gauss Theorem and Applications:-

1) **Area Vector** – It is vector associated with small elemental area and expressed as $\vec{dS}$=dS $\hat{n}$.

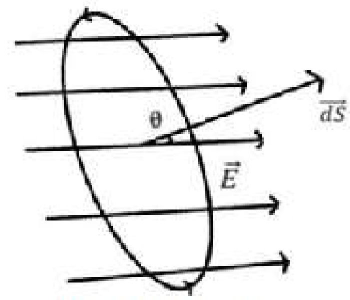


Area traced- Anti-Clockwise



Area traced- Clockwise

2) **Electric Flux**: -Electric flux over an area represents/measures total number of electric field lines crossing the area when it is held normal to the field direction. $\Phi_{E\ Total} = \oint_S \vec{E}.\vec{dS} = \oint_S E\, dS\, cos\theta$



$d\Phi_E = E\ dS\ cos\ \theta$

3) **Gauss Theorem or Gauss's Law of Electrostatics**

It states that total electric flux over closed surfaces enclosing volume V in vacuum is $1/\epsilon_o$ times the total charge enclosed inside closed surface S.

$$\Phi_{E\ Total} = q_{Total} / \epsilon_o \quad \text{And} \quad \Phi_{E\ Total} = \oint_S \vec{E}.\vec{dS}$$

$$\therefore \oint_S \vec{E}.\vec{dS} = q_{Total} / \epsilon_o$$

4) **Gaussian Surface**: -It is an imaginary surface around a point charge or charge distribution such that electric field intensity E at every point of it is same.

1) Electric field due to infinitely long uniformly charged straight wire $E = \lambda/2\pi\epsilon_o r = 2\lambda/4\pi\epsilon_o r$
2) Electric field intensity due to uniformly charged thin infinite plane sheet. $E = \sigma/2\epsilon_o$
3) Electric field at a point due to uniformly charged spherical shell.
   i) Electric field intensity at point 'P' outside shell distant r (r >R).

$$\boxed{\therefore E = q/4\pi\,\epsilon_o\, r^2}$$

   ii) Electric field at a point P on the surface of sphere r= R

$$E = q/4\pi\,\epsilon_o\, R^2 = \sigma\, A/4\pi\,\epsilon_o\, R^2$$
$$= \sigma\,(4\pi R^2)/4\pi\,\epsilon_o\, R^2$$
$$\boxed{\therefore E = \sigma/\epsilon_o}$$

   iii) Electric field at a point P inside shell (r < R)

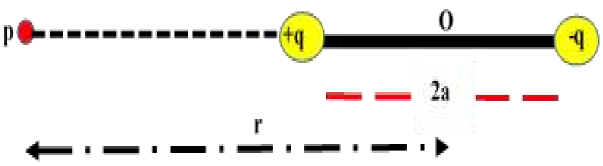
$$\boxed{\therefore E=0}$$

DIAGRAMS:

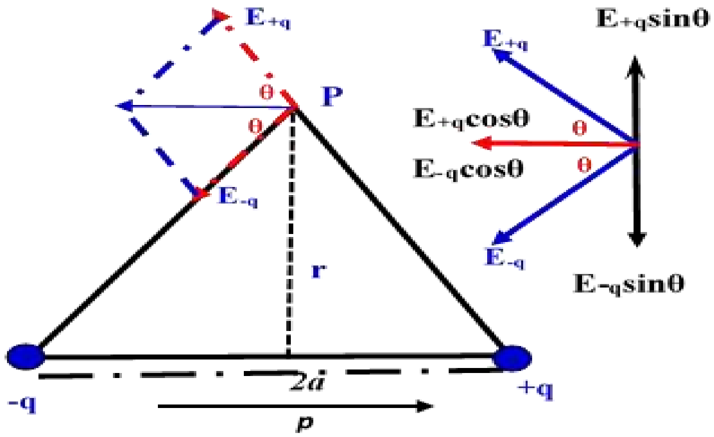
1. Electric Dipole

2. Electric Field Intensity Due to an Electric Dipole:

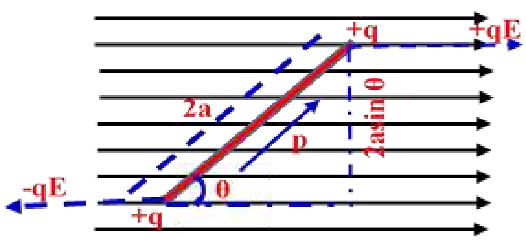
i) Axial Point

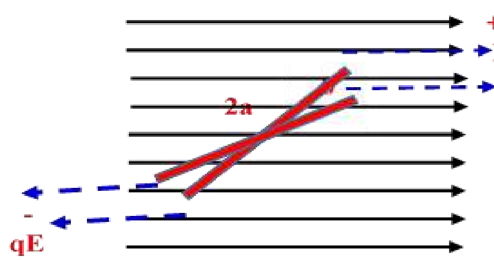


ii) Equatorial point

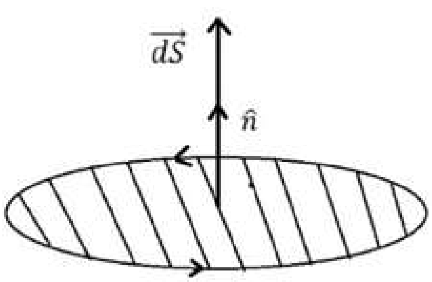


3. Electric Dipole in a Uniform Electric Field:

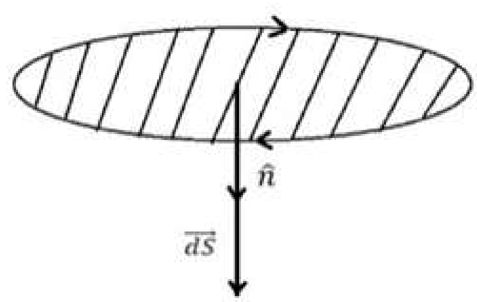




4. Area Vector $\vec{dS}$=dS $\hat{n}$



Area traced- Anti-Clockwise

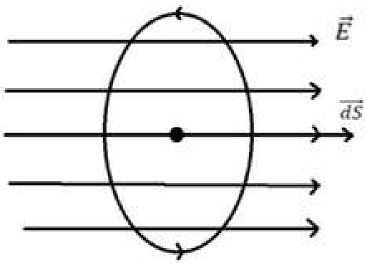


Area traced- Clockwise

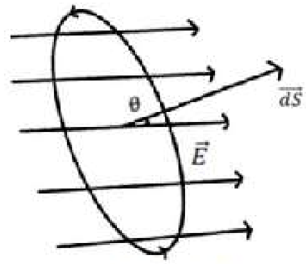
5. Electric Flux: - Electric

flux over an area represents/measures total number of electric field lines crossing the area when it is held normal to the field direction.

SI Unit of electric flux = SI Unit of E x SI Unit of area = Nm^2C^{-1} or V-m

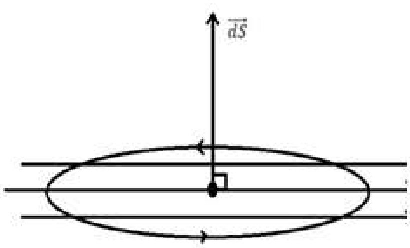


$(d\Phi_E)_{max} = E\ dS$

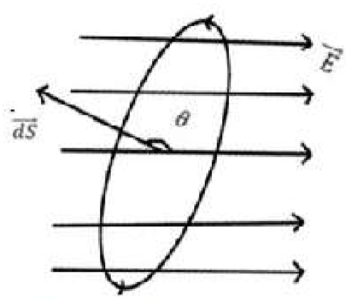


$d\Phi_E = E\ dS \cos\theta$

$d\Phi_E > 0$ for $\theta < 90°$



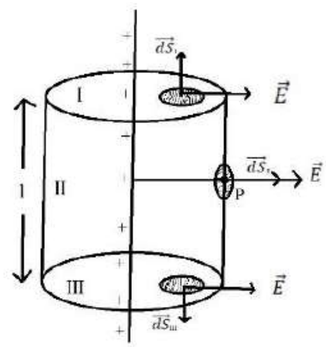
$d\Phi_E = 0$ for $\theta = 90°$



$d\Phi_E < 0$ for $\theta > 90°$

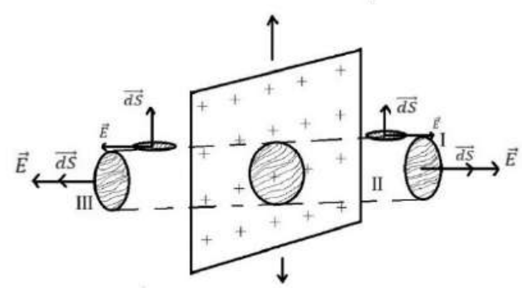
6. Diagrams for Applications of GAUSS THEOREM

a) Electric field due to infinitely long uniformly charged straight wire



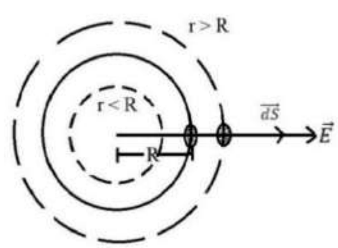
$E = \lambda/2\pi\epsilon_o r = 2\lambda/4\pi\epsilon_o r$

b) Electric field intensity due to uniformly charged thin infinite plane sheet.



$\boxed{E = \sigma/2\epsilon_o}$

c) Electric field intensity due to uniformly charged thin spherical shell

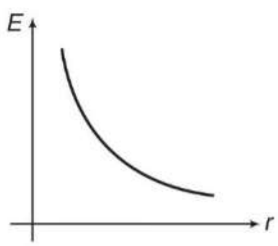


UNITS

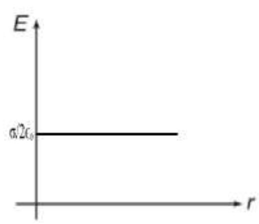
- **The SI unit of 'dipole moment' is Coulomb metre (C m)'.**
- **Electric Field intensity= F/q. Unit of E is NC^{-1} or Vm**
- **SI unit of torque is newton metre (Nm).**
- **SI unit of potential energy is joule.**
- **SI Unit of electric flux = SI Unit of E x SI Unit of area**
- **= Nm^2C^{-1} or V-m**
- **Dimensional Formula = $[M^1L^3T^{-3}A^{-1}]$.**
- **Electric flux is a scalar quantity.**

GRAPHS

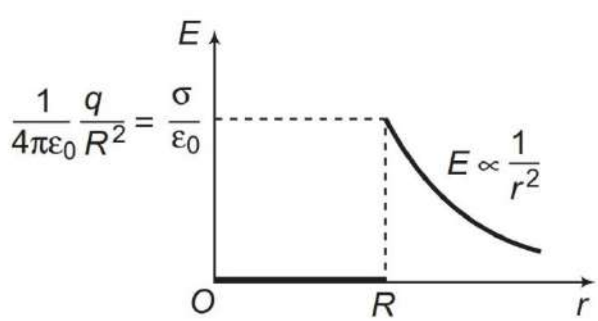
a) Electric field due to infinitely long uniformly charged straight wire



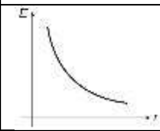
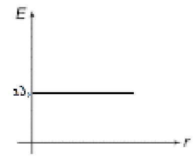
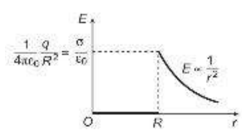
b) Electric field intensity due to uniformly charged thin infinite plane sheet.



c) Electric field intensity due to uniformly charged thin spherical shell



TABLES:

Electric Field Intensity	$\tau = \vec{p} \times \vec{E}$	*U = - p E cos θ*
E_{Axial}=2 $E_{Equatorial}$	**Case i: If θ = 0°, then τ = 0. Case ii: If θ = 90°, then τ = pE (maximum value). Case iii: If θ = 180°, then τ = 0.**	**Case i: If θ = 0°, then U = - pE (Stable Equilibrium) Case ii: If θ = 90°, then U = 0 Case iii: If θ = 180°, then U = pE (Unstable Equilibrium)**
Electric field at a point due to	**Formula**	**Graph**
infinitely long uniformly charged straight wire	E=λ/2πϵor	
uniformly charged thin infinite plane sheet.	E= σ/2ϵo	
uniformly charged thin spherical shell	E= q/4π ϵo r^2	

Some important points to remember

1) Total electric flux over closed surface depends only upon total charge enclosed within the surface and is independent of charge distribution within closed surface.

2) Total electric flux through surface is zero if charge enclosed is zero or algebraic sum of charges enclosed is zero.

3) Charges situated outside the closed surface makes no contribution to electric flux over surface boundary.

4) Increasing or decreasing the volume of closed surface S does not affect the flux through closed surface S as long as total charge enclosed remains unchanged/same.

FORMULAE

1. Dipole Moment: $\vec{p} = (q \times 2a)$

2. Electric Field Intensity (Axial point): $E_{Axial} = \frac{1}{4\pi\varepsilon_0}\left[\frac{2p}{r^3}\right]$

3. Electric Field Intensity (equatorial line): $E_{equat} = -\frac{1}{4\pi\varepsilon_0}\left[\frac{p}{r^3}\right]$

Electric Dipole in a Uniform Electric Field:

i)Torque on an Electric Dipole: $\tau = q\,E\,(2a \sin\theta) = p\,E \sin\theta$, $\tau = \vec{p} \times \vec{E}$

ii) Work done On an Electric Dipole: $W = p\,E\,(\cos\theta_1 - \cos\theta_2)$

iii) Potential Energy: $U = -\,p\,E\cos\theta$

GAUSS'S LAW:

- **Total Electric flux through closed surface** $\Phi E_{Total} = q_{Total} / \epsilon_O$
- **Mathematical form of Gauss law** $\oint_S \vec{E}.\vec{dS} = q_{Total}/\epsilon_o$
- **Electric field due to infinitely long uniformly charged straight wire**

  $E = \lambda/2\pi\epsilon_o r = 2\lambda/4\pi\epsilon_o r$
- **Electric field intensity due to uniformly charged thin infinite plane sheet.**

  $E = \sigma/2\epsilon_o$
- **Electric field at a point due to uniformly charged spherical shell.**
- **Electric field intensity at point 'P' outside shell distant r (r >R).**

  $\boxed{\therefore E = q/4\pi\epsilon_o r^2}$
- **Electric field at a point P on the surface of sphere r= R**

  $E = q/4\pi\epsilon_o R^2 = \sigma A/4\pi\epsilon_o R^2$

  $= \sigma(4\pi R^2)/4\pi\epsilon_o R^2$

  $\boxed{\therefore E = \sigma/\epsilon_o}$
- **Electric field at a point P inside shell (r < R)**

  $\boxed{\therefore E = 0}$

Unit I: Electrostatics

CHAPTER–2: ELECTROSTATIC POTENTIAL AND CAPACITANCE

GIST OF THE CHAPTER:-

Electric potential, potential difference, electric potential due to a point charge, a dipole and system of charges; equipotential surfaces, electrical potential energy of a system of two-point charges and of electric dipole in an electrostatic field.

Conductors and insulators, free charges and bound charges inside a conductor. Dielectrics and electric polarization, capacitors and capacitance, combination of capacitors in series and in parallel, capacitance of a parallel plate capacitor with and without dielectric medium between the plates, energy stored in a capacitor (no derivation, formulae only).

DEFINITIONS & CONCEPTS:-

1. **Electric potential**. The electric potential at a point in an electric field is defined as the amount of work done per unit positive test charge in moving the test charge from infinity to that point against the electrostatic force due to the field.

2. Electric potential difference. The electric potential difference between two points in an electric field is defined as theamount of work done per unit positive test charge in moving the test charge from one point to the other against the electrostatic force due to the field of charge Q. Its unit is volt

Mathematically: If W is work done in moving a small positive test charge q, from point A to B in the electrostatic field of charge Q, then potential difference between points B and A,

$$V_A - V_B = \frac{W_{AB}}{q} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

3. **Electric potential due to group of charges.** The electric potential at a point due to a group of charges is equal to the algebraic sum of the electric potentials due to individual charges at that point. It is a scalar quantity.

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + - - - - - - - + \frac{q_n}{r_n}\right)$$

4. **Potential gradient.** The rate of change of potential with distance at a point is called potential gradient at that point. The electric field at a point is equal to the negative potential gradient at that point. E = - dv/dr.

5. **Electric potential at a point due to a dipole**:

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

Equipotential Surfaces:

A surface with a constant value of potential at all points on the surface. Example: Surface of a charged conductor.

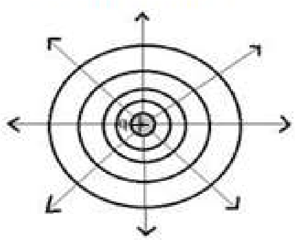
Properties of Equipotential Surfaces:

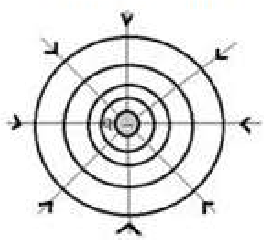
(i) No work is required to move a test charge on the equipotential surface.
(ii) The electric field is always normal to the equipotential surface at every point.
(iii) No two equipotential surfaces can intersect each other.
(iv) These are closer in the regions of strong electric fields and farther apart in the regions of weak field.

Equipotential Surfaces for various charge systems

For isolated point charge - concentric spheres

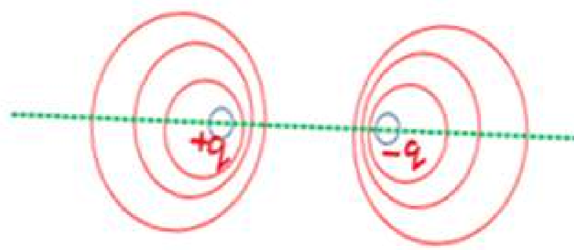
(Positive charge) **(Negative charge)**



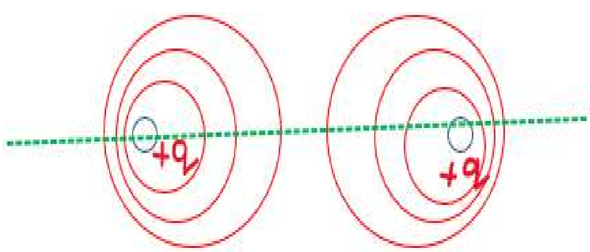


For electric dipole

(system of two equal and opposite charges)

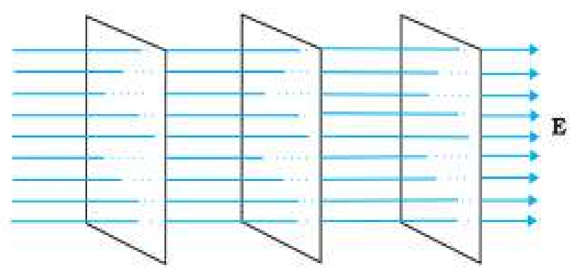


For like charges:

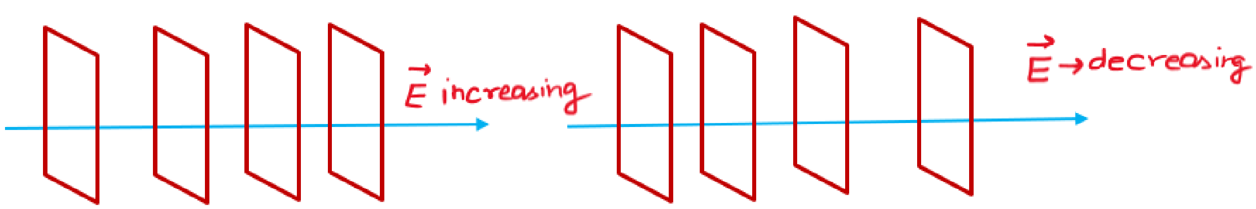


For uniform electric field:

Parallel planes perpendicular to the electric field



For non-uniform electric field:



Electric Potential Energy

Electric P.E. (U) is an amount of work done in assembling the charges at their locations by bringing them in, from infinity.

Note that **U is +ve** for like charges and **-ve** for unlike charges.

For Potential energy of a single point charge:

$$\boxed{U(\mathbf{r}) = q\,V(\mathbf{r})}$$

For Potential energy of a system of two-point charges:

$$\boxed{U(\mathbf{r}) = q_1 V(\mathbf{r_1}) + q_2 V(\mathbf{r_2}) + \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r_{12}}}$$

For <u>Potential Energy of a system of three-point charges</u>:

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

Potential Energy in an External Field-

$$\boxed{\mathbf{U = -pE\cos\theta = -\vec{p}.\vec{E}}}$$

CONDUCTORS, INSULATORS:-

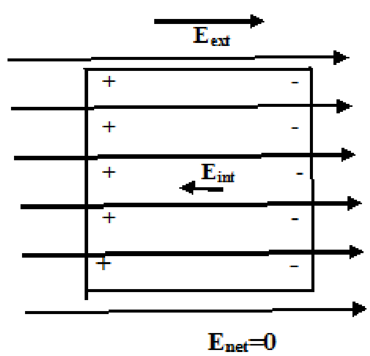
On the basis of their behaviour in an external field, material can be classified into two categories.

1. **Conductor:** The material which allow the electric current to pass through them, are called conductor.

   Example: Metals, human body, electrolytes etc.

2. **Insulator :** The material which do not allow electric current to pass through them, are called insulator.

   Example: glass, wood ,mica, wax etc.



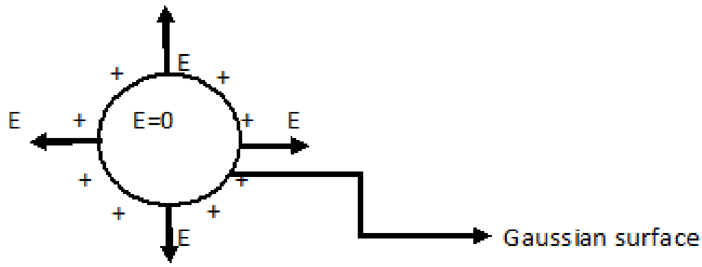
Behaviour of conductors in electrostatic fields

1. Net electrostatic field is zero in the interior of a conductor.

2. Just outside the surface of charged conductor, electric field is normal to the surface.

3. The net charge in the interior of a conductor is zero and any excess charge resides at its

surface.



4. Potential is constant within and on the surface of a conductor.
5. Electric field at the surface of a charged conductor is proportional to the surface charge density.
6. Electric field is zero in the cavity of a hollow charged conductor.

DIELECTRIC: Dielectric are insulating material which transmit electric effect without actually conducting itself. Example: Mica, ceramics etc.

There are two types of dielectric -

1. **Non polar dielectric**: These are the dielectrics in which the center of positive charge coincides with the center of negative charge is called non polar dielectric. Example: H_2, N_2, O_2 etc.
2. **Polar dielectric :** These are the dielectrics in which the center of positive charge do not coincide with the center of negative charge is called polar dielectric. Example: H_2O, HCl etc.

DIELECTRIC CONSTANT (K) : It can be regarded as the ratio of absolute permittivity of medium to that of free space is called dielectric constant ($K \; or \; \varepsilon_r$).

$$K = \varepsilon_r = \frac{\varepsilon_0}{\varepsilon}$$

DIELECTRIC POLARIZATION: Dielectric Polarization occurs when an external electric field is applied to a dielectric substance. When an electric field is applied, it causes charges (both positive and negative) to be displaced**.**

POLARIZATION DENSITY: The induced dipole moment developed per unit volume of a dielectric when placed in an external electric field is called polarization density.

$$P = \frac{Dipole\ moment\ of\ dielectric}{volume\ of\ dielcetric}$$

$$P = \frac{Qd}{Ad} = \frac{Q}{A} = \sigma_p$$

ELECTRIC SUSCEPTIBILITY: The ratio of the polarization to $\boldsymbol{\varepsilon_0}$ times the electric field is called the electric susceptibility of the dielectric.

The unit of electric susceptibility is $\mathbf{C^2/Nm^2}$

DIELECTRIC STRENGTH: The maximum electric field that can exist in a dielectric without causing the breakdown of its insulating property is called dielectric strength of the material.

The Unit of dielectric strength is **V/m**.

NOTE : 1. Liquid crystal Displays use dielectrics.

2. The dielectric material is used as an insulator and as a cooling agent in a transformer

*CAPACITOR AND CAPACITANCE (C):-

Capacitor: A device to store charges & electrostatic potential energy.

Capacitance: Ratio of charge & potential difference. (It is Scalar) $C = \frac{Q}{V}$.

SI. unit : **farad (F)**

Capacitance of a parallel plate capacitor with no medium between plates : $C_0 = C = \frac{\epsilon_0 A}{d}$

Capacitance of a parallel plate capacitor with a dielectric medium of dielectric constant K in between :

Thicness = t	**Thicness = t=0**	**Thicness = t=d**
$C_m = \frac{\epsilon_0 A}{\left(d-t+\frac{t}{K}\right)}$	$C_0 = \frac{\varepsilon_0 A}{d}$	$C_m = K\frac{\epsilon_0 A}{d}$

$\Rightarrow \quad C_m = KC_0$

*__Combination of capacitors__: (i) Capacitors in series: $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

(ii) Capacitors in parallel : $C = \sum_{i=1}^{n} C_i$

*__Energy stored in capacitors__: $U = \frac{1}{2}CV^2 = \frac{1}{2}QV = \frac{Q^2}{2C}$

*__Energy density__ : $U_d = \frac{1}{2}\epsilon_0 E^2 = \frac{\sigma^2}{2\epsilon_0}$

*__Introducing dielectric slab between the plates of the charged conductor with:__

PROPERTY	**BATTERY CONNECTED**	**BATTERY DISCONNECTED**
Charge	KQ_0	Q_0
Potential difference	V_0	V_0/K
Electric Field	E_0	E_0/K
Capacitance	KC_0	KC_0
Energy	$K\frac{1}{2}\epsilon_0 E^2$ (Energy is supplied by battery)	$\frac{1}{K}\frac{1}{2}\epsilon_0 E^2$ (Energy used for polarization)

***On connecting two charged capacitors:**

(a) Common Potential : $V = \dfrac{C_1V_1 + C_2V_2}{V_1 + V_2}$

(b)Loss of energy : $\Delta U = \dfrac{1}{2}\dfrac{C_1 \times C}{(C_1 + C_2)}(V_1 - V_2)^2$

SOME USEFUL LINKS:

https://www.learncbse.in/important-questions-for-class-12-physics-chapter-2/

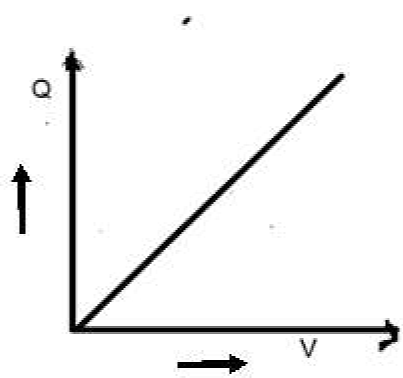
https://www.learncbse.in/ncert-exemplar-problems-class-12-physics-electrostatic-potential-capacitance/

https://phet.colorado.edu/sims/html/capacitor-lab-basics/latest/capacitor-lab-basics_en.html

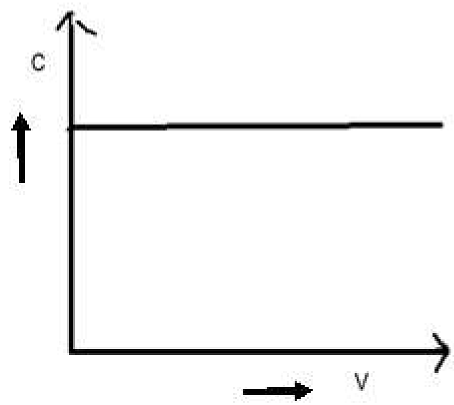
https://ophysics.com/em5.html

GRAPHS

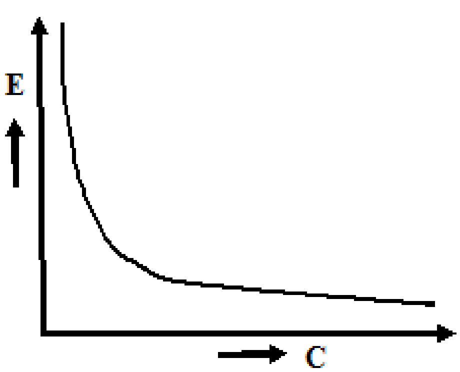
1.Graph between Q &V



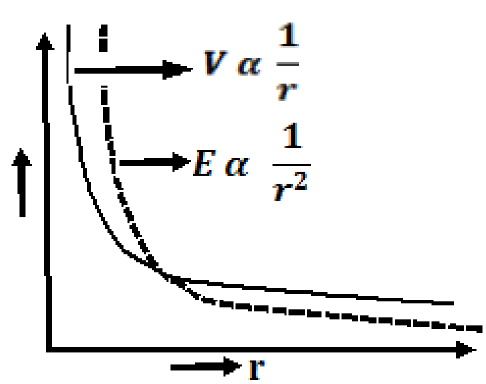
2.Graph between C& V



3.Graph between E & C



4. Graph of E & V verses distance r for a point charge



Formulae and Units:

Potential difference : work done / charge =W/q

*Electric potential due to point charge q at a distance r from it : V =Kq /r (1 /4π∈0 = K)

* Electric potential at a point due to N point charges:

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1}{r_1}+\frac{q_2}{r_2}+\frac{q_3}{r_3}+-------+\frac{q_n}{r_n}\right)$$

. Electric potential at a point due to a dipole:

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

Potential Energy of a system of two-point charges: $U = \frac{q_1 q_2}{4\pi\epsilon_0 r}$

<u>Potential Energy of a system of three-point charges:</u> $U = \frac{1}{4\pi\epsilon_0}\left[\frac{q_1 q_2}{r_{12}}+\frac{q_1 q_3}{r_{13}}+\frac{q_2 q_3}{r_{23}}\right]$

Potential energy of a single charge in an external Field: U (**r**) = q V (**r**)

Potential energy of two charges in an external Field U (**r**) = q_1V (**r₁**) +q_1V (**r₁**) + $\frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r_{12}}$

Electric Potential Energy of an electric dipole

U= pE($\cos\theta_1$ - $\cos\theta_2$)

if $\theta_1 = 90^o$ *and* $\theta_2 = \theta$ then U= -pE$\cos\theta$ = $-\vec{p}.\vec{E}$

Units: Charge- coulomb, Electric dipole moment- coulomb metre (Cm)

Distance- metre ,

Energy- joule or electron volt (eV) (1eV = 1.6 × 10^{-19} J)

Unit II: Current Electricity

CHAPTER–3: CURRENT ELECTRICITY

GIST OF THE CHAPTER:-

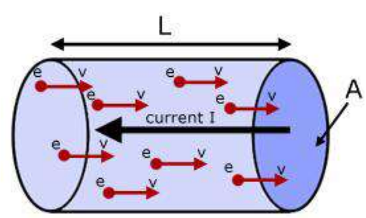
Electric current, flow of electric charges in a metallic conductor, drift velocity, mobility and their relation with electric current; Ohm's law, V-I characteristics (linear and non-linear), electrical energy and power, electrical resistivity and conductivity, temperature dependence of resistance, Internal resistance of a cell, potential difference and emf of a cell, combination of cells in series and in parallel, Kirchhoff's rules, Wheatstone bridge.

DEFINITIONS & CONCEPTS:-

Electric current- It is the rate of flow of electric charge through a conductor.

Drift velocity- It is the velocity with which a free electron in the conductor gets drifted under the influence of the applied external electric field.

Mathematically - $v_d = \frac{e\,E\,\tau}{m}$



Here, A is the area of cross-section of the conductor, τ is average relaxation time and n is number of free electrons per unit volume in the conductor.

Ohm's law- It states that the current flowing through a conductor is directly proportional to the potential difference across its two end provided physical conditions remains same.

Mathematically - V=IR, Hence R=$\frac{V}{I}$

Here, R is called resistance of the conductor. 1ohm (Ω) = 1 volt/ampere

Ohmic Conductors-Those conductors which obey Ohm's law, are called ohmic conductors e.g., all metallic conductors are ohmic conductor. Examples of ohmic conductors are metals, resistors, nichrome wires, etc.

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

Resistance -Resistance of a conductor measures the opposition to the current flow. The resistance of a conductor depends on its length l, Area of cross-section A, nature of material and temperature of conductor.

Resistivity or specific resistance- The resistivity of the material of a conductor is defined as the resistance offered by a conductor of this material of unit length and unit area of cross-section. Resistivity is purely a characteristic of the material of wire, it does not depends on length or area of conductor. ρ = $\frac{RA}{l}$

Conductance- The reciprocal of the resistance of a conductor is called its conductance (G).G=$\frac{1}{R}$

Conductivity- The reciprocal of the resistivity of the material of a conductor is called its conductivity.

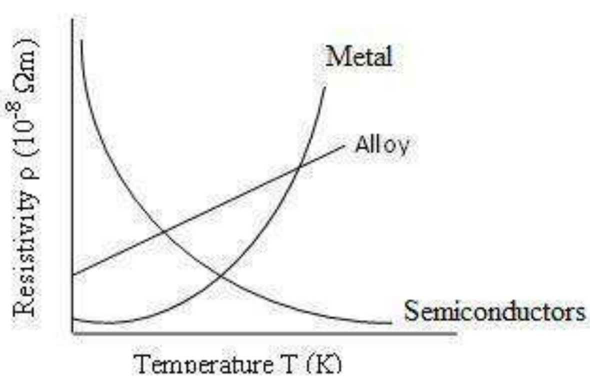
Mobility-The drift velocity of electron per unit electric field is mobility of electron.

Current Density:- The electric current flowing per unit area of cross-section of conductor is called current density.
It is a vector quantity and its direction is in the direction of motion of positive charge or in the direction of flow of current.
Electric energy- Energy due to electric potential or kinetic energy of charges.
Electric Power:- Power is defined as the rate of absorption/dissipation of energy

Temperature Dependence of Resistivity:

The resistivity of a material is found to be dependent on the temperature.
The resistivity of a metallic conductor is given by $\rho_T = \rho_0 [1 + \alpha(T - T_0)]$
α is called the temperature co-efficient of resistivity.
For meals, α is positive.
For alloys, α change very little with temperature.
For semiconductors, resistivity decreases with increasing temperature.
$\rho = \frac{1}{\sigma} = \frac{m}{ne^2\tau}$, from this equation ρ depends inversely on the number n of free electrons per unit volume and on the average time τ between collisions.
With increase in temperature

Conductors	τ ↓	ρ ↑
Semiconductors	τ ↑	ρ ↓



Electrical Energy: The total electric work done.
Energy supplied by the source of emf in maintaining the current in an electric circuit for a given time
Electric energy = $E = VIt = I^2Rt = Heat$

Power: The rate at which electric work is done. Power = $\frac{Work}{time} = VI = I^2R = \frac{V^2}{R}$

Cell, EMF, Internal Resistance:

Cell: 1] Dry Cell 2] Electrolytic cell
EMF: It is the maximum potential difference between the two electrodes of the cell when no current is draw from the cell.
Internal Resistance: The opposition offered by the electrolyte and electrodes of a cell to the flow of current through it.

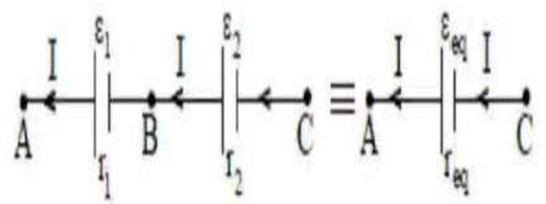
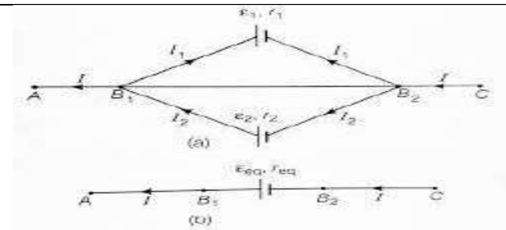
Internal resistance depends on separation between electrodes of the cell, conductivity of the electrolyte, nature of electrodes and common area of the electrodes dipped in the electrolyte.

$$V = \varepsilon - Ir$$

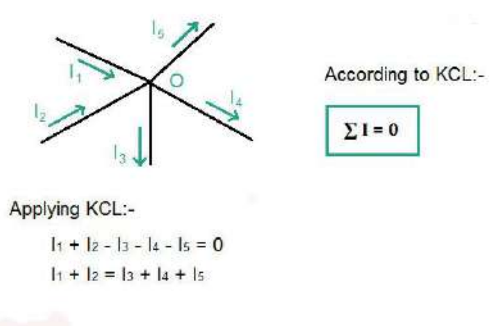
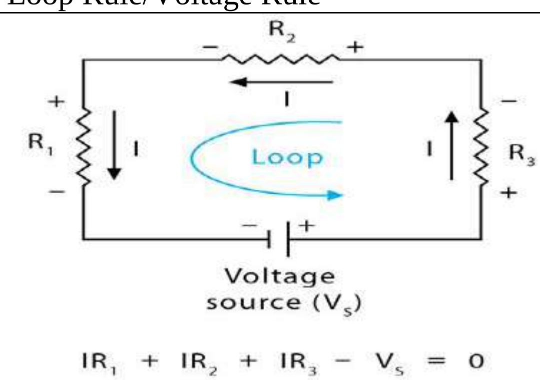
$$V = IR$$

$$I = \frac{\varepsilon}{R + r}$$

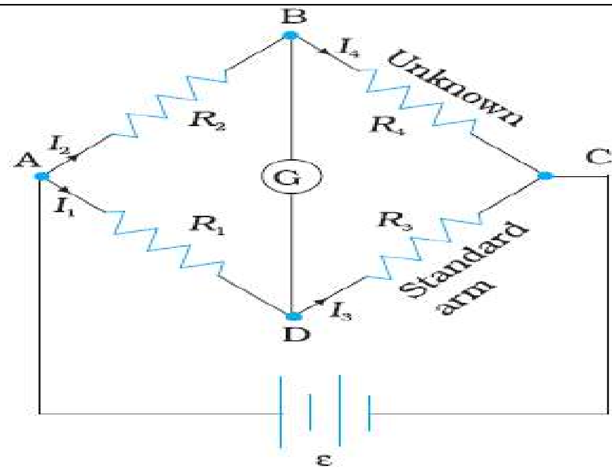
Grouping of cell:

Series Combination	Parallel Combination
	
$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2$ $r_{eq} = r_1 + r_2$ $I = \frac{nE}{(R + nr)}$	$V = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2} - I\frac{r_1 r_2}{r_1 + r_2}$ $\varepsilon_{eq} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}$ *and* $r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$ $\frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} + ...+ \frac{\varepsilon_n}{r_n}$ *and* $I = \frac{mE}{(mR + r)}$

Kirchhoff's Rules:

Junction Rule/Current Rule	Loop Rule/Voltage Rule
	
Algebraic sum of all current at junction is zero.	Algebraic sum of changes in potential and cells in the loop is zero.

Wheatstone Bridge:

Wheatstone Bridge

In case of balancing bridge IG=0, then $I_1=I_3$ and $I_2=I_4$ so $\frac{R_1}{R_2}=\frac{R_3}{R_4}$

UNITS AND DIMENSIONS-

SN	Quantity and Units	Dimension
1	Current- Ampere (A) or coulomb /second(C s-1)	[A]
2	Drift velocity- ms^{-1}	$[LT^{-1}]$
3	Resistance- ohm or volt amp^{-1}	$[ML^2T^{-3}A^{-2}]$
4	Resistivity- ohm-mt	$[ML^3T^{-3}A^{-2}]$
5	Conductance- mho or siemen	$[M^{-1}L^{-2}T^3A^2]$
6	Conductivity- mho-mt^{-1}or siemen /m	$[M^{-1}L^{-2}T^3A^2]$
7	Current density- Amp $metre^{-2}$	$[L^{-2}A]$
8	Mobility- m^2s^{-1} V^{-1}	$[M^{-1}T^2A]$
9	Energy- Joule or watt-sec	$[[ML^2T^{-2}]$
10	Power- Watt or volt-amp	$[ML^2T^{-3}]$

FORMULAE-

Physical Quantity	FORMULA	MEANING OF NOTATIONS USED	UNIT
Current-	I= $\frac{q}{t} = \frac{ne}{t}$	**q- charge flown in time t** **n- number of electrons**	**1 ampere (A) = 1 coulomb /second(C s-1)**
	For non-uniform flow, I= $\frac{dq}{dt}$ Or, q = $\int I\, dt$		
Drift velocity	$v_d = \frac{eE\tau}{m}$	**A-the area of cross-section of the conductor,** **τ is average relaxation time and** **n is number of free electrons per unit volume in the conductor.**	**ms^{-1}**
	$v_d = \frac{eV}{ml}\tau$	**Here V is the potential difference between the ends of conductor of length l.**	
Ohm's law-	V=IR, Hence R=$\frac{V}{I}$	**Here, R is called resistance of the conductor.**	**1ohm (Ω) = 1 volt/ampere**
Resistance-	R = $\frac{\rho l}{A}$ R = $\frac{ml}{Ane^2\tau}$	**Here, ρ is resistivity of the material of the conductor.**	**1ohm (Ω) = 1 volt/ampere**
Resistivity-	ρ = $\frac{RA}{l}$ Also ρ = $\frac{m}{ne^2\tau}$	**A-the area of cross-section of the conductor,** **τ is average relaxation time and** **n is number of free electrons per unit volume in the conductor.**	**ohm-meter (Ω m)**
Conductance -	G=$\frac{1}{R}$ Also = $\frac{Ane^2\tau}{ml}$	**It is the reciprocal of the resistivity of the material of a conductor**	**$metre^{-1}ohm^{-1}$**
Conductivity -	σ = $\frac{1}{\rho}$Also σ = $\frac{ne^2\tau}{m}$		
Mobility	(μ) = $\frac{v_d}{E} = \frac{e\tau}{m}$		
Current Density -	J = $\frac{I}{A}$ $J = nev_d$	**Relation between current density electric field:** J =σE = $\frac{ne^2\tau}{m}$E	
Resistivity of metallic conductor	$\rho_T = \rho_0[1+\alpha(T-T_0)]$	**ρ_T=Resistivity at T temperature** **ρ_0= Resistivity at reference temperature** **α = temperature co-efficient of resistivity**	**ρ : Ω m** **α : $^0C^{-1}$** **T : ^0C**

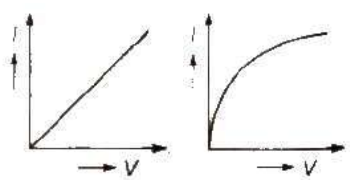
Table 2

Physical Quantity	FORMULA	MEANING OF NOTATIONS USED	UNIT
temperature co-efficient of resistivity	$\alpha = \frac{R_2 - R_1}{R_1(T_1 - T_2)}$	**α = temperature co-efficient of resistivity R_2= Resistance at final temperature R_1= Resistance at initial temperature T_1 and T_2= Initial and final temperature**	**α : $^0C^{-1}$ R_1, R_2: Ω T_1, T_2 : ^0C**
Electrical Energy	$E = VIt = I^2Rt$	**E= Energy, V= Voltage, I= Current, R= Resistance, t= Time**	**E: joule V: volt I: ampere**
Power	$P = VI = I^2R = \frac{V^2}{R}$	**P= Power, V= Voltage, I= Current, R= Resistance**	**P: watt**
EMF of Cell	$\varepsilon = \frac{W}{q}$	**ε= emf of cell W= work done q= charge**	**ε: volt W: joule q: coulomb**
Potential Difference of Cell	$V = IR = \varepsilon - Ir$	**V= Potential difference, I= Current, R= Resistance, ε= emf, r = Internal resistance**	**V: volt ε: volt r: Ω**
Internal resistance of cell	$r = \frac{\varepsilon}{I} - R$	**r= Internal resistance, ε= emf, I= Current, R= External resistance**	**r, R: Ω**
	$I = \frac{\varepsilon}{R + r}$		**I: ampere (A)**
Combination of Cell	**1] In Series:** $\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2$ $r_{eq} = r_1 + r_2$	**ε_{eq}= Equivalent emf r_{eq} = Equivalent internal resistance**	**ε_{eq}: volt r_{eq} = Ω**
	$I = \frac{nE}{(R + nr)}$	**I= Current, n= no. cells in series, E= emf, R= external resistance, r= internal resistance**	**I: A E: volt R,r: Ω**
	2] In Parallel: $V = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2} - I\frac{r_1 r_2}{r_1 + r_2}$	**V= Potential Difference, I= Current, ε_1, ε_2= emf's of cell 1 and 2 r_1, r_2= internal resistances of cell 1 and 2**	**V: volt ε_1, ε_2: volt r_1, r_2: Ω**
equivalent emf	$\varepsilon_{eq} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}$	**ε_{eq}= equivalent emf, ε_1, ε_2= emf's of cell 1 and 2 r_1, r_2= internal resistances of cell 1 and 2**	**ε_{eq} : volt ε_1, ε_2: volt r_1, r_2: Ω**

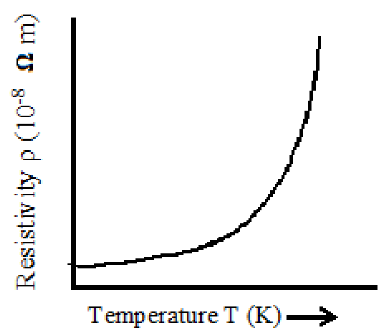
Physical Quantity	FORMULA	MEANING OF NOTATIONS USED	UNIT
equivalent internal resistance	$r_{eq} = \dfrac{r_1 r_2}{r_1 + r_2}$	r_{eq}= equivalent resistance r_1, r_2= internal resistances of cell 1 and 2	r_{eq}: Ω r_1, r_2: Ω
	$\dfrac{\varepsilon_{eq}}{r_{eq}} = \dfrac{\varepsilon_1}{r_1} + \dfrac{\varepsilon_2}{r_2} + ...+ \dfrac{\varepsilon_n}{r_n}$	ε_{eq}= Equivalent emf r_{eq} = Equivalent internal resistance	ε_{eq}: volt r_{eq} = Ω
Current due to combination	$I = \dfrac{mE}{(mR + r)}$	I= Current, E= emf, R= external resistance, r= internal resistance, m= number of cells connected in parallel	I: ampere E: emf R. r: Ω
Kirchhoff's Rules:	1] Junction Rule: $\sum I = 0$ 2] Loop Rule: $\sum (V - IR) = 0$		
Wheatstone Bridge:	$\dfrac{R_1}{R_2} = \dfrac{R_3}{R_4}$	R_1, R_2, R_3, R_4= Resistances	

GRAPHS-

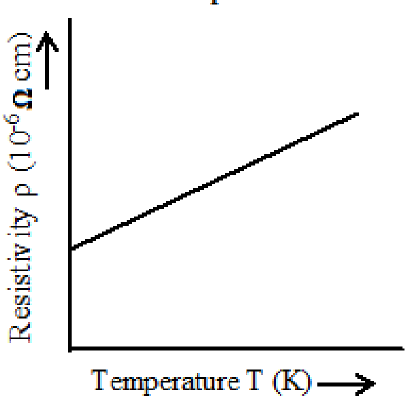
Ohmic Conductors **Non-Ohmic conductors**



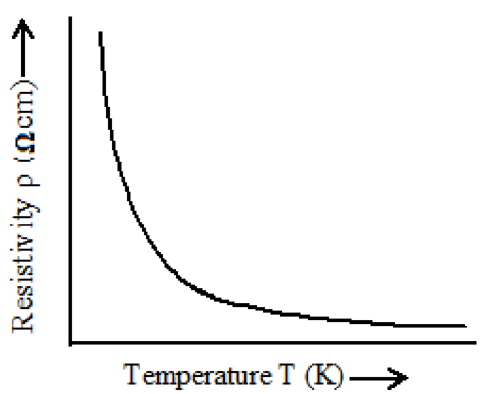
Resistivity ρ_T of copper as a function of temperature T.



Resistivity ρ_T of nichrome as a function of temperature T.



Temperature dependence of resistivity for a typical semiconductor.



Unit III: Magnetic Effects of Current and Magnetism

CHAPTER - 4 MOVING CHARGE AND MAGNETISM

GIST OF THE CHAPTER:

Concept of magnetic field, Oersted's experiment,
Biot - Savart law and its application to the current carrying circular loop, Ampere's law and its applications to infinitely long straight wire, Straight solenoid (only qualitative treatment), Force on a moving charge in uniform magnetic and electric fields, Force on a current-carrying conductor in a uniform magnetic field, Force between two parallel current-carrying conductors-definition of ampere , Torque experienced by a current loop in uniform magnetic field, Current loop as a magnetic dipole and its magnetic dipole moment, Moving coil galvanometer - its current sensitivity and conversion to ammeter and voltmeter.

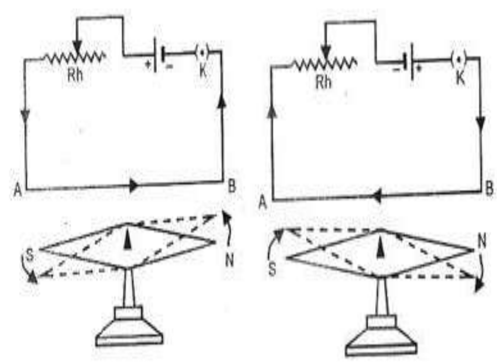
CONTENT/ CONCEPTS-

1. Magnetic field

A magnetic field is associated with an electric current flowing through a metallic wire. This is called the magnetic effect of current. On the other hand, a stationary electron produces an electric field only.

2. Oersted's experiment

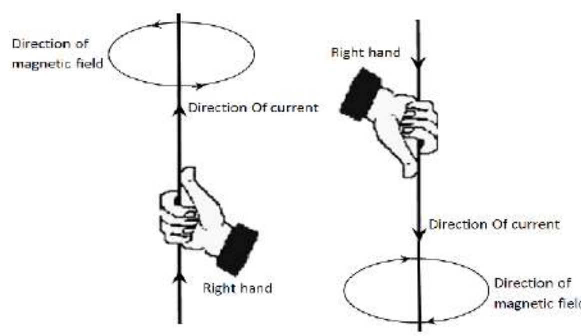
Hans christian Oersted performed simple experiment,
(i) When a needle is placed below the current carrying conductor it shows deflection.
(ii) When the direction of current is reversed the needle deflected in the opposite direction.
(iii) Deflection of the magnetic needle changes with the strength of electric current.



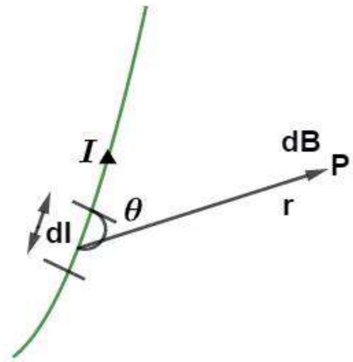
The SI unit of magnetic field is Wm^{-2} or T (tesla).
The strength of magnetic field is called one tesla, if a charge of one coulomb, when moving with a velocity of 1 ms^{-1} along a direction perpendicular to the direction of the magnetic field experiences a force of one newton.
1 tesla (T) = 1 weber meter^{-2} (Wbm^{-2}) = 1 newton ampere^{-1} meter^{-1} (NA^{-1} m^{-1})
CGS units of magnetic field are called gauss or oersted.
1 gauss = 10^{-4} tesla.

3. Right hand thumb rule

Hold a conductor is Right Hand in such a way that thumb indicates the direction of current and curled finger encircling the conductor will give the direction of magnetic field lines.



4. Biot - Savart law



It states that the magnetic field strength $\overrightarrow{dB}$ produced due to a current element (of current I and length dl) at a point having position vector r relative to current element is-

$$\overrightarrow{dB} = \frac{\mu_0}{4\pi}\frac{I\,\overrightarrow{dl} \times \vec{r}}{r^3}$$

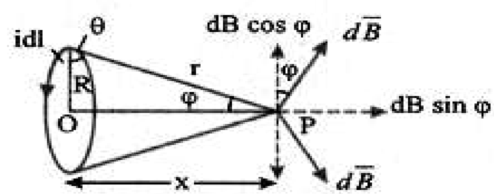
where μ_0 is the permeability of free space. Its value is -
$\mu_0 = 4\pi \times 10^{-7}$ Wb/A-m.
The magnitude of magnetic field is -

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

where θ is the angle between current element Idl and position vector $\vec{r}$ as shown in the figure. The direction of magnetic field $\overrightarrow{dB}$ is perpendicular to the plane containing Idl and $\vec{r}$.

5. Magnetic field due to a current carrying circular loop

The magnetic field due to current carrying circular coil of N-turns, radius a, carrying current I at a distance x from the center of coil is -



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

The magnetic field due to current carrying circular coil is along the axis.

At center, x=0

$$B_c = \frac{\mu_0 N I}{2R}$$

The direction of the magnetic field at the center is perpendicular to the plane of the coil.

6. Ampere's circuital law

It states that the line integral of magnetic field $\vec{B}$ along a closed BOUNDARY of an open surface is equal to μ_0-times the current (I) passing through the open surface with closed boundary.

$$\oint \vec{B}.\overrightarrow{dl} = \mu_0 I$$

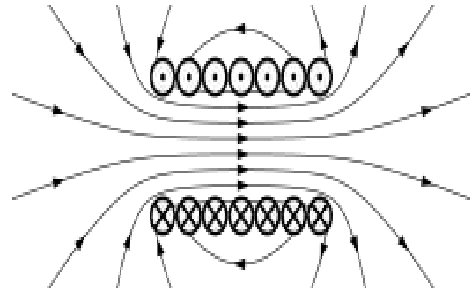
7. Magnetic field due to infinitely long straight wire using ampere's law

According to ampere's circulate law

$$\oint \vec{B}.\overrightarrow{dl} = \mu_0 I \Rightarrow \oint B dl\, cos 0^o = \mu_0 I$$

$$\Rightarrow \oint B dl = \mu_0 I \;\Rightarrow B \times\; 2\pi r \;= \mu_0 I \;\Rightarrow B = \frac{\mu_0 I}{2\pi r}$$

8. Straight solenoid (only qualitative treatment)



At the axis of a long solenoid, carrying current I

$B=\mu_0 nI$, where n = N/L = number of turns per unit length

Tip - When we look at any end of the coil carrying current,

If the current is in anticlockwise direction then that end of the coil behaves like north pole, and

If the current is in clockwise direction then that end of the coil behaves like the south pole.

9. Force on a moving charge in uniform magnetic and electric fields

The force on a charged particle moving with velocity $\vec{v}$ in a uniform magnetic field $\vec{B}$ is given by

$\overrightarrow{F_m} = q(\vec{v} \times \vec{B})$ = qvBsinθ

The direction of this force is determined by using Fleming's left hand rule.

The direction of this force is perpendicular to both $\vec{v}$ and $\vec{B}$,

When $\vec{v}$ is parallel to $\vec{B}$, then $\overrightarrow{F_m} = 0$

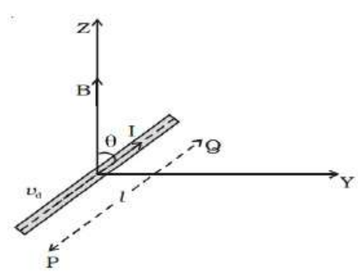
When $\vec{v}$ is perpendicular to $\vec{B}$, then $\overrightarrow{F_m}$ is maximum, i.e., $F_m = qvB$

The total force on a charged particle moving in simultaneous electric field $\vec{E}$ and magnetic field $\vec{B}$ is given by

$$\vec{F} = q(\vec{E} + \vec{V} \times \vec{B})$$

This is called the Lorentz force equation.

10. Force on a current-carrying conductor in a uniform magnetic field



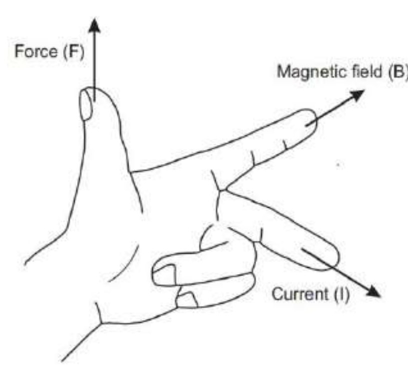
$$\vec{F} = I(\vec{l} \times \vec{B})$$

Magnitude of force is F = IlBsinθ

Direction of force $\vec{F}$is normal to $\vec{l}$ and $\vec{B}$ given by Fleming's Left Hand Rule.

If θ = 0 (i.e. $\vec{l}$ is parallel to $\vec{B}$), then the magnetic force is zero.

11. Fleming's Left Hand Rule



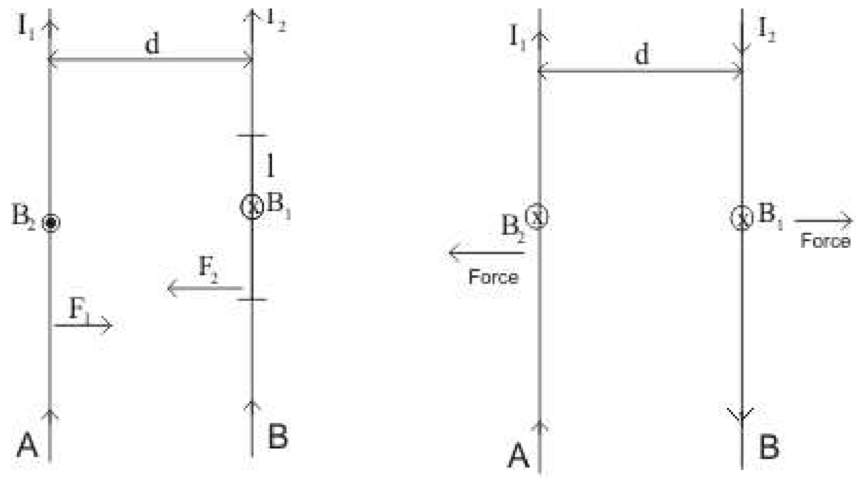
Stretch the left hand such that the fore-finger, the central finger and thumb are mutually perpendicular to each other. When the fore-finger points in the direction of the magnetic field and the central finger points in the direction of current then thumb gives the direction of the force acting on the conductor.

12. <u>Force between two parallel current-carrying conductors-definition of ampere</u>

Two parallel current carrying conductors attract while antiparallel current carrying conductors repel. The magnetic force per unit length on either current carrying conductor at separation 'a' is given by

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

Its unit is newton/meter abbreviated as N/m



Definition of ampere in SI system :- 1 ampere is the current which when flowing in each of the two parallel wires in vacuum at separation of 1 m from each other exert a force of $\frac{\mu_0}{2\pi} = 2 \times 10^{-7}$ N/m on each other.

13. <u>Torque experienced by a current loop in uniform magnetic field</u>

$$\vec{\tau} = NI\left(\vec{A} \times \vec{B}\right) = \vec{M} \times \vec{B} = MB \sin\theta$$

Where $\vec{M} = NI\vec{A}$ is the magnetic moment of the loop.

The unit of magnetic moment in SI system is Am^2

The torque is maximum when the coil is parallel to the magnetic field and zero when the coil is perpendicular to the magnetic field.

14. <u>Potential energy of a current loop in a magnetic field</u>

When a current loop of magnetic moment M is placed in a magnetic field, then potential energy of magnetic dipole is

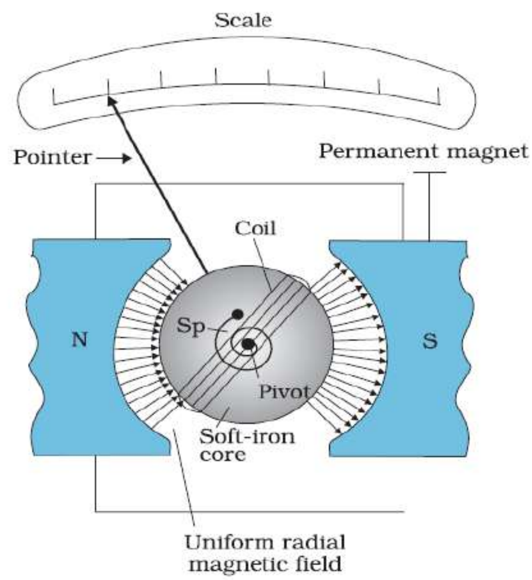
$$U = -\vec{M}.\vec{B} = -MBcos\theta$$

(i) When θ=0, U = - MB (minimum or stable equilibrium position)

(ii) When $\theta=\pi$, U = +MB (maximum or unstable equilibrium position)

(iii) When $\theta = \frac{\pi}{2}$, potential energy is zero

15. Moving coil galvanometer



A moving coil galvanometer is a device used to detect flow of current in a circuit. A moving coil galvanometer consists of a rectangular coil placed in a uniform radial magnetic field produced by cylindrical pole pieces. Torque on coil due to current-

τ = NIBA

where N is the number of turns, A is the area of coil. If k is torsional rigidity of material of suspension wire, then for deflection θ, torque-

$$\tau = k\theta$$

For equilibrium NIAB = kθ

$$\theta = \frac{NAB}{k} I \Rightarrow \theta \, \alpha \, I$$

Clearly, deflection in galvanometer is directly proportional to current, so the scale of galvanometer is linear.

Use of radial magnetic field :

The angle between the normal of the plane of loop and magnetic field θ = 90°, τ ∝ I, when radial magnetic field is used the deflection of coil is proportional to the current flowing through it. Hence a linear scale used to determine the deflection of coil.

Uses of galvanometer :

(i) Used to detect electric current is a circuit.
(ii) Used to convert the ammeter by putting a low resistor.
(iii) Used to convert voltmeter by putting a high resistor.
(iv) Used as ohmmeter by making special arrangement

Figure of Merit of a galvanometer: - The current which produces a deflection of one scale division in the galvanometer is called its figure of Merit. It is equal to $k = \frac{E}{(R+G)\theta}$

Sensitivity of a galvanometer:-

(i) **Current sensitivity:** It is defined as the deflection of coil per unit current flowing in it.

Current Sensitivity $I_S = \frac{\theta}{I} = \frac{NAB}{k}$

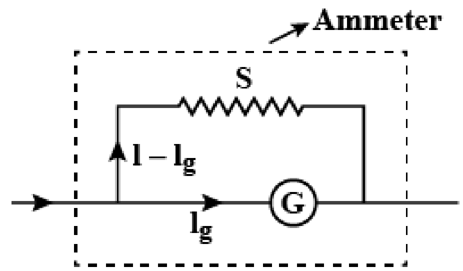
(ii) **Voltage sensitivity:** It is defined as the deflection of coil per unit potential difference across its ends

Voltage sensitivity $V_S = \frac{\theta}{IR} = \frac{NAB}{kR}$

16. Conversion of Galvanometer into Ammeter :-

A galvanometer may be converted into ammeter by using very small resistance in parallel with the galvanometer coil. The small resistance connected in parallel is called a shunt.

If G is resistance of galvanometer, I_g is current in galvanometer for full scale deflection, then for conversion of galvanometer into ammeter of range I ampere, the shunt is given by

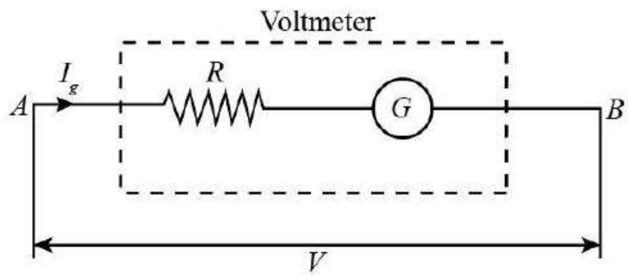


$$S = \frac{I_g}{I - I_g} G$$

Resistance of ideal ammeter is zero.

17. Conversion of Galvanometer into Voltmeter :-

A galvanometer may be converted into voltmeter by connecting high resistance (R) in series with the coil of the galvanometer. If V volt is the range of voltmeter formed, then series resistance is given by



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

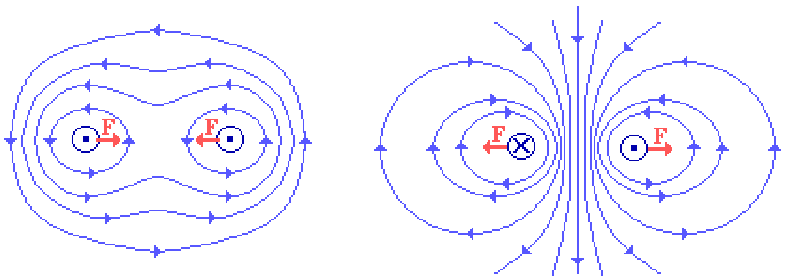
Resistance of ideal voltmeter is infinite.

UNITS :-

Physical quantity	Symbol	Nature	Dimensions	Units	Remarks
Permeability of free space	μ_0	scalar	$[MLT^{-2}A^{-2}]$	Henry/meter Or TmA^{-1}	$4\pi \times 10^{-7}$
Magnetic field	B	vector	$[MT^{-2}A^{-1}]$	T (tesla) or N/A-m or Wb/m^2	
Magnetic moment	M	vector	$[L^2A]$	$A\text{-}m^2$ or J/T	
Torsion constant	K	scalar	$[ML^2T^{-2}]$	$N\text{-}m\text{-}rad^{-1}$	
Torque	τ	vector	$[ML^2T^{-2}]$	N-m	

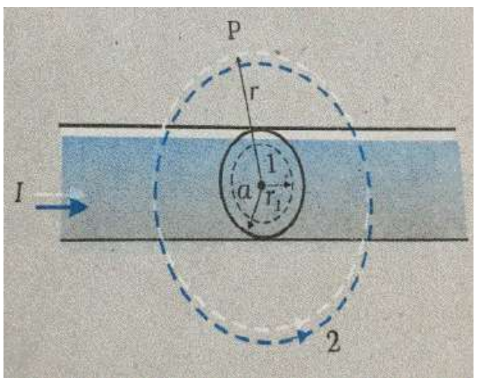
GRAPHS :-

1. Field pattern for force between two parallel current carrying conductors -

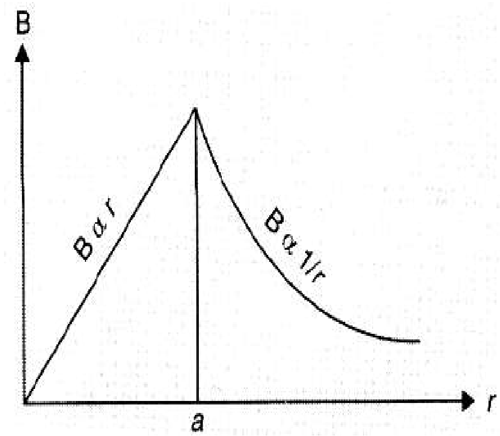


Same direction **Opposite direction**

2. Magnetic field in the region r < a and r > a, for a long straight wire of a circular cross-section

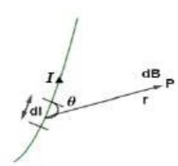
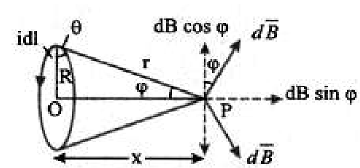


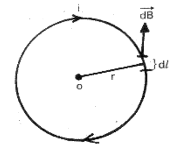
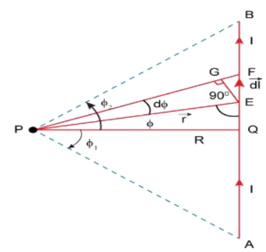
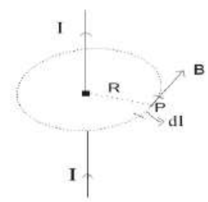
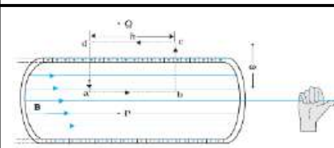
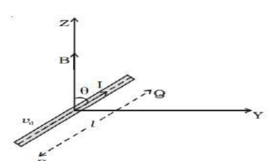
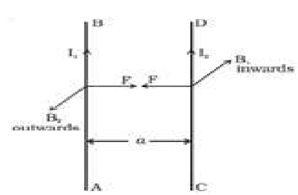
(NCERT image)

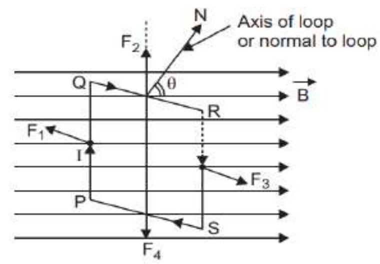
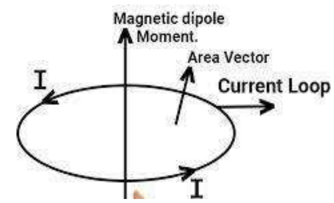
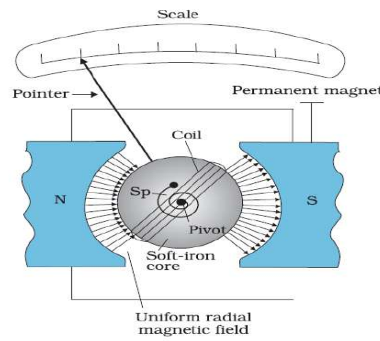
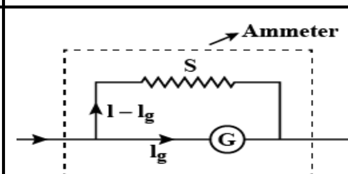
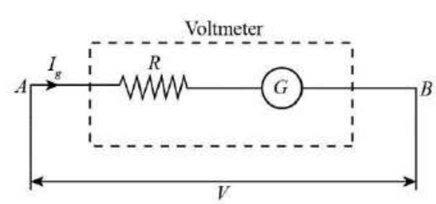


A long straight wire of a circular cross-section

FORMULAE & DIAGRAMS :-

Sr. No.	Term	Formula	Diagram
1	Biot Savart's Law	$dB = \dfrac{\mu_0 I\ dl\ sin\theta}{4\pi r^2}$	
2	Magnetic field at a point on the axis of a current carrying circular coil	$B = \dfrac{\mu_0 N I R^2}{2(R^2 + x^2)^{3/2}}$	

3	Magnetic field at a center of a current carrying circular coil	$$B = \frac{\mu_0 I}{2r}$$	
4	Magnetic field due to a current in a straight conductor	$$B_0 = \frac{\mu_0}{4\pi}\frac{I}{r}(sin\phi_1 + sin\phi_2)$$	
5	Ampere's circuital law	$$\oint \vec{B}.\vec{dl} = \mu_0 I$$	
6	Magnetic field due to an infinitely long current carrying straight wire	$$B = \frac{\mu_0 I}{2\pi R}$$	
7	Magnetic field due to straight solenoid	B = μ_0 n I , where n = N/L n = number of turns per unit length	
8	**Lorentz force** Force on a moving charge in uniform magnetic and electric fields	$$\vec{F} = q(\vec{E} + \vec{V} \times \vec{B})$$	
9	Force on a current-carrying conductor in a uniform magnetic field	$$\vec{F} = I(\vec{l} \times \vec{B})$$ $$F = BIl\,sin\theta$$	
10	Force between two parallel current-carrying conductors	$$F = \frac{\mu_0 I_1 I_2 l}{2\pi a}$$	

11	Torque experienced by a current loop in uniform magnetic field	$\tau = NIBA\ sin\theta$ $\vec{\tau}\ =\ \vec{m}\ \times\ \vec{B}$ Where m = IA = magnetic moment	
12	Current loop as a magnetic dipole and its magnetic dipole moment	$B = \frac{\mu_0}{4\pi}\frac{2m}{x^3}$ Where x is the distance along the axis from the center of the loop m = NIA = NIπr^2	
13	Moving coil galvanometer -	1. $I = G\theta$ Where $G = \frac{k}{NAB}$ = galvanometer constant K = torsional N = number of turns A = area of coil B = magnetic field θ = deflection	
14	Moving coil galvanometer Current sensitivity Voltage sensitivity	$I_s = \frac{\theta}{I} = \frac{NAB}{k}$ $V_s = \frac{\theta}{IR} = \frac{NAB}{kR}$	
15	Conversion of galvanometer to ammeter	$S\ =\ \frac{I_g}{I - I_g}G$ G = galvanometer resistance	
16	Conversion of galvanometer to voltmeter	$R = \frac{V}{I_g} - G$ G = galvanometer resistance R = high resistance in series	

Unit III: Magnetic Effects of Current and Magnetism

CHAPTER–5: MAGNETISM AND MATTER

GIST OF THE CHAPTER:

Bar magnet, bar magnet as an equivalent solenoid (qualitative treatment only), magnetic field intensity due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis (qualitative treatment only), torque on a magnetic dipole (bar magnet) in a uniform magnetic field (qualitative treatment only), magnetic field lines.
Magnetic properties of materials- Para-, dia- and ferro - magnetic substances with examples, Magnetization of materials, effect of temperature on magnetic properties.

CONTENT/ CONCEPTS-

1. Bar magnet

It is a rectangular shaped small piece of a rod having south and north poles of same strength separated by a small distance.

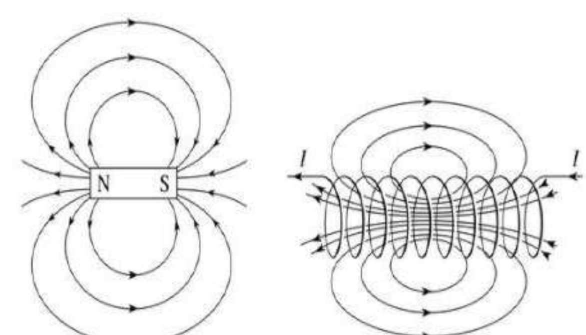
Properties :

(i) Property of attraction.
(ii) Property of alignment.
(iii) Like magnetic poles repel each other, while unlike magnetic poles attract each other.
(iv) Property of pairs
(v) Property of testing
(vi) Property of induction.

2. Bar magnet as an equivalent solenoid (qualitative treatment only)

A current carrying straight solenoid behaves like a bar magnet. A study of magnetic field lines around a solenoid carrying current and magnetic field lines around a bar magnet shows that solenoid acts like a bar magnet.

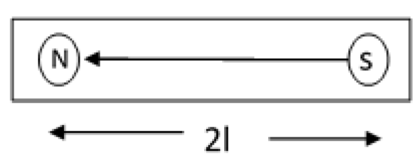
(i) Magnetic field inside a solenoid is stronger than inside a bar magnet.
(ii) Magnetic field outside a solenoid is very weak.
(iii) Magnetic field inside a solenoid is uniform, while outside it is non-uniform.



(a) (b)

3. Magnetic dipole (bar magnet) in a uniform magnetic field :

A magnetic field dipole consists of a pair of magnetic poles of equal and opposite strength separated by a small distance.



Dipole Moment of magnetic dipole-

The product of pole strength of either pole and distance between the magnetic pole.

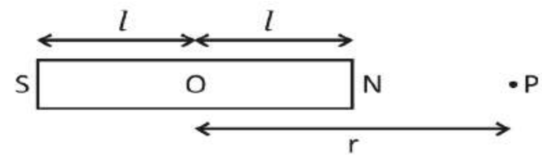
$$m = q_m \times 2l$$

S.I unit : Ampere-meter^2

4. Magnetic field intensity due to a magnetic dipole (bar magnet) along its axis

Magnetic field intensity due to a short bar magnet ($r >> l$) along its axis

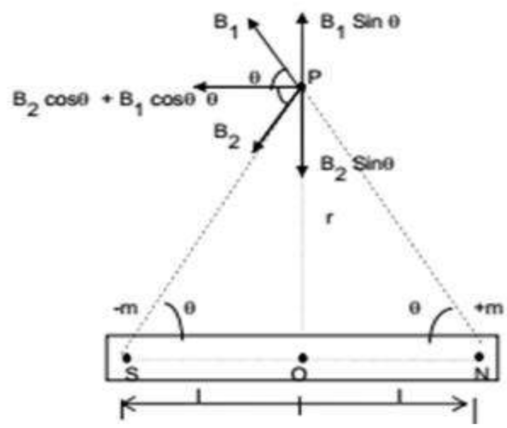
$$B_{axis} = \mu_0 \frac{2m}{4\pi r^3}$$



5. Magnetic field intensity due to a magnetic dipole (bar magnet) perpendicular to its axis

Magnetic field intensity due to a short bar magnet ($r >> l$) perpendicular to its axis (at equatorial point)

$$B_{equitorial} = \mu_0 \frac{m}{4\pi r^3}$$



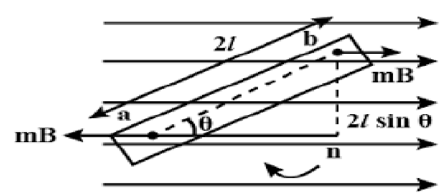
Note - $B_{axis} = 2 \times B_{equitorial}$

6. Torque on a magnetic dipole (bar magnet) in a uniform magnetic field

Torque acting on bar magnet

τ = magnitude of force × perpendicular dist.

$$\vec{\tau} = \vec{m} \times \vec{B} = mB\, sin\theta\, \hat{n}$$



Special case -

(i) When $\theta = 0/\pi$, $\tau = 0$

(ii) When $\theta = \frac{\pi}{2}$, τ = mB (maximum torque)

7. Potential energy of magnetic dipole in magnetic field

Work done to rotate a magnetic dipole in uniform magnetic field is stored as potential energy the magnetic dipole.

$$U = -\vec{M}.\vec{B} = -MBcos\theta$$

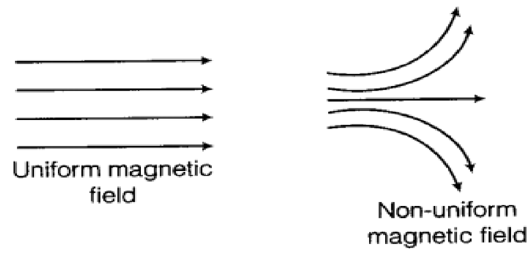
(i) When θ=0, U = - MB (minimum or stable equilibrium position)

(ii) When $\theta=\pi$, U = +MB (maximum or unstable equilibrium position)

(iii) When $\theta = \frac{\pi}{2}$, potential energy is zero

8. Magnetic field lines

It is the space around a magnet within which its influence can be experienced by a small magnet.



(i) **Uniform Magnetic Field :**

Magnetic field in a region is uniform if it has the same strength and same direction at all points in the region.

(ii) **Non uniform Magnetic Field :**

If it has different strength at different points in the region

Properties of Magnetic Field Lines:

(a) It is continuous and closed curves traveling from north pole to south pole outside but south pole to north pole inside the mag.

(b) The tangent at any point on the magnetic field line gives the direction of strength of the magnetic field.

(c) Two magnetic field lines do not intersect or cross each other because at the point of intersection there will be two directions at a single point, which is not possible.

(d) Widely spaced field lines represent weak magnetic field and closely spaced field lines represent strong may field.

(e) Magnetic field lines are not real yet they represent a magnetic field which is real.

9. Magnetic flux

Number of magnetic field lines passing normally through a given surface. It is denoted by ϕ.

$$\emptyset = \vec{B}\,.\vec{A}$$

SI unit- Weber.

Dimension = $[ML^2T^{-2}A^{-1}]$

10. Gauss's law in magnetism

It states that the surface integral of a magnetic field over a closed surface is always zero.

$$\oint \vec{B}.\vec{ds} = 0$$

11. Some important terms

Magnetisation or Intensity of magnetisation :

The degree or extent to which a substance is magnetized when placed in the magnetizing field is called magnetisation denoted by I or M.The magnetic dipole moment per unit volume of the substance is known as intensity of magnetisation.

$$\vec{M} = \frac{\vec{m}}{V}$$

Intensity of Magnetizing Field :

The extent to which the magnetizing field can magnetize a substance is known as intensity of magnetizing field. Denoted by H.

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

Magnetic Permeability :

The extent to which magnetic field lines can enter a substance is known as magnetic permeability.

$$\mu = \frac{B}{H}$$

Relative Magnetic Permeability :

The ratio of the flux density inside the material to the flux density in vacuum (B_0) is known as relative magnetic permeability.

$$\mu_r = \frac{B}{B_0} = \frac{\mu}{\mu_0}$$

Magnetic Susceptibility :

It is the property of a substance which shows how easily the substance can be magnetized when placed is the magnetizing field denoted by χ_m

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

Relation between magnetic permeability and magnetic susceptibility :

$$\mu_r = 1 + \chi_m$$

12. Magnetic materials :

1. Dimagnetic Materials 2. Paramagnetic Materials 3. Ferro-magnetic Materials

1. Dimagnetic Materials :

These are the substances in which feeble magnetism is produced in a direction opposite to the applied magnetic field. These substances are repelled by a strong magnet. These substances have small negative values of susceptibility χ and positive low value of relative permeability μ_r

$-1 \leq \chi_m \leq 0$ and $0 \leq \mu_r \leq 1$

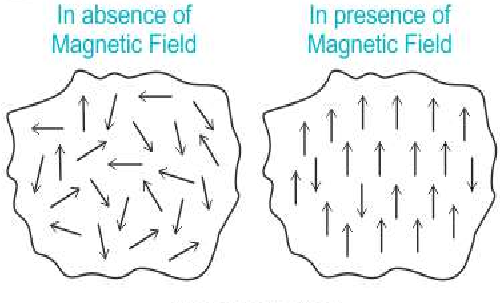
The examples of diamagnetic substances are bismuth, antimony, copper, lead, zinc, tin, gold, silicon, water, nitrogen (at STP) and sodium chloride.

2. Paramagnetic Materials :

These are the substances in which feeble magnetism is induced in the same direction as the applied magnetic field. These are feebly attracted by a strong magnet. These substances have small positive values of M and χ and relative permeability μ_r greater than 1

$0 \leq \chi_m \leq \varepsilon$ and $1 \leq \mu_r \leq 1 + \varepsilon$

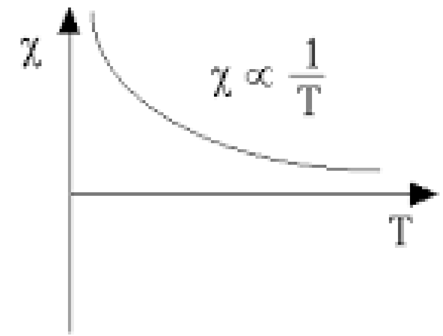
where ε is a small positive number. The examples of paramagnetic substances are platinum, chromium, sodium, aluminium, calcium, manganese, oxygen (at STP) and copper chloride.



Paramagnetism

Electron Theory :

These materials have some permanent magnetic dipole moment. Due to thermal agitation they cancel the magnetic moments of each other. When a magnetic field is applied, atomic dipoles try to line up in the direction of and get weakly magnetized.



Curie's Law in Paramagnetism :

Curie's law states that magnetisation of a paramagnetic material is inversely proportional to absolute temperature (T) of the material.

$$\frac{M}{H} = \chi_m = \frac{\mu_0 C}{T} \Rightarrow \chi_m \alpha \frac{1}{T}$$

3. <u>Ferromagnetic Materials :</u>

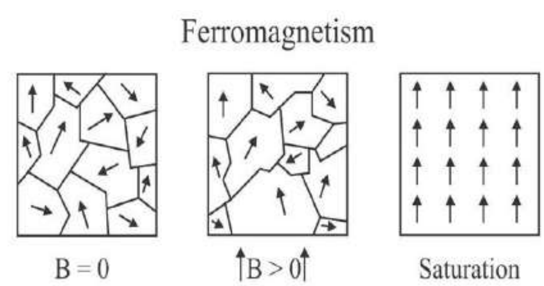
These are the substances in which a strong magnetism is produced in the same direction as the applied magnetic field. These are strongly attracted by a magnet. These substances are characterized by large positive values of M and χ and values of μ_r much greater than 1,

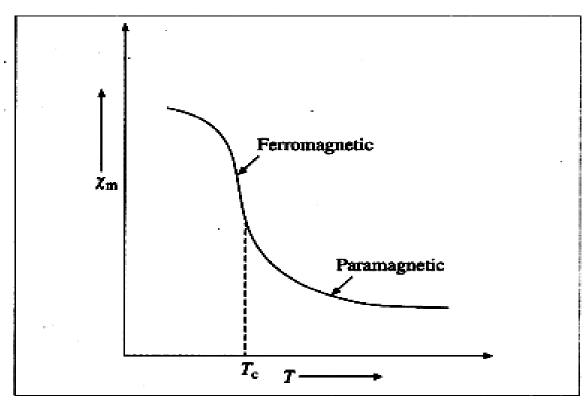
eg. Iron, cobalt, nickel, gadolinium and alloy like alnico.

$\chi_m >> 1$ and $\mu_r >> 1$

Electron Theory :

Domain is a small region formed by a large number of atoms of a ferromagnetic substance. Electron of one atom interacts with the electron of a nearby atom known as coupling. So each domain possesses a strong magnetic moment. In the absence of an external magnetic field, these domains are randomly oriented so that the net magnetic moment of the substance is zero. When a magnetic field is applied, all domains align themselves along the direction of the field.



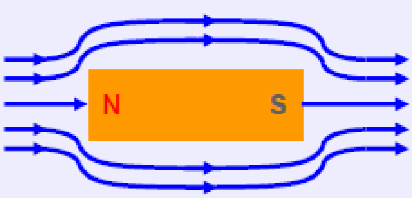
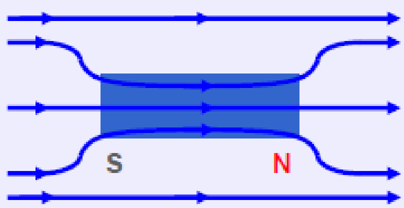
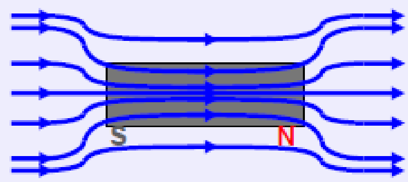
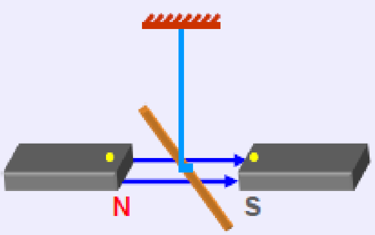
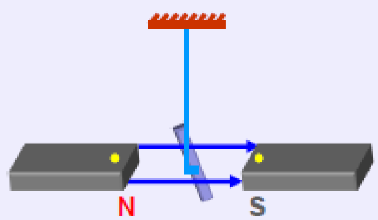
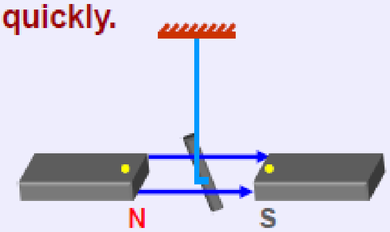


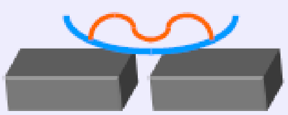
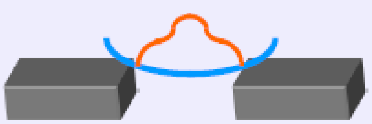
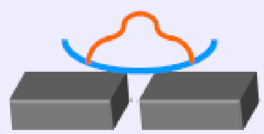
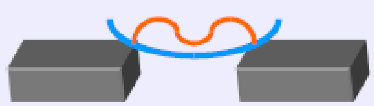
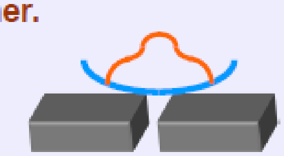
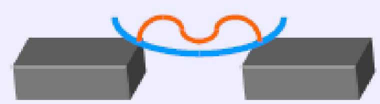
Curie's law of transition from ferromagnetism to paramagnetism :

$$\chi_m = \frac{C}{T - T_c} \quad where\ T > T_c$$

When the temperature of ferromagnetic substance is greater than curie temperature then it is a paramagnetic substance.

Distinguish between Diamagnetism, Para magnetism and Ferromagnetism

DIA	PARA	FERRO
1. Diamagnetic substances are those substances which are feebly repelled by a magnet. Eg. Antimony, Bismuth, Copper, Gold, Silver, Quartz, Mercury, Alcohol, water, Hydrogen, Air, Argon, etc.	Paramagnetic substances are those substances which are feebly attracted by a magnet. Eg. Aluminium, Chromium, Alkali and Alkaline earth metals, Platinum, Oxygen, etc.	Ferromagnetic substances are those substances which are strongly attracted by a magnet. Eg. Iron, Cobalt, Nickel, Gadolinium, Dysprosium, etc.
2. When placed in magnetic field, the lines of force tend to avoid the substance. 	The lines of force prefer to pass through the substance rather than air. 	The lines of force tend to crowd into the specimen. 
3. When a diamagnetic rod is freely suspended in a uniform magnetic field, it aligns itself in a direction perpendicular to the field. 	When a paramagnetic rod is freely suspended in a uniform magnetic field, it aligns itself in a direction parallel to the field. 	When a paramagnetic rod is freely suspended in a uniform magnetic field, it aligns itself in a direction parallel to the field very quickly. 

2. When placed in non-uniform magnetic field, it moves from stronger to weaker field (feeble repulsion).	When placed in non-uniform magnetic field, it moves from weaker to stronger field (feeble attraction).	When placed in non-uniform magnetic field, it moves from weaker to stronger field (strong attraction).
4. If diamagnetic liquid taken in a watch glass is placed in uniform magnetic field, it collects away from the centre when the magnetic poles are closer and collects at the centre when the magnetic poles are farther.  	If paramagnetic liquid taken in a watch glass is placed in uniform magnetic field, it collects at the centre when the magnetic poles are closer and collects away from the centre when the magnetic poles are farther.  	If ferromagnetic liquid taken in a watch glass is placed in uniform magnetic field, it collects at the centre when the magnetic poles are closer and collects away from the centre when the magnetic poles are farther.  
5. When a diamagnetic substance is placed in a magnetic field, it is weakly magnetised in the direction opposite to the inducing field.	When a paramagnetic substance is placed in a magnetic field, it is weakly magnetised in the direction of the inducing field.	When a ferromagnetic substance is placed in a magnetic field, it is strongly magnetised in the direction of the inducing field.
6. Induced Dipole Moment (M) is a small – ve value.	Induced Dipole Moment (M) is a small + ve value.	Induced Dipole Moment (M) is a large + ve value.

7. Intensity of Magnetisation (I) has a small – ve value.	Intensity of Magnetisation (I) has a small + ve value.	Intensity of Magnetisation (I) has a large + ve value.
8. Magnetic permeability μ is always less than unity.	Magnetic permeability μ is more than unity.	Magnetic permeability μ is large i.e. much more than unity.

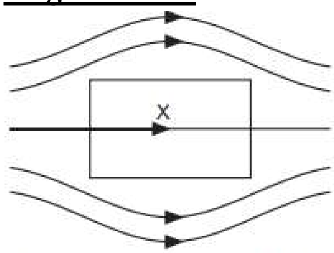
9. Magnetic susceptibility c_m has a small – ve value.	Magnetic susceptibility c_m has a small + ve value.	Magnetic susceptibility c_m has a large + ve value.

10. They do not obey Curie's Law. i.e. their properties do not change with temperature.	They obey Curie's Law. They lose their magnetic properties with rise in temperature.	They obey Curie's Law. At a certain temperature called Curie Point, they lose ferromagnetic properties and behave like paramagnetic substances.

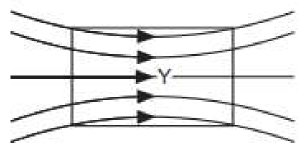
S. No.	Property	Diamagnetic	Paramagnetic	Ferromagnetic	Remark
1	Magnetic induction B	$B < B_0$	$B > B_0$	$B >> B_0$	B_0 is magnetic induction in free space
2	Intensity of magnetization M	Small and negative	Small and positive	Very high and positive	
3	Magnetic susceptibility χ	Small and negative	Small and positive	Very high and positive	
4	Relative permeability μ_r	$\mu_r < 1$	$\mu_r > 1$	$\mu_r >> 1$ (of the order of thousand)	

GRAPHS :-

1. **Magnetic field lines when diamagnetic and paramagnetic substances are placed in external magnetic field**

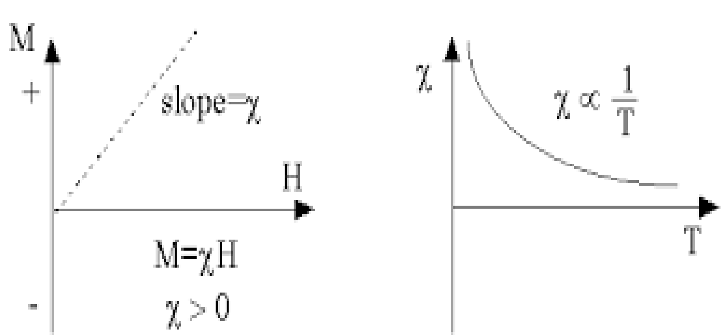


(a) Diamagnetic subsistence

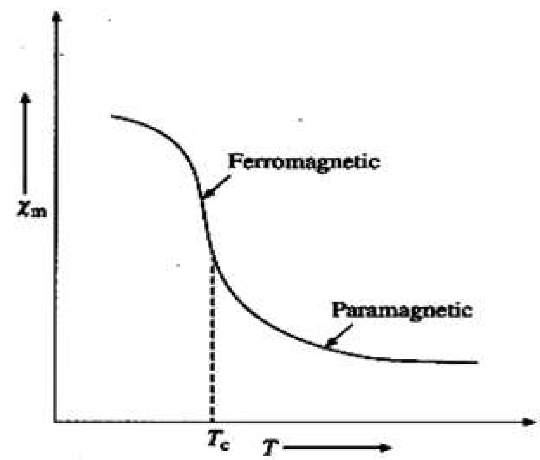


(b) Paramagentic subsistence

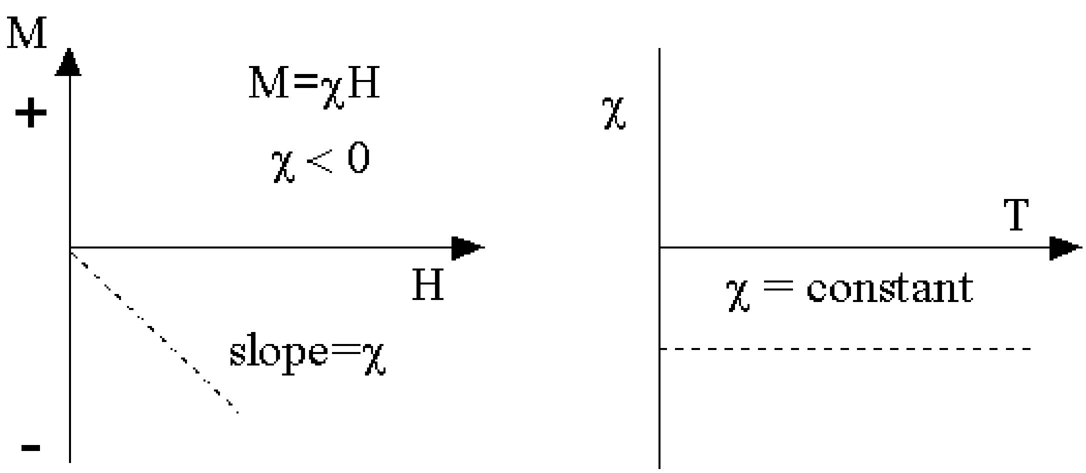
2. **Effect of temperature on**
   Paramagnetic material (Curie's law) **Ferromagnetic material**



Paramagnetism



3. **Effect of temperature on diamagnetic material**



Diamagnetism

UNITS :-

Physical quantity	**Symbol**	**Nature**	**Dimensions**	**Units**	**Remarks**
Permeability of free space	μ_0	Scalar	$[MLT^{-2}A^{-2}]$	Henry/meter Or TmA^{-1}	$4\pi \times 10^{-7}$
Magnetic field	B	Vector	$[MT^{-2}A^{-1}]$	T (tesla) or N/A-m or Wb/m^2	
Magnetic moment	m	Vector	$[L^2A]$	$A\text{-}m^2$ or J/T	
Magnetic flux	ϕ	Scalar	$[ML^2T^{-2}A^{-1}]$	Weber	
Magnetisation	M	Vector	$[L^{-1}A]$	Am^{-1}	$\frac{Magnetic\ m}{volum}$
Magnetic intensity	H	Vector	$[L^{-1}A]$	Am^{-1}	
Magnetic susceptibility	χ	Scalar	Dimensionles s	unitless	$\chi = \frac{M}{H}$
Relative magnetic permeability	μ_r	Scalar	Dimensionles s	unitless	$B = \mu_0\mu_r H$
magnetic permeability	μ	Scalar	$[MLT^{-2}A^{-2}]$	NA^{-2} Or TmA^{-1}	$\mu = \mu_0\mu_r$

Unit IV: Electromagnetic Induction and Alternating Currents

CHAPTER–6: ELECTROMAGNETIC INDUCTION

GIST OF CHAPTER:

Electromagnetic induction; Faraday's laws, induced EMF and current; Lenz's Law, Self and mutual induction.

CONTENT/ CONCEPTS-

Magnetic flux - Total number of magnetic lines of forces passing normally through a given surface is called magnetic flux.

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

Electromagnetic induction - Phenomenon of production of induced emf (and hence induce current) due to change of magnetic flux linked with the coil or conductor is called electromagnetic induction.

Faraday's law of electromagnetic induction -

First Law - Whenever magnetic flux linked with the close circuit changes, emf (and hence current) is induced in it. This induced emf last as long as the change in magnetic flux continuous.

Second law - The magnitude of induced emf is directly proportional to the rate of change of magnetic flux linked with circuit.

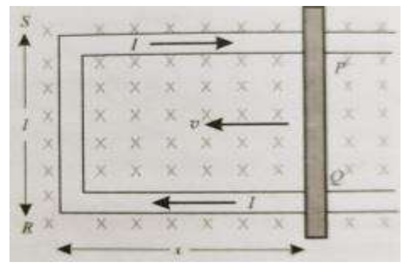
$$\epsilon = -\frac{d\emptyset}{dt}$$

If coil consists of N turns then $\in\ = -N\frac{d\emptyset}{dt}\ =\ -N\ \frac{(\emptyset_2 - \emptyset_1)}{t}$

Lenz law - The direction of induced emf is such that it always opposes the change in magnetic flux which produces it.

Motional emf - emf induced across the ends of a conductor due to its motion in magnetic field is called motional EMF.

EMF induced across the ends of conductor moving in a perpendicular magnetic field -



A] Magnetic flux enclose by loop, $\phi = BA = Blx$

According to Faraday's law, $\epsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(Blx)$

$\epsilon = +Blv$ where, $\frac{dx}{dt} = -v$

B] Induced current, $I = \frac{\epsilon}{R} = \frac{Blv}{R}$

$\therefore$ External force required, $F = BIl\sin 90 = B \times \frac{Blv}{R} \times l = \frac{B^2l^2v}{R}$

C] Power supplied by external force to maintain motion of movable arm,

$P = Fv = \frac{B^2\, l^2\, v^2}{R}$

D] Power dissipated as joule heating heat, $P = I^2R = \frac{B^2\, l^2\, v^2}{R}$

Eddy current (Foucault current)- When a solid conducting material is placed in changing magnetic field, induced current is set up inside conductor. These current loops are just like eddies produced on water and hence known as eddy current.

Uses - 1] Magnetic braking in electric trains.

2] To produce heat in induction furnaces.

3] Electromagnetic damping

Disadvantages –

1] Heat up metallic core and dissipate energy.

2] Damage insulation of coil due to heat.

3] Always oppose motion.

Minimization of eddy current –

1] Using laminating iron core.

2] Using slotted iron blocks.

Self-induction - Self-induction is the property of coil by virtue of which it opposes any change in the current flowing through it by inducing emf in itself. (Also called inertia of electricity.)

Coefficient of self-induction(L) - At any instant, $\emptyset \propto I$ => $\emptyset = L I$

As $\in = \frac{d\emptyset}{dt}$ (In mag.) => $\in = L\frac{dI}{dt}$

If $\frac{dI}{dt} = 1$ amp/sec then $\in = L$ =>

Definition - The self-inductance of coil is defined as emf induced in the coil due to unit rate of change of current in the same coil.

Self-inductance of a long solenoid (L) $= \frac{\mu_0 (n\,l)^2 A}{l} = \mu_0 n^2 l$

If solenoid is filled with a material of relative permeability μ_r then $L = \mu_r \mu_0 n^2 l A$

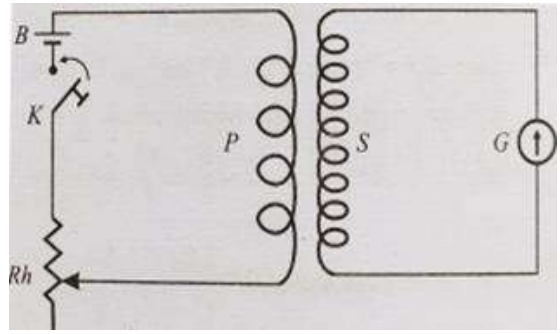
$\mu_m n^2 A l$ (As $\mu_r = \frac{\mu_m}{\mu_0}$)

Factors on which self-inductance depends - 1] Number of turns

2] Area of cross section, 3] Permeability of core material

Mutual induction - Mutual induction is the phenomenon of production of induced emf in one coil due to change of current is the neighbouring coil.

Coefficient of mutual induction(M) –



At any instant,

$$\phi \propto I_P$$

$$\Rightarrow \phi = M I_P$$

As $\in = \frac{d\phi}{dt}$ (In mag.) => $\in = M \frac{dI_P}{dt}$

If $\frac{dI_P}{dt}$ = 1 amp/sec

then $\in = M$

Definition- Mutual inductance between primary and secondary coil is defined as the emf induced in secondary coil due to unit rate of change of current in primary coil.

Mutual inductance between two long solenoids of same length (M): -

$$M = \mu_0 n_1 n_2 A l$$

If solenoid is filled with a material of relative permeability μ_r then

$$M = \mu_r \mu_0 n_1 n_2 A l$$

$$= \mu_m n_1 n_2 A l$$

Factor on which mutual inductance depends –

1] Number of turns

2] Common cross-sectional area

3] Relative separation.

4] Relative orientation of two coil.

5] Permeability of core material

FORMULAE

Magnetic flux $\emptyset = AB\cos\theta = \overline{A}\,.\,\overline{B}$

Induced emf $\in = -N\frac{d\emptyset}{dt} = -N\frac{\emptyset_2 - \emptyset_1}{t}$

Induced across the ends of conductor moving in a perpendicular magnetic field

$\in = Blv$

Induced current, $I = \frac{\in}{R} = \frac{Blv}{R}$

External force required, $F = \frac{B^2l^2v}{R}$

Power supplied by external force $P = \frac{B^2\,l^2\,v^2}{R}$

Power dissipated as joule heating heat, $P = I^2R = \frac{B^2\,l^2\,v^2}{R}$

Induce emf in a conducting rod rotated in a uniform magnetic field

$$\in = \frac{1}{2}\,B\,R^2\omega$$

Self-inductance of a long solenoid $L = \mu_0 n^2\, l\, A$

If solenoid is filled with a material of relative permeability μ_r then

$$L = \mu_r\mu_0 n^2\, l\, A \qquad = \mu_m n^2\, A\, l$$

Mutual inductance between two long solenoids of same length $M = \mu_0\, n_1\, n_2 A\, l$

If solenoid is filled with a material of relative permeability μ_r then

$$M = \mu_r\,\mu_0\,n_1\,n_2\,A\,l \qquad = \mu_m\,n_1\,n_2\,A\,l$$

Unit IV: Electromagnetic Induction and Alternating Currents

CHAPTER–7: ALTERNATING CURRENT

GIST OF CHAPTER:

Alternating currents, peak and RMS value of alternating current/voltage; reactance and impedance; LCR series circuit (phasors only), resonance, power in AC circuits, power factor, wattles current. AC generator, Transformer.

CONTENT/ CONCEPTS-

AC VOLTAGE AND AC CURRENT: -The voltage and current whose magnitude changes continuously and polarity / direction reverses periodically is called alternating voltage and alternating current.

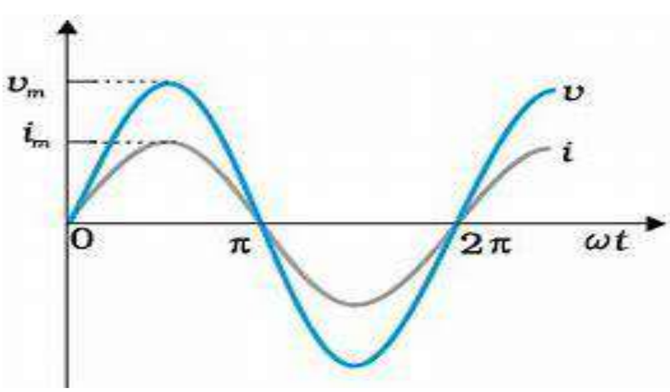
DC source supplies steady unidirectional current and controlled by ohmic resistances. Apart from ohmic resistance AC can also be controlled by inductors and capacitors.

AC is preferred over DC mainly because of the following reasons-

(a) Long distance transmission of electrical energy in the form of AC is economical.
(b) AC voltage can step or step down easily with the help of transformers.

ALTERNATING CURRENT	ALTERNATING VOLTAGE
$I = I_m \sin \omega t$	$V = V_m \sin \omega t$
I→instantanious value of current I_m →Peak value of current ω→ angular freq. rad/s ϕ→ phase angle, it gives information about the variation of alternating current with respect to the alternating voltage.	V →instantanious value of voltage V_m →Peak value of voltage ω → angular freq. rad/s

VARIATION OF AC VOLTAGE AND AC CURRENT WITH TIME: -



<u>Average or mean value of AC over a cycle</u>: - In 1 cycle of an AC it has positive values in the first half of a cycle and equal negative values in the second half of a cycle. Average becomes zero over a cycle. Hence, Average value is measured over half of a cycle and its value is $\boldsymbol{I_{av}}=\frac{\boldsymbol{2I_0}}{\boldsymbol{\pi}}$.

To measure the alternating voltage or current heating effect of current is used which is independent of the direction, that value is called as R.M.S or Effective or Virtual value.

<u>R.M.S or Effective or Virtual value</u>: - R.M.S value of A.C is defined as the D.C equivalent which produces the same amount of heat energy in same time as that of an A.C when passed through the same resistor.

Relation between R.M.S. value and peak value is

$$I_{rms} = \frac{I_m}{\sqrt{2}} \;\; and \; V_{rms} = \frac{V_m}{\sqrt{2}}$$

<u>AC VOLTAGE APPLIED TO A RESISTOR</u>

Consider an A.C voltage,

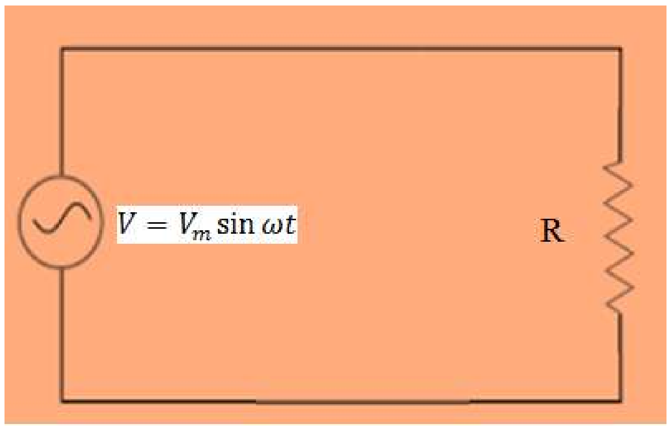
$V = V_m \sin \omega t$.................. (1)

Divide both the side of the equation by R ,

$\Rightarrow \; \frac{V}{R} = \frac{V_m}{R} \sin \omega t$

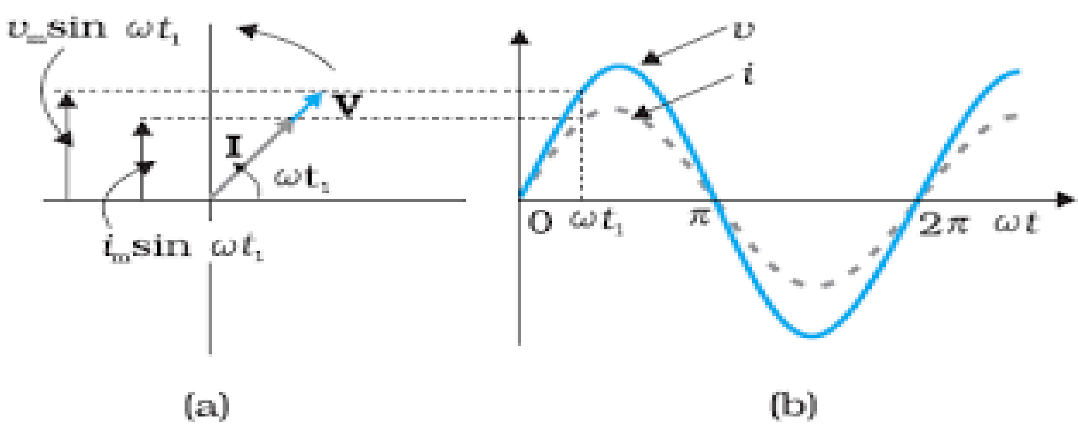
$\Rightarrow I = I_m \sin \omega t$ .... (2)

$where \; I_m = \frac{V_m}{R}$

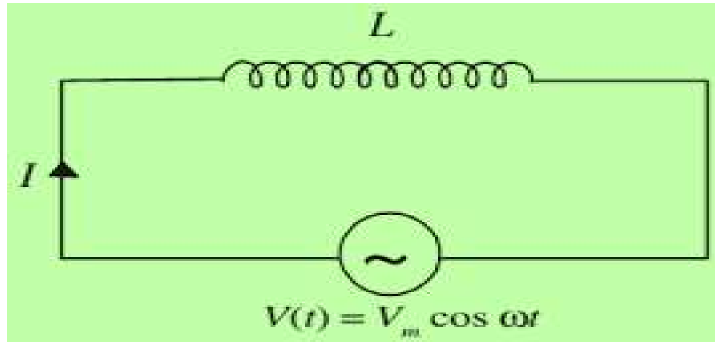


From equation (1) and (2) we can see that both the **voltage and current are in phase** with each other.

Phasor Diagram for pure resistive circuit: -



AC VOLTAGE APPLIED TO AN INDUCTOR: -



Consider an A.C voltage,

$V = V_m \sin \omega t$.................. (1)

Using the Kirchhoff's loop rule,

$$\Rightarrow V - L\frac{dI}{dt} = 0$$

$$\Rightarrow V_m \sin \omega t - L\frac{dI}{dt} = 0$$

$$\Rightarrow \int dI = \frac{V_m}{L}\int \sin \omega t \, dt \Rightarrow I = \frac{V_m}{\omega L}\,(-\cos \omega t)$$

$$\Rightarrow I = \frac{V_m}{\omega L}\sin(\omega t - \frac{\pi}{2}) = I_m \sin(\omega t - \frac{\pi}{2}) \qquad where\ I_m = \frac{V_m}{\omega L}$$

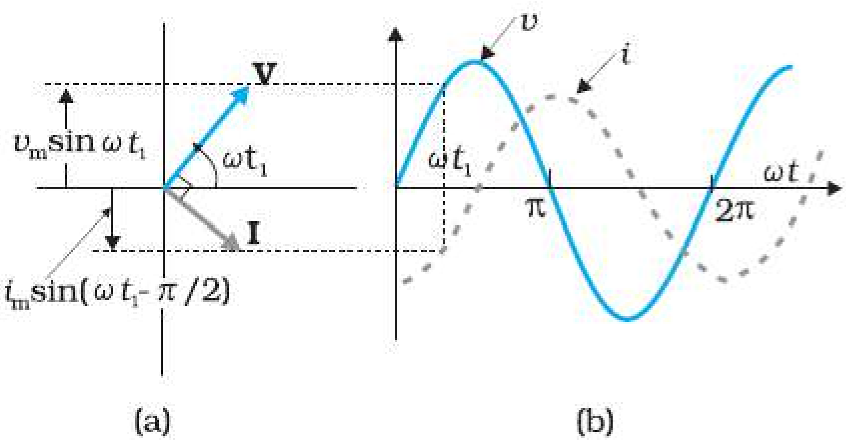
Thus, a comparison of equations for the source voltage and the current in an inductor shows that the current lags the voltage by π/2 or one-quarter (1/4) cycle. Now,

$$I = I_m \qquad when\ \sin(\omega t - \frac{\pi}{2}) = 1$$

$$\Rightarrow \boxed{i_m = \frac{v_m}{X_L}}$$

- $X_L = \omega L$ it is called as inductive reactance. This is the resistance offered by the inductor to an ac through it. It offers no resistance to a dc current.

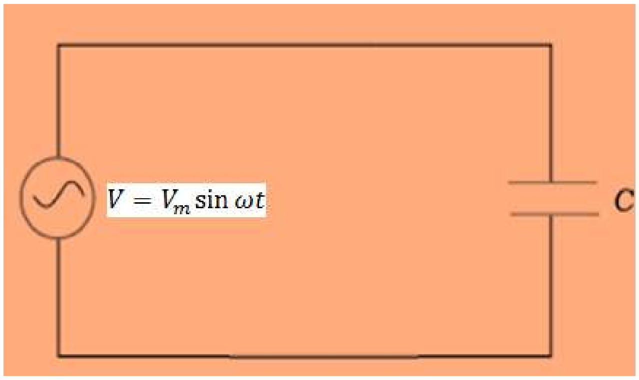
Phasor Diagram for pure inductive circuit:



AC VOLTAGE APPLIED TO A CAPACITOR

Consider an A.C voltage,

$V = V_m \sin \omega t$………………. (1)



The instantaneous voltage V across the capacitor is

$$V = \frac{q}{C} ---------- (2)$$

From (1) and (2) we get

$$V_m \sin \omega t = \frac{q}{C}$$

If I is the instantaneous current flowing through the capacitor,

$$I = \frac{dq}{dt} = \frac{d(CV_m sin\omega t)}{dt} = CV_m\omega \ \cos \omega t = \frac{V_m}{\frac{1}{\omega C}} \sin\left(\omega t + \frac{\pi}{2}\right)$$

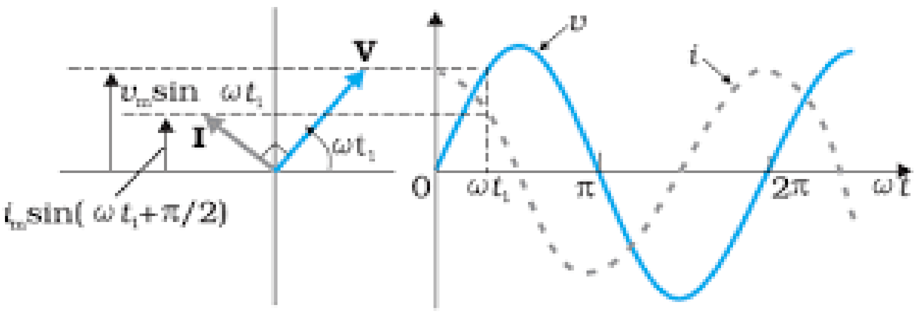
$$I = I_m \ \sin(\omega t + \frac{\pi}{2}) \qquad \qquad where\ I_m = \frac{V_m}{1/\omega C}$$

$$I = I_m \qquad \qquad when\ \sin(\omega t + \frac{\pi}{2}) = 1$$

In an ac circuit containing capacitor current leads the voltage by π/2 or voltage lags the current by π/2.

$X_C = \frac{1}{\omega C}$ = Capacitive reactance, This is the resistance offered by the capacitor to an AC through it it offers infinite resistance to dc current.

Phasor Diagram for pure capacitive circuit:-



Phasor diagram Graph of v vs ωt

For a purely capacitive circuit

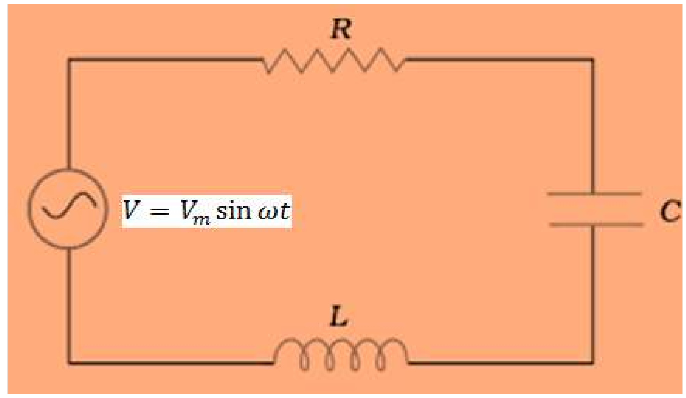
Series R-L-C circuit

Consider an A.C voltage,

$V = V_m \sin \omega t$.................. (1)

The resistor, inductor and capacitor are in series.

Therefore, **the ac current in each element is the same at any time**, having the same amplitude and phase.



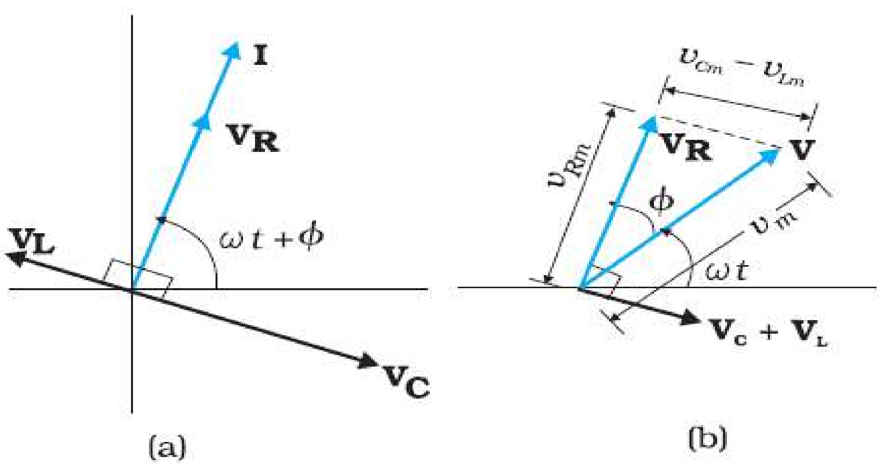
Let it be $I = I_m \sin(\omega t + \varphi)$ where φ is the phase difference between the voltage across the source and the current in the circuit.

(i) Maximum voltage across R $\Rightarrow V_R = I_m R$, In the resistive circuit voltage and current are in the same phase.

(ii) Maximum voltage across inductor $\Rightarrow V_L = I_m X_L$, In the inductive circuit current lags the voltage or voltage leads the current by π/2.

(iii) Maximum voltage across inductor $\Rightarrow V_C = I_m X_C$, In the capacitive circuit current leads the voltage or voltage lags the current by π/2.

Phasor Diagram for L C R circuit: -



From above figure (a) **I** represent the current in each element and $\mathbf{V_R}$, $\mathbf{V_L}$ **and** $\mathbf{V_C}$ represent the voltage phasors. $\mathbf{V_L}$ **and** $\mathbf{V_C}$ act along the same line but are in opposite directions.

$\mathbf{V_R}$ is along **I,** The difference phasor $(\mathbf{V_L}+\mathbf{V_C})$ is perpendicular to the $\mathbf{V_R}$.

$Here, |\boldsymbol{V_L} + \boldsymbol{V_C}| = (V_C - V_L)$

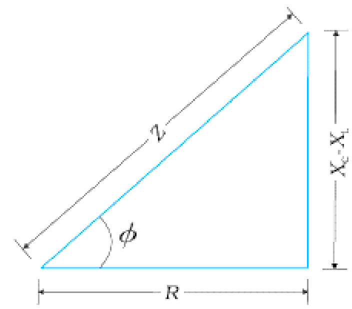
The Resultant Potential is given by $\boldsymbol{V} = \boldsymbol{V_R} + \boldsymbol{V_C} + \boldsymbol{V_L}$

Magnitude of Resultant Potential is given by

$$V_m = |\boldsymbol{V}| = \sqrt{{V_R}^2 + (V_C - V_L)^2}$$

$$V_m = \sqrt{(I_m R)^2 + (I_m X_C - I_m X_L)^2} = I_m \sqrt{(R)^2 + (X_C - X_L)^2}$$

$$Z = \frac{V_m}{I_m} = \sqrt{(R)^2 + (X_C - X_L)^2}$$



IMPEDANCE TRAINGLE

This is an effective resistance in series RLC circuit called the **Impedance Z.**

$$From\ figure, \qquad \tan\varphi = \frac{X_L - X_C}{R}$$

The impedance triangle for a series RLC circuit,

(i) If $X_L > X_C$ *then* $X_L - X_C$ is positive means voltage leads the current by phase angle of φ.

(ii) If $X_L < X_C$ *then* $X_L - X_C$= negative means voltage lags the current by phase angle of φ.

(iii) If $X_L = X_C$ *then* $X_L - X_C = 0$, means voltage is in the same phase with current and φ= 0.

Resonance: -

Resonance is said to be occur at this stage and the circuit becomes purely resistive. When $X_L = X_C$, current has its maximum value and impedance has minimum value.

Maximum current at resonance

$$I_{max} = \frac{Z}{R}$$

Minimum impedance at resonance

$$Z_{min} = R$$

If frequency ω is varied, then at a particular frequency ω_0 , $X_L = X_C$ this is called **resonant frequency**.

$$\Rightarrow X_L = X_C \Rightarrow \frac{1}{\omega_0 C} = \omega_0 L \Rightarrow \omega_0 = \frac{1}{\sqrt{LC}}$$

$$\nu_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi\sqrt{LC}}$$

When $\nu_0 =$ natural frequency of the series LCR circuit becomes equal to frequency of AC source and current becomes the maximum then the phenomenon is called **Resonance**.

POWER IN AC CIRCUIT: THE POWER FACTOR

An A.C voltage, $V = V_m \sin \omega t$ applied to a series LCR circuit drives a current in the circuit given by $I = I_m \sin(\omega t + \varphi)$.

Instantaneous Power = Instantaneous Current x Instantaneous voltage, as voltage and current changes continuously in an ac circuit.

$$P = VI = V_m \sin \omega t \text{ X } I_m \sin(\omega t + \varphi)$$

$$Average\ power\ over\ the\ complete\ cycle = P_{av} = \frac{V_m\, I_m}{2} \cos \varphi = V_{rms}\, I_{rms}\, \cos \varphi$$

True power = apparent power or virtual power X cos ϕ

Power Factor = cos $\boldsymbol{\varphi} = \boldsymbol{\frac{R}{Z}}$ = True power / Apparent power

(1) If ϕ =0°, cos 0°=1 $\Rightarrow Z = R$, means circuit consists of pure resistance.

(2) If ϕ =90°, cos 90°=0, $\Rightarrow 0 = R \Rightarrow Z = X_L - X_C$ means circuit consists of pure inductance or capacitance or their combination in series.

(3) The average power consumed over a cycle is zero and current is called **wattless current**.

(4) If circuit has all the three elements R, L and C then

Power Factor = cos $\varphi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + (X_L - X_C)^2}}$.

From this we get the information that power spent in the circuit depends upon the power factor.

Transformer

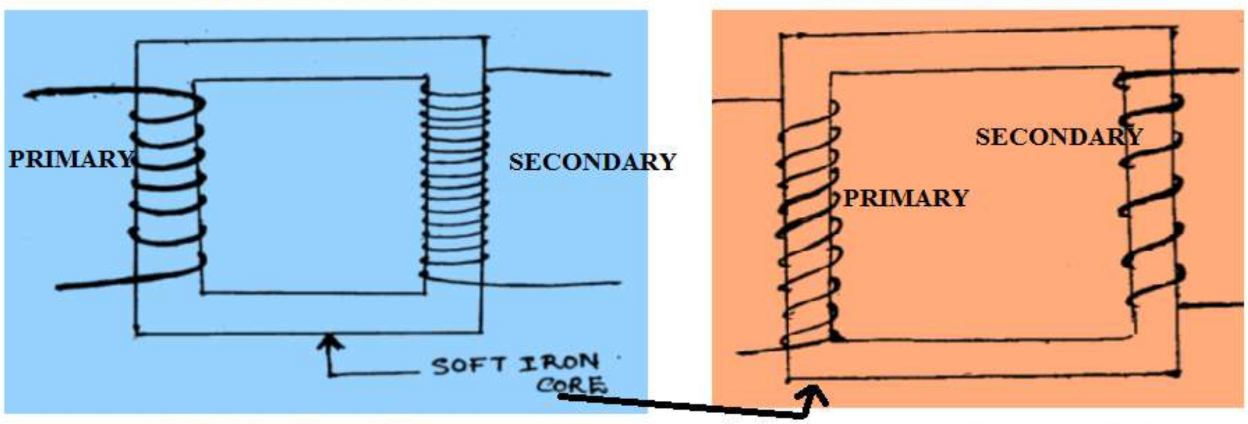
Transformer is a device used to increase or decrease A.C. voltage

Principal: - Transformer works on the principle of mutual induction.

Construction: -

When a.c. flows through the primary coil, a changing magnetic field is produced around it. The secondary coil is placed in this changing magnetic field and hence an e.m.f. is induced across the secondary coil.

Step Up Transformer **Step Down Transformer**



Ns>Np, Vs>Vp and **is<ip** **Ns<Np, Vs<Vp and is>ip**

Let **Np** and **Ns** be the number of turns in the primary and secondary of the transformer. The voltage induced in the secondary, when **AC** flows through the primary is given by

Vs = Ns$\frac{d\phi}{dt}$………. (1)

At the same time, due to self-induction, the back e.m.f. produced in the primary is

Vp = Np$\frac{d\phi}{dt}$……… (2)

Dividing equation (1) by (2)

$$\frac{Vs}{Vp} = \frac{N_S}{N_P} = \frac{I_P}{I_S} = k$$

Efficiency of transformer,

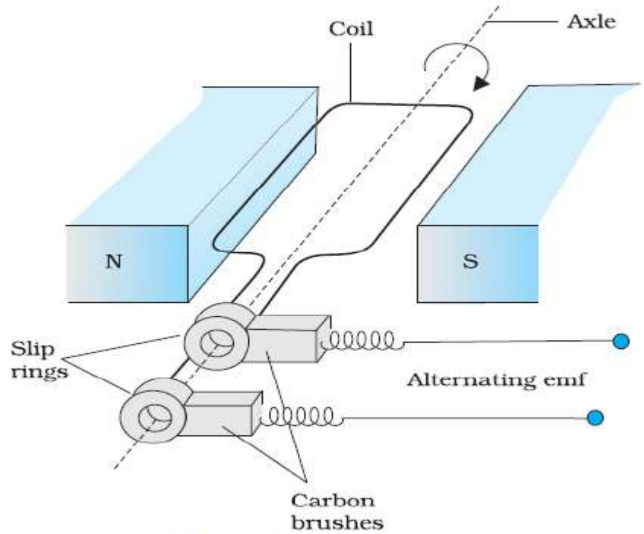
$$\eta = \frac{\text{output power}}{\text{input power}} X100\%$$

A.C. Generator

It is a device which convert mechanical energy in to an electric energy and generates alternating current.

Principle

A.C. generator works on the principle of electro-magnetic induction.



A C GENERATOR

Construction: -

1.Armature coil
2.field magnet
3.slip ring
4.Brushes

Theory: -

When the armature coil rotates between the pole pieces of field magnet,

The effective area of the coil is A cos θ,

The flux at any time is $\phi = \vec{B}.\vec{A}$ = NBA cos θ

where θ is the angle between Area vector $\vec{A}$ and magnetic field $\vec{B}$.

Since, coil is being rotated about its axis to change the flux ϕ at rate ω rad per sec.

ϕ= NBA cos ωt

Where ω is the angular frequency of the coil.

The induced e.m.f.

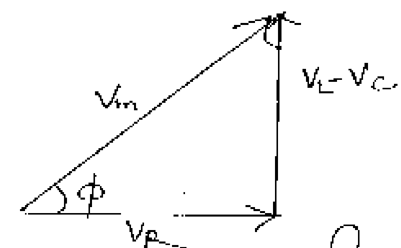
$$\varepsilon = -\frac{d\phi}{dt} = -N\frac{d(BA\ \cos\omega t)}{dt} = -NBA\omega\sin\omega t$$

$$Magnitude\ of\ induced\ EMF \quad V = \varepsilon = NBA\omega\sin\omega t$$

V_{max} = NABω = V_0 (numerically), which is the maximum value of induced emf.

Formulae: -

1. $v = v_m \sin\omega t = v_m \sin 2\pi\nu t$ and $i = i_m \sin 2\pi\nu t$ where, i and v are the instantaneous values and i_m and v_m are the peak values.
2. $i_{rms} = \frac{I_m}{\sqrt{2}}$ rms, virtual or effective values of ac current.
3. $v_{rms} = \frac{V_m}{\sqrt{2}}$ rms, virtual or effective values of ac voltage.



Phasor Diagram for Series RLC circuit.

4. $X_L = \omega L$ inductive reactance. Unit: - ohm Ω
5. $X_C = \frac{1}{\omega C}$ Capacitive reactance. Unit: - ohm Ω
6. In an ac circuit containing inductor current lags or voltage leads by $\pi/2$.
7. In an ac circuit containing capacitor current leads or voltage lags by $\pi/2$.
8. $Z = \sqrt{R^2 + (X_L - X_C)^2}$ Impedance of series RLC circuit. Unit: - ohm Ω.
9. $\tan\phi = \frac{X_L - X_C}{R}$ where ϕ is the phase angle between current and voltage.
10. $P_{av} = v_{rms}\, i_{rms} \cos\phi$
11. Unit: - W (watt)
12. $P_{av} = i_{rms}^2 R$ ……. equation obtained from above phasor diagram.
13. Power factor = $\cos\phi = \frac{R}{Z}$, in case of an ideal capacitor or a capacitor $\phi = 90°$ and $P_{av} = 0$
14. $i_m \sin\phi$ = wattless component of current.

Unit V: Electromagnetic waves

Chapter–8: Electromagnetic Waves

GIST OF CHAPTER:

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

CONTENT/ CONCEPTS-

Basic idea of displacement current

Conduction Current (i_c)- Conduction current is the current, which arises due to flow of electrons through the connecting wires in an electric circuit.

Displacement current (i_d)-Displacement current is the current, which arises due to time rate of change of electric flux (ϕ_E).

Flaw in Ampere's circuital law

When a capacitor is charged or a charged capacitor is allowed to discharge,

To find the magnetic field at a point such as P, in a region outside the parallel plate capacitor using **Ampere's circuital law**.

(I) If a plane circular loop of radius *r* whose plane is perpendicular to the direction of the current-carrying wire, and which is centred symmetrically with respect to the wire. Then magnetic field at point P is given by

$$B(2\pi r) = \mu_0 i_{passing\ through\ the\ surface} \Rightarrow B = \frac{\mu_0 i}{2\pi r}$$

(II) If a different surface, which has the same boundary which is a pot like surface has its bottom between the capacitor plates which nowhere touches the current. Hence current passing through surface =0.
Then magnetic field at point P is given by

$$B(2\pi r) = \mu_0 i_{passing\ through\ the\ surface} \Rightarrow B = \frac{\mu_0\ X0}{2\pi r} = 0$$

So we have a *contradiction*; calculated one way, there is a magnetic field at a point P; calculated another way, the magnetic field at P is zero.

Maxwell's correction in Ampere's circuital law

The second surface has a surface S between the capacitor plates. If the plates of the capacitor have an area A, and a total charge Q, the magnitude of the electric field E between the plates is

$$E = \frac{Q}{\varepsilon_0 A}$$

The field is perpendicular to the surface S. It has the same magnitude over the area A of the capacitor plates, and vanishes outside it.
The electric flux through the surface S Using Gauss's law,

$$\phi_E = EA = \frac{Q}{\varepsilon_0} \Rightarrow Q = \varepsilon_0 \phi_E \Rightarrow \frac{dQ}{dt} = \varepsilon_0 \frac{d\phi_E}{dt}$$

Here $\frac{dQ}{dt} = \varepsilon_0 \frac{d\phi_E}{dt} = i_d$ is called **Displacement current**.

The displacement current between plates of capacitor is always equal to the conduction current in wire.

i_c= Conduction current(flows in conducting wire)

i_d = Displacement current (between plates of capacitor).

Hence ,the Ampere's circuital law is modified.

Modified Ampere's circuital law states that the line integral of magnetic field B over a closed boundary of an open surface is equal to μ_o, times the sum of the conduction current (Ic) and the displacement current (I_d) threading the surface. Mathematically-

$\oint \boldsymbol{B}.\boldsymbol{dl}= \mu_o (I_C + \epsilon_o d\phi_B dt)$

It is also known as **Ampere-Maxwell's circuital law.**

Maxwell's Equations:- Following four equations, which describe the laws of electromagnetism, are called Maxwell's equations

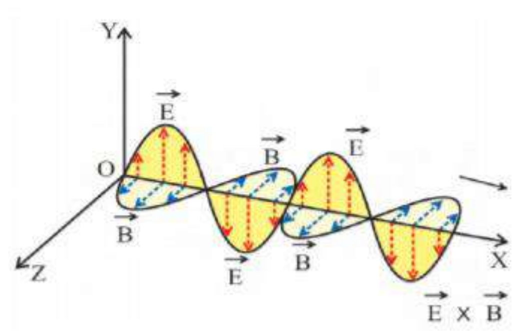
(i) $\oint \boldsymbol{E} .\boldsymbol{dS}= q/\in_o$ (Gauss's law in electrostatics)
(ii) $\oint \boldsymbol{B}.\boldsymbol{dS} =0$ (Gauss's law in magnetism)
(iii) $\oint \boldsymbol{E}.\boldsymbol{dl} = - d\phi_B/dt$ (Faraday's law of electromagnetic induction)
(iv) $\oint \boldsymbol{E}.\boldsymbol{dl} = \mu_o(I_c+I_d)$((Ampere-Maxwell's circuital law)

Source of electromagnetic waves-

Electromagnetic waves are produced due to oscillating or accelerating charge.

Characteristics of Electromagnetic Waves

1.The **electric (E)** and **magnetic fields (B)** varying sinusoidally in space and time and propagating through space, such that the two fields are perpendicular to each other and perpendicular to the direction of propagation, constitute electromagnetic waves.



2. The direction of propagation of an electromagnetic wave is given by the cross product of electric field and magnetic field vectors

3. The electromagnetic waves are transverse in nature.

4.The velocity of electromagnetic waves in free space is given by c = $1/\sqrt{\mu_o \epsilon_o}$ = 3 x 10^8m/s In a material medium, velocity of electromagnetic waves is given by v = $\mathbf{1}/\sqrt{\boldsymbol{\mu}\epsilon}$

5. The ratio of the amplitudes of electric and magnetic fields is constant and it is equal to velocity of the electromagnetic waves in free space. Mathematically- $\boldsymbol{E_O}/\boldsymbol{B_O}$ = c

6. The energy in electromagnetic waves is divided equally between the electric and magnetic field vectors

7. The electric vector of an electromagnetic wave is responsible for its optical effect. For this reason, the electric vector is also called light vector. The energy transported by electromagnetic waves is given by U = hν = $\boldsymbol{hc}/\boldsymbol{\lambda}$ where U is energy transported by electromagnetic waves in a given time and c is speed of electromagnetic waves in free space

8. The momentum transported by electromagnetic waves is given by p= $\boldsymbol{U}/\boldsymbol{c}$ = $\boldsymbol{h\nu}/\boldsymbol{c}$ = $\boldsymbol{h}/\boldsymbol{\lambda}$.

9. The intensity of electromagnetic waves i.e. energy crossing per second per unit area of a surface normally is given by I = $\mathbf{1}/\mathbf{2}\epsilon_{\boldsymbol{o}}\boldsymbol{E_o}^{\mathbf{2}}$

10. When electromagnetic waves strike a surface, they exert pressure on the surface.

11. The orderly distribution of electromagnetic waves (according to wavelength or frequency) in the form of distinct groups, having widely differing properties, is called electromagnetic spectrum.

12. The main parts of electromagnetic spectrum are namely- **$\boldsymbol{\gamma}$-rays, X-rays, ultra-violet rays, visible light, infrared rays, microwaves and radio waves.**

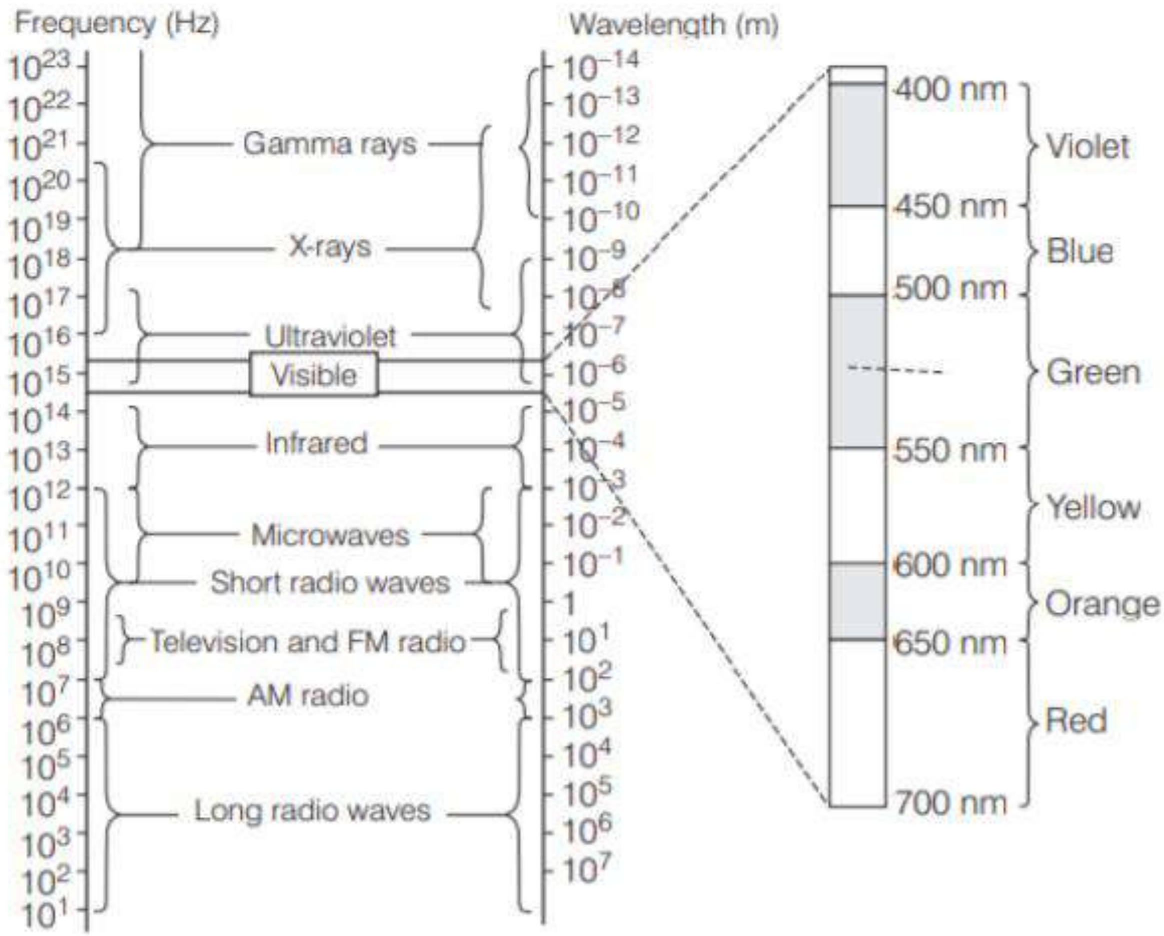
13. The frequency of electromagnetic waves is its inherent characteristic. When an electromagnetic wave travels from one medium to another, its wavelength changes but frequency remains unchanged.

14. All the types of electromagnetic waves travel with the same speed in free space.

15. The orderly arrangement of EM waves in increasing or decreasing order of wavelength and frequency is called electromagnetic spectrum.

Electromagnetic wave spectrum

Electromagnetic wave spectrum is shown below



[Hint to remember EMW – Rahul's Mother Is Visiting Uncle Xavior Garden.]

Elementary facts about the Uses of Electromagnetic waves

Radio waves - Radio waves are produced by the accelerated motion of charges in conducting wires. They are used in radio and television communication systems. They are generally in the frequency range from 500kHz to about 1000MHz. The AM (amplitude modulated) band is from 530kHz to 1710kHz. Higher frequencies upto 54MHz are used for short wave bands. TV waves range from 54MHz to 890MHz. The FM (frequency modulated) radio band extends from 88MHz to 108MHz. Cellular phones use radio waves to transmit voice communication in the ultrahigh frequency (UHF) band.

Microwaves-Microwaves (short-wavelength radio waves), with frequencies in the gigahertz (GHz) range, are produced by special vacuum tubes (called klystrons, magnetrons and Gunn diodes). Due to their short wavelengths, they are suitable for the radar systems used in aircraft navigation. Radar also provides the basis for the speed guns used to time fast balls, tennisserves, and automobiles. Microwave ovens are an interesting domestic application of these waves. In such ovens, the frequency of the microwaves is selected to match the resonant frequency of water molecules so that energy from the waves is transferred efficiently to the kinetic energy of the molecules. This raises the temperature of any food containing water.

Infrared waves-Infrared waves are produced by hot bodies and molecules. This band lies adjacent to the low-frequency or long-wave length end of the visible spectrum. Infrared waves are sometimes referred to as heat waves. This is because water molecules present in most materials readily absorb infrared waves (many other molecules, for example, CO_2 , NH_3 , also absorb infrared waves). After absorption, their thermal motion increases, that is, they heat up and heat their surroundings. Infrared lamps are used in physical therapy. Infrared radiation also plays an important role in maintaining the earth's warmth or average temperature through the greenhouse effect. Incoming visible light (which passes relatively easily through the atmosphere) is absorbed by the earth's surface and reradiated as infrared (longer wavelength) radiations. This radiation is trapped by greenhouse gases such as carbon dioxide and water vapour. Infrared detectors are used in Earth satellites, both for military purposes and to observe growth of crops. Electronic devices (for example semiconductor light emitting diodes) also emit infrared and are widely used in the remote switches of household electronic systems such as TV sets, video recorders and hi-fi systems

Visible rays-It is the most familiar form of electromagnetic waves. It is the part of the spectrum that is detected by the human eye. It runs from about 4×10^{14} Hz to about 7×10^{14} Hz or a wavelength range of about 700 –400 nm. Visible light emitted or reflected from objects around us provides us information about the world. Our eyes are sensitive to this range of wavelengths. Different animals are sensitive to different range of wavelengths. For example, snakes can detect infrared waves, and the 'visible' range of many insects extends well into the ultraviolet.

Ultraviolet rays-It covers wavelengths ranging from about 4 × 10–7 m (400 nm) down to 6 × 10–10m (0.6 nm). Ultraviolet (UV) radiation is produced by special lamps and very hot bodies.

The sun is an important source of ultraviolet light. But fortunately, most of it is absorbed in the ozone layer in the atmosphere at an altitude of about 40 – 50 km. UV light in large quantities has harmful effects on humans. Exposure to UV radiation induces the production of more melanin, causing tanning of the skin. UV radiation is absorbed by ordinary glass. Hence, one cannot get tanned or sunburn through glass windows. Welders wear special glass goggles or face masks with glass windows to protect their eyes from large amount of UV produced by welding arcs. Due to its shorter wavelengths, UV radiations can be focussed into very narrow beams for high precision applications such as LASIK (Laser assisted in situ keratomileusis) eye surgery. UV lamps are used to kill germs in water purifiers. Ozone layer in the atmosphere plays a protective role, and hence its depletion by chlorofluorocarbons (CFCs) gas (such as freon) is a matter of international concern.

X-rays -Beyond the UV region of the electromagnetic spectrum lies the X-ray region. We are familiar with X-rays because of its medical applications. It covers wavelengths from about 10^{-8} m (10 nm) down to 10^{-13} m (10^{-4} nm). One common way to generate X-rays is to bombard a metal target by high energy electrons. X-rays are used as a diagnostic tool in medicine and as a treatment for certain forms of cancer. Because X-rays damage or destroy living tissues and organisms, care must be taken to avoid unnecessary or over exposure.

Gamma rays -They lie in the upper frequency range of the electromagnetic spectrum and have wavelengths of range from about 10^{-10}m to less than 10^{-14}m. This high frequency radiation is produced in nuclear reactions and also emitted by radioactive nuclei. They are used in medicine to destroy cancer cells. As mentioned earlier, the demarcation between different region is not sharp and there are over laps.

Type	Wavelength range	Production	Applications
Radio	**>0.1 m**	**Rapid acceleration and decelerations of electrons in aerials**	**In radio and T.V. communication system,Cellular phones**
Microwave	**0.1m to 1mm**	**Klystron, magnetron valve, Gun diode**	**In aircraft and satellite communication and to cook food (microwave oven)**
Infrared	**1mm to 700mm**	**Vibration of atoms and molecules**	**In Physiotherapy, green house, military purpose and in agriculture**

Visible	**700 nm to 400nm**	**Electrons in atoms emit light when the move from one energy level to a lower energy level**	**In fibre optic communications,photography.**
Ultraviolet	**400nm to 1nm**	**Inner shell electrons in atoms moving from one energy level to a lower level**	**In welding , eye surgery and to kill germs**
X-rays	**1nm to1pm**	**X-ray tubes or inner shell electrons of atom**	**To destroy living tissues and organisms,checking for bone fractures.**
Gamma rays	**<1pm**	**Radioactive decay of the nucleus**	**To destroy cancer cells**

Unit VI: Optics

Chapter–9: Ray Optics and Optical Instruments

GIST OF THE CHAPTER:

Ray Optics: Reflection of light, spherical mirrors, mirror formula, refraction of light, total internal reflection and optical fibers, refraction at spherical surfaces, lenses, thin lens formula, lens maker's formula, magnification, power of a lens, combination of thin lenses in contact, refraction of light through a prism.

Optical instruments: Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers.

CONTENT/ CONCEPTS-

Reflection

Reflection is the phenomenon of changing the path of light without any change in the medium.

Reflection of Light

The returning back of light in the same medium from which it has come after striking a surface is called reflection of light.

Laws of Reflection

Two laws of reflection are given as below:

(i) The angle of incidence i is equal to the angle of reflection r. i.e. $\angle i = \angle r$.

(ii) The incident ray, reflected ray and normal to the reflecting surface at the point of incidence all lie in the same plane.

A SPHERICAL MIRROR:

A spherical mirror whose reflecting surface is curved inwards, i.e. faces towards the centre of the mirror, is called a concave mirror

A spherical mirror whose reflecting surface is curved outwards, i.e. faces away from the centre of the mirror, and is called a convex mirror.

Pole (P) is the centre of reflecting surface lying on the surface.

Centre of curvature (C) is the centre of the imaginary sphere from which spherical mirror is cut out.

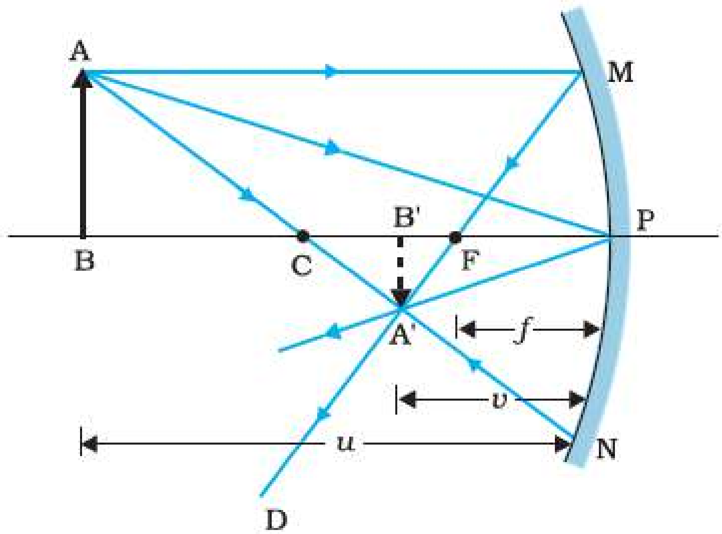
Radius of curvature (R) is the distance between the pole and the centre of curvature.

Principal axis (PCX or CPX) is the line passing through the pole and the centre of curvature and extending to ∞. It is the normal to the mirror at the pole.

<u>Principal Focus (F) i</u>s the point on the principal axis at which the incident rays of light parallel to principal axis either really pass through or appear to pass through after getting reflected from the mirror.

<u>Focal length (f)</u> is the distance between the pole and the principal focus.

MIRROR FORMULA



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

u – Object distance

v – Image distance

f – Focal length of the mirror

MAGNIFICATION PRODUCED BY A MIRROR

Magnification produced by a mirror is defined as the ratio of the size of the image to the size of the object.

Magnification produced by a mirror is also defined as the ratio of the image distance to object distance.

$$m = \frac{h'}{h} = -\frac{v}{u}$$

SIGN CONVENTIONS FOR REFLECTION BY SPHERICAL MIRRORS

1. The object is always placed to the left of the mirror. i.e. the incident rays from the object always move from left to right.

2. All distances parallel to the principal axis are measured from the pole (P) of the mirror.

3. All the distances measured to the right of the Pole (along +ve x-axis) are taken +ve while those measured to the left of the Pole (along - ve x-axis) are taken –ve.

4. Distances measured perpendicular to and above the principal axis (along +ve y-axis) are taken +ve while those measured below the principal axis (along –ve y-axis) are taken –ve.

TOTAL INTERNAL REFLECTION (TIR)

Total Internal Reflection is the phenomenon of complete reflection of light back into the same medium for angles of incidence greater than the critical angle of that medium.

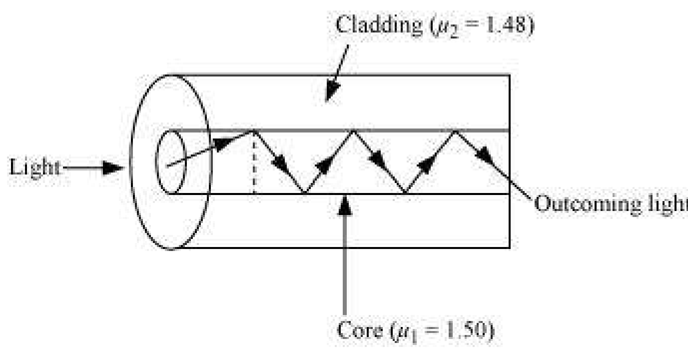
Conditions for TIR:

The incident ray must be in optically denser medium.

The angle of incidence in the denser medium must be greater than the critical angle for the pair of media in contact.

$$i > i_C \quad \textit{and refractive index } n = \frac{1}{\sin i_C}$$

OPTICAL FIBRE



Optical fibres consist of several thousands of very long fine quality fibres of glass or quartz.

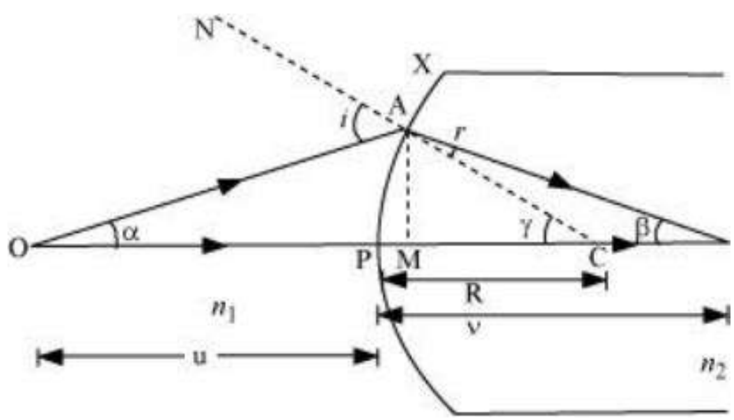
The diameter of each fibre is of the order of 10^{-4} cm with refractive index of material being of the order of 1.5.

The fibres are coated with a thin layer of material of lower refractive index of the order of 1.48.

Propagation of light through an optical fibre:

Light incident on one end of the fibre at a small angle passes inside and undergoes repeated total internal reflections inside the fibre. It finally comes out of the other end, even if the fibre is bent or twisted in any form.

REFRACTION THROUGH A SPERICAL SURFACE



Consider a point object *O* lying on the principal axis of the surface.

From A, draw AM ⊥ OI

Let **∠AOM = α, ∠AIM = β, ∠ACM = γ**

As external angle of a triangle is equal to sum of internal opposite angles,

Therefore, in ΔIAC, $r + \beta = \gamma \quad \Rightarrow r = \gamma - \beta \quad ----- (i)$

Similarly, in ΔOBC, $i = \alpha + \gamma \quad ---- (ii)$

According to Snell's law,

$$\frac{n_2}{n_1} = \frac{\sin i}{\sin r} \simeq \frac{i}{r} \qquad (2)$$

(∵ Angles are small) $\Rightarrow \boldsymbol{n_2 r = n_1 i}$

Using (i) & (ii), we obtain $\Rightarrow \boldsymbol{n_2(\gamma - \beta) = n_1(\alpha + \gamma)}$

As angle α, β, and γ are small, using $\tan\theta \approx \theta$, we obtain

$$\therefore n_1\left(\frac{AM}{MO} + \frac{AM}{MC}\right) = n_2\left(\frac{AM}{MC} - \frac{AM}{MI}\right) \qquad (3)$$

As aperture of the spherical surface is small, M is close to P.

Therefore using new Cartesian sign conventions MO ≈ PO = -u, MI ≈ $PI = +\boldsymbol{v}$, $MC \approx PC = R$

From (3),

$$\Rightarrow \boldsymbol{n_2\left(\frac{1}{PC} - \frac{1}{PI}\right) = n_1\left(\frac{1}{PO} - \frac{1}{PC}\right) \Rightarrow \frac{n_2}{PI} + \frac{n_1}{PO} = \frac{n_2 - n_1}{PC}}$$

Using new Cartesian sign conventions, we put

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

(i) Refraction from rarer to denser medium

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R} \qquad (n_2 > n_1)$$

(ii) Refraction from denser to rarer medium

$$\frac{n_1}{v} - \frac{n_2}{u} = \frac{n_1 - n_2}{R} \qquad (n_1 > n_2)$$

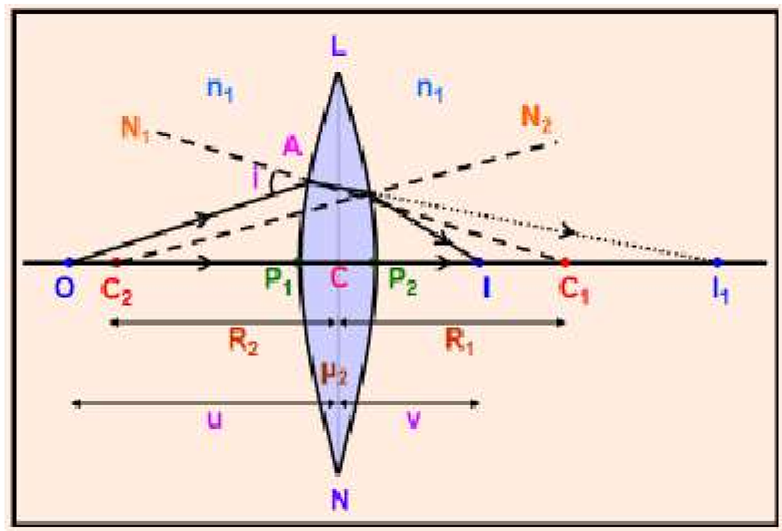
<u>Refraction by Spherical Lenses</u>

Lenses whose refracting surfaces are spherical are called 'spherical lenses'.

A spherical lens whose refracting surfaces are bulging outwards at the centre is called a 'double convex lens'. It is thicker in the middle compared to the edges.

A spherical lens whose refracting surfaces are curved inwards at the centre is called a 'double concave lens'. It is thinner in the middle compared to the edges.

LENS MAKER'S FORMULA



(i) Refraction from rarer to denser medium

$$\frac{n_2}{v_1} - \frac{n_1}{u} = \frac{n_2 - n_1}{R_1}$$

$$(n_2 > n_1)$$

(ii) Refraction from denser to rarer medium

$$\frac{n_1}{v} - \frac{n_2}{v_1} = \frac{n_1 - n_2}{R_2}$$

$$(n_1 > n_2)$$

Adding two equations

$$\frac{n_1}{v} - \frac{n_1}{u} = (n_2 - n_1)\left(\frac{1}{R1} - \frac{1}{R2}\right)$$

Taking $v = f \quad when\ u = \infty$

$$\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R1} - \frac{1}{R2}\right)$$

LENS FORMULA

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

LINEAR MAGNIFICATION

Linear magnification produced by a lens is defined as the ratio of the size of the image to the size of the object.

$$m = \frac{h'}{h} = \frac{v}{u}$$

POWER OF A LENS

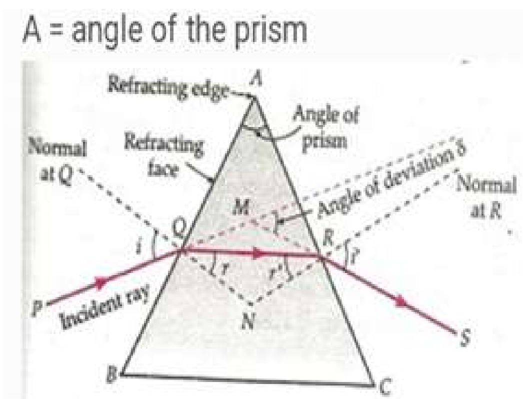
Power of a lens is its ability to bend a ray of light falling on it and is reciprocal of its focal length.

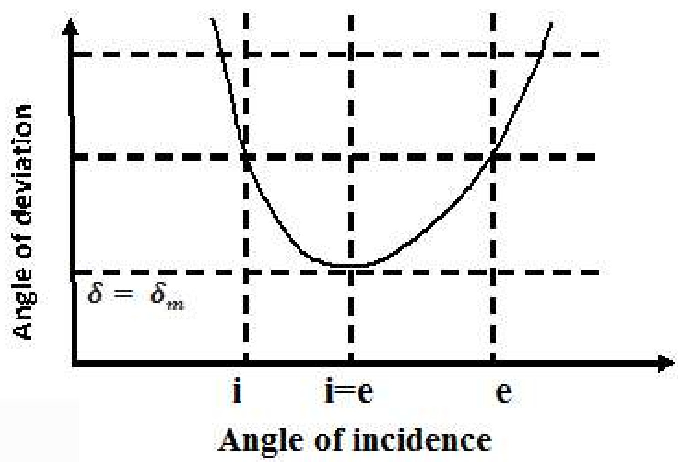
When f is in metre, power is measured in Dioptre (D).

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

REFRACTIVE INDEX OF THE MATERIAL OF A PRISM

Refraction by a Small-angled Prism for Small angle of Incidence:





In prism $\Rightarrow$ $r_1 + r_2 = A$ And The total deviation = $\delta = i + e - A$

In general, any given value of δ, corresponds to two values $\boldsymbol{i}$ and hence of $\boldsymbol{e}$. This is related to the fact that the path of ray can be traced back, resulting in the same angle of deviation.

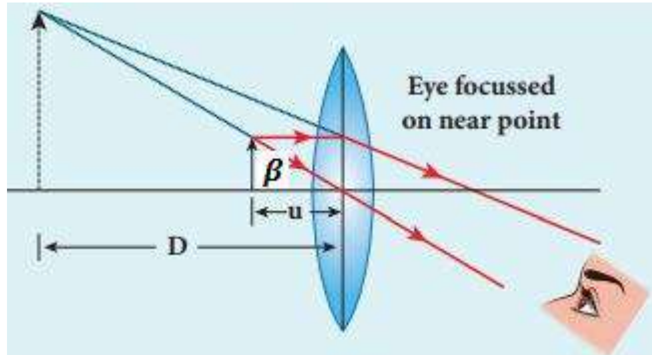
When $\boldsymbol{\delta = \delta_m}$, $\Rightarrow$ $i = e$ and $\Rightarrow$ $r_1 = r_2 = r\ (say) \Rightarrow r = \frac{A}{2}$

$and \Rightarrow$ $\boldsymbol{\delta_m} = 2i - A$ $\Rightarrow i = \dfrac{\boldsymbol{\delta_m + A}}{2}$

$PRISM\ FORMULA$ $$n = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$ $for\ thin\ prism$ $\delta_m = A(n-1)$

SIMPLE MICROSCOPE

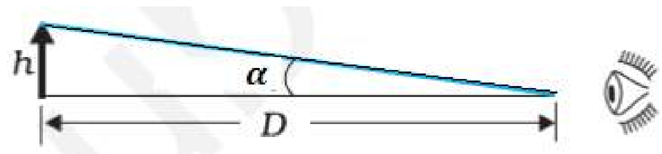
It is a convex lens of short focal length



Magnifying power (m): The magnifying power of a microscope is defined as the ratio of the angle β subtended by the image at the eye to the angle α subtended by the object seen directly, when both lie at the least distance of distinct vision.

$$m = \frac{\beta}{\alpha} = \frac{h/u}{h/D} = \frac{D}{u} = \frac{D}{v} + \frac{D}{f}$$

$(using\ lense\ formula\ with\ sign\ )$



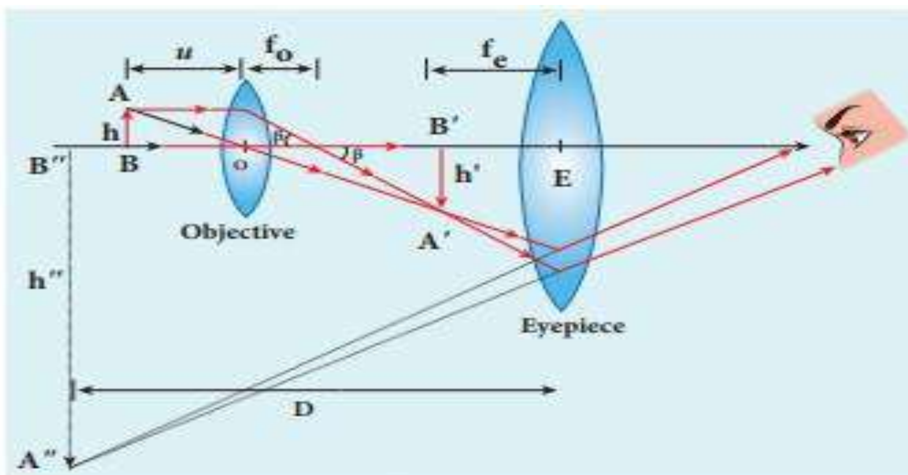
For image at near point $(v = D)$ $\quad m = 1 + \frac{D}{f}$

For image at far point $(v = \infty)$ $\quad m = \frac{D}{f}$

COMPOUND MICROSCOPE

Objective is a convex lens of short focal length and of small aperture .

Eye piece is a convex lens of slightly larger focal length of larger aperture.



Magnification of the compound microscope

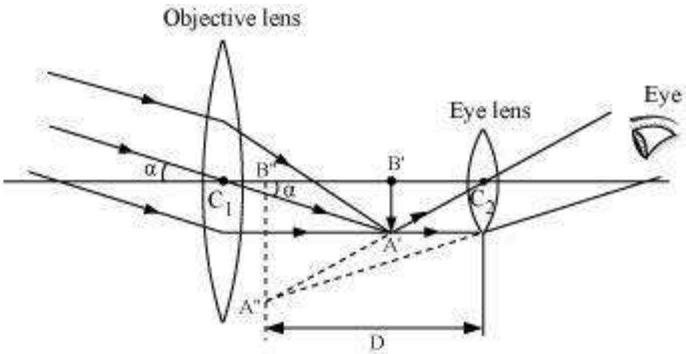
(a) when the final image is formed at the least distance of distinct vision is given by, $v_e = D$

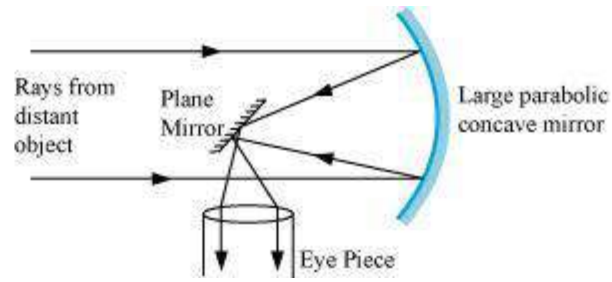
$$m = -\frac{L}{f_o} x \frac{D}{u_e} = m_o m_e = -\frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$$

(b) Magnification of the compound microscope when the final image is formed at the infinity is given by, $v_e = \infty$

$$m = m_o m_e = -\frac{v_0}{u_0}\left(\frac{D}{f_e}\right)$$

ASTRONOMICAL TELESCOPE





Magnifying power of telescope (m) The magnifying power of a telescope in normal adjustment is defined as the ratio of the angle subtended by the image at the eye / lens as seen through the telescope to the angle subtended by the object seen directly,

$$Magnifying\ Power\ m = \frac{\beta}{\alpha} = -\frac{AB/u_e}{AB/f_o} = -\frac{f_o}{u_e}$$

Magnification of the refracting telescope **Magnification of the refracting telescope**

(i) when the final image is formed at the infinity is given by

$$m = -\frac{f_o}{f_e}$$

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

(ii) when the final image is formed at the infinity is given by

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

Advantages of reflecting type telescope over a refracting type telescope

1. No chromatic aberration because mirror is used
2. Spherical aberration gets removed by using a paraboloid mirror
3. The image is bright ,because there is no loss of light due to reflection and absorption by objective
4. Higher resolution can be obtained by using a mirror of large aperture.
5. A mirror provides an easier mechanical support over its entire back surface.
6. It is difficult and expensive to make large sized lens free from chromatic aberrations and distortions

Unit VI: Optics

CHAPTER–10: WAVE OPTICS

GIST OF THE CHAPTER:-

Wave optics: Wave front and Huygen's principle, reflection and refraction of plane wave at a plane surface using wave fronts. Proof of laws of reflection and refraction using Huygen's principle. Interference, Young's double slit experiment and expression for fringe width (No derivation final expression only), coherent sources and sustained interference of light, diffraction due to a single slit, width of central maxima (qualitative treatment only).

DEFINITION & CONCEPTS:-

Wave Front: a wave front is defined as the continuous locus of all such particles of the medium which are vibrating in the same phase at any instant

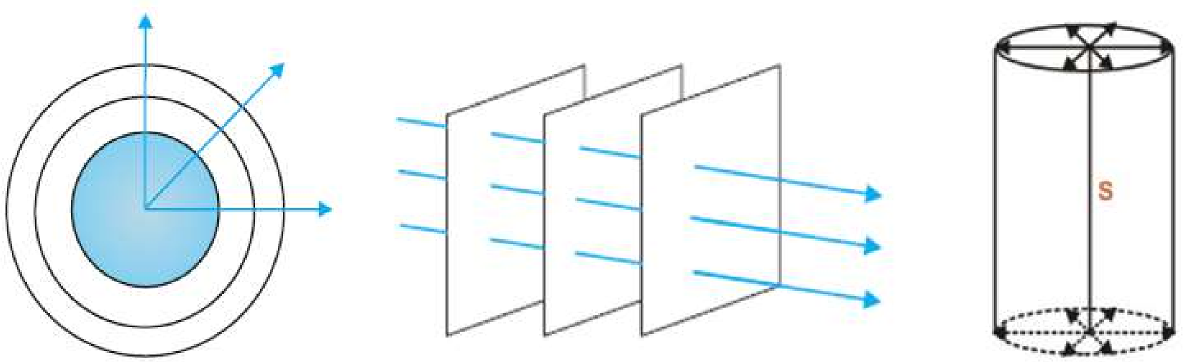
Ray: An arrow drawn perpendicular to a wavefront in the direction of propagation of a wave is called a ray

Different types of wave front:-

Spherical wavefront- produced by point source at finite distance

Cylindrical wavefront- produced by linear or fine rectangular slit at finite distance.

Plane wavefront- produced by point source or linear or fine rectangular slit at infinite distance.



Spherical *Plane* *Cylindrical*

Huygens' Principle.

Huygens's principle is based on wave theory of light. According to Huygens's principle each point on a wavefront is a source of secondary waves, which add up to give a wavefront at any later time.

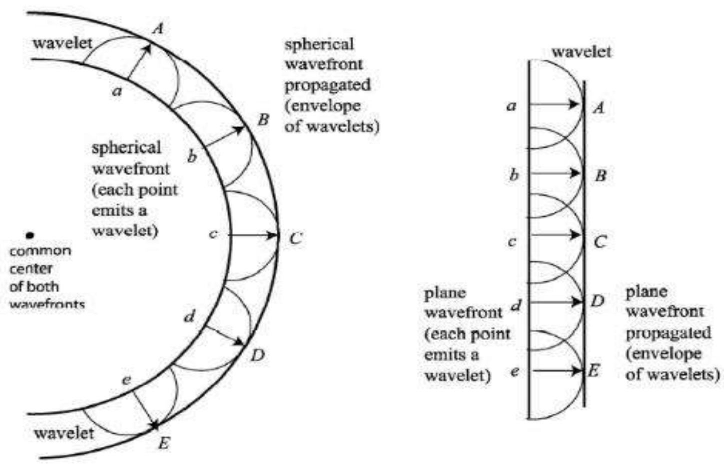
This principle is based on the following assumptions

(i) Each point on a wavefront acts as a fresh source of new disturbance, called secondary waves or wavelets.

(ii) The secondary wavelets spread out in all directions with the speed of light in the given medium.

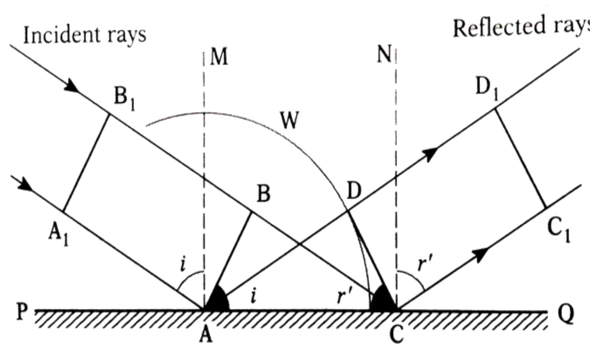
(iii) The new wavefront at any later time is given by the forward envelope (tangential surface in the forward direction) of the secondary wavelets at that time.

Construction of spherical and cylindrical wavefront



Laws of reflection on the basis of Huygens' principle

According to Huygens principle from each point On AB, secondary wavelets start growing with the speed c. during the time the disturbance from B reaches the point C, the secondary wavelets from A must have spread over a hemisphere of radius AC = AD = ct



PQ : Plane mirror, AM and CN : Normals to PQ,
AB : Incident wavefront, i : Angle of incidence,
CD : Reflected wavefront, r': Angle of reflection,
W : Wavelet originating at A and of radius AD = BC

Reflection of a plane wavefront of light at a plane surface

Let angles of incidence and reflection be $i \text{ and } r$ respectively. In $\Delta BAC \text{ and } \Delta DCA$, we have

$\angle ABC = \angle$ADC ….. 90

AC = AC. …… Common

BC =AD = vt ……Each is equal to vt

$$So\ \Delta ABC \cong \Delta\, DCA$$

$$\angle BAC = \angle DCA$$

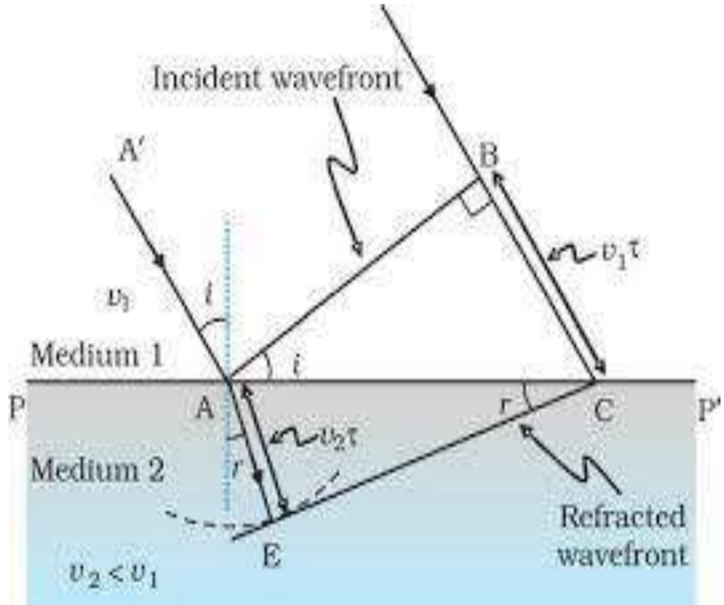
$$\text{Hence } i = r$$

The angle of incident is equal to the angle of reflection this prove the first law of reflection

Laws of refraction on the basis of Huygens' principle

AB = Incident wavefront
CE = refracted wavefront
AE = V_2t
BC = V_1t

$$\angle BAC = i$$
$$\angle ACE = r$$



From right ΔBAC

$$\sin i = \frac{BC}{AC}$$

From right ΔACE

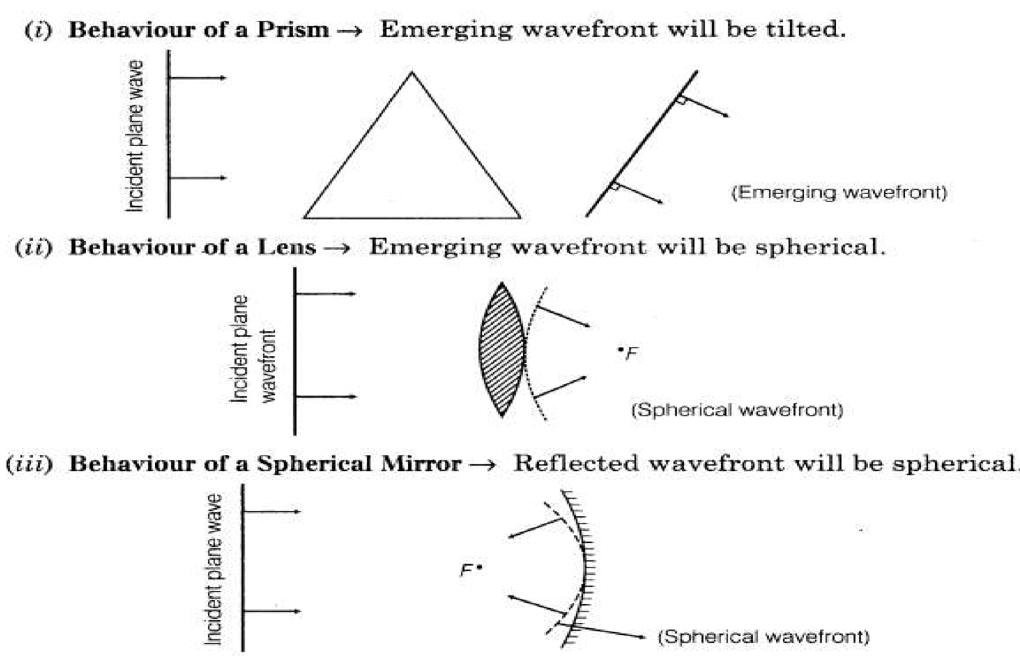
$$\text{Sin}\, r = \frac{AE}{AC}$$

$$\therefore \frac{\sin i}{\sin r} = \frac{BC}{AE} = \frac{V_1t}{V_2t}$$

$$\therefore \frac{\sin i}{\sin r} = \frac{V_1t}{V_2t} = a\ constant$$

This prove Snell's law of refraction. The constant is called the refractive index of the second medium with respect to the first.

A plane wavefront incident on a prism, convex lens and concave mirror



Principle of superposition of waves

This principle states that when a number of waves travelling through a medium superpose on each other, the resultant displacement at any point at a given instant is equal to the vector sum of the displacements due to the individual waves at that point.

$$y = y_1 + y_2 + Y_3 \dots \dots \dots \dots$$

Interference of light

When two light waves of the same frequency and having zero or constant phase difference travelling in the same direction superpose each other, the intensity in the region of superposition gets redistributed, becoming maximum at some points and minimum at others, this phenomenon is known as interference of light

Interference of light

Constructive interference

Superposition of wave in same phase

$$Phase\ difference = 2n\pi.$$

Where n = 0,1,2,3……

$$Path\ difference = n\,\lambda$$

Destructive interference

Superposition of wave in opposite phase

$$Phase\ difference = (2n+1)\pi$$

Where n = 0,1,2,3……

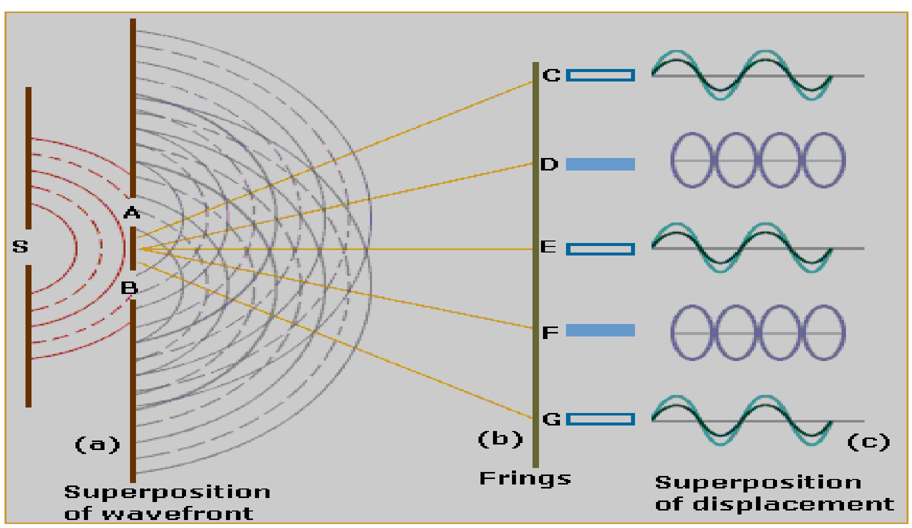
$$Path\ difference = (2n+1)\frac{\lambda}{2}$$

$$\boxed{Phase\ difference = \frac{2\pi}{\lambda}\,(Path\ difference)}$$

Young's double slit experiment

S = Monochromatic light source
A and B - Rectangular Slits

When 'S' is illuminated we get bright dark, bright dark pattern on screen CG



Bright fringe

When the crest of one wave falls over the crest of other wave or the trough of one wave falls over the trough of other wave, the amplitudes of the two waves get added up and hence the intensity becomes maximum. This is called constructive interference.

Dark fringe

When the crest of one wave falls over the trough of other or the amplitudes of the two waves get subtracted and hence the intensity becomes minimum. This is called destructive interference.

Expression for intensity at any point in interference pattern
Conditions for constructive and destructive interference

Suppose the displacement of two waves

$$y_1 = a_1 \sin \omega t$$
$$y_2 = a_2 \sin(\omega t + \phi)$$

Where $a_1 = amplitude\ of\ first\ wave$
$a_2 = amplitude\ of\ second\ wave$

Resultant wave at any point by superposition principle

$$y = y_1 + y_2$$
$$y = a_1 \sin \omega t + a_2 \sin(\omega t + \phi)$$

$$y = R \sin(\omega t + \theta)$$

Where R = Amplitude of resultant wave
$\theta = intial\ Phase$

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

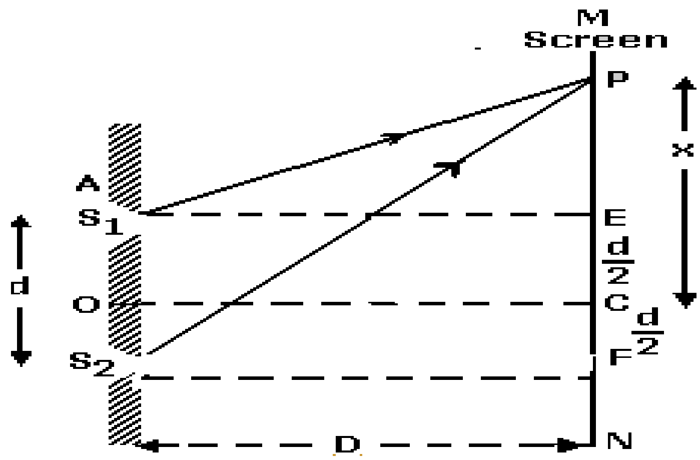
Intensity of light

$$\boldsymbol{intensity\ of\ light} \propto (\boldsymbol{amplitude}^{\mathbf{2}})$$
$$I \propto R^2$$

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \phi$$

Constructive interference	Destructive interference
When $\phi = 0, 2\pi, 4\pi, 6\pi \ldots\ldots$ $\cos\phi = 1$ $R_{max} = \sqrt{a_1^2 + a_2^2 + 2a_1a_2(1)}$ $R_{max} = (a_1 + a_2)$ $I_{max} = I_1 + I_2 + 2\sqrt{I_1 I_2}(1)$ $I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$	When $\phi = \pi, 3\pi, 5\pi \ldots\ldots$ $\cos\phi = -1$ $R_{min} = \sqrt{a_1^2 + a_2^2 + 2a_1a_2(-1)}$ $R_{min} = (a_1 - a_2)$ $I_{min} = I_1 + I_2 + 2\sqrt{I_1 I_2}(-1)$ $I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2$

FRINGE WIDTH



Where d = distance between two slits
D = distance between slits and screen
x = distance of any fringe from centre of screen(c)

Path difference between two waves reaches at point p

$$\Delta = \frac{x_n d}{D}$$

Position of bright fringes

For constructive interference $\Delta = n\lambda$ & $x_n = \frac{n\lambda D}{d}$

$$x = 0, \frac{D\lambda}{d}, \frac{2D\lambda}{d}, \frac{3D\lambda}{d} \dots\dots\dots\dots\dots\dots..$$

Position of dark fringes

For destructive interference $\Delta = (2n+1)\frac{\lambda}{2}$ & $x'_n = (2n+1)\frac{\lambda}{2}$

$$x = \frac{1D\lambda}{2d}, \frac{3D\lambda}{2d}, \frac{5D\lambda}{2d} \dots\dots\dots\dots\dots\dots\dots$$

Fringe width. It is the separation between two successive bright and dark fringe

$$\beta = \frac{\lambda D}{d}$$

Coherent and incoherent sources

Two sources of light which continuously emit light waves of same frequency (or wavelength) with a zero or constant phase difference between them, are called coherent sources.

Two independent sources cannot be coherent
This is because of the following reasons:

(i) Light is emitted by individual atoms and not by the bulk of matter acting as a whole.
(ii) Even a tiniest source consists of millions of atoms, and emission of light by them takes place independently.
(iii) Even an atom emits an unbroken wave of about 10^{-8} second due to its transition from a higher energy state to a lower energy state.

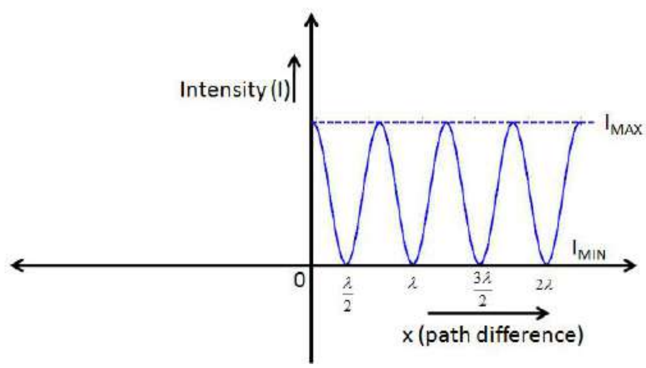
Sustained interference pattern
The interference pattern, in which the positions of maxima and minima of intensity on the observation screen do not change with time, is called a sustained or permanent interference pattern..

Conditions for obtaining sustained and observable interference pattern:

(i) The two sources should continuously emit waves of same frequency
(ii) The two sources of light should be coherent.
(iii) The amplitudes of the interfering waves should be equal.
(iv) The two sources should be narrow.
(v) The interfering waves must travel nearly along the same direction.
(vi) The sources should be monochromatic.
(vii) The interfering waves should be in the same state of polarisation.
(viii) The distance between the two coherent sources should be small and the distance between the two sources and the screen should be large.

Intensity distribution curve for interference

$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$
When $I_1 = I_2 = I_o$
$I = 4I_o(\cos\frac{\phi}{2})^2$



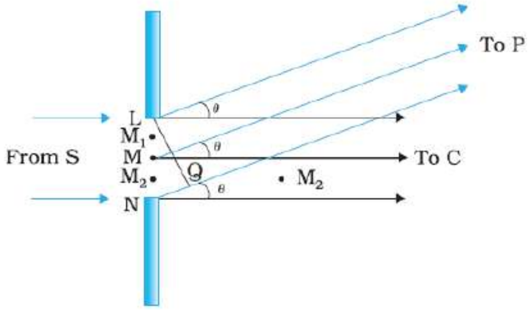
Conservation of energy in interference

$$I_{max} = I_1 + I_2 + 2\sqrt{I_1 I_2}(1)$$
$$I_{min} = I_1 + I_2 + 2\sqrt{I_1 I_2}(-1)$$

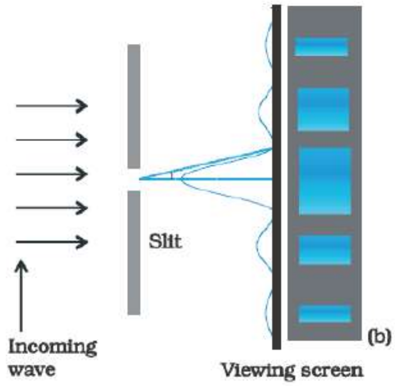
$I_{ave} = I_1 + I_2$
So above two equations we can say whatever energy disappear ($-2\sqrt{I_1 I_2}$) from a dark fringe, an equal energy appear($2\sqrt{I_1 I_2}$) in a bright fringe so total energy conserve in interference pattern

Diffraction of light
The phenomenon of bending of light around the corners of small obstacles or apertures and its consequent spreading into the regions of geometrical shadow is called diffraction of light.
Example. A pinhole placed at a distance of 2 m from a sodium lamp forms alternate bright and dark bands on a screen placed behind the pinhole.

Diffraction of light at a single slit



The geometry of path differences for diffraction by a single slit.



(a)

Intensity distribution and photograph of fringes due to diffraction at single slit.

The diffraction pattern consists of a central bright band surrounded by alternate dark and bright bands and is obtained on a distant screen

$$a = LN = width\ of\ a\ slit$$

The path difference between the wavelets from L and N will be

$$path\ difference\ \Delta = a \sin\theta$$

points M_1 and M_2 of the two halves of the slit will be $\frac{\lambda}{2}$. This means the contribution from M_1 and M_2 are 180° out of phase and cancel. Contribution from the two halves LM and MN cancel each other. Net intensity at P will be zero.

POSITION FOR SECONDARY MINIMA

For secondary minima, $a \sin\theta = n\lambda$ Where n=1,2,3,4…………

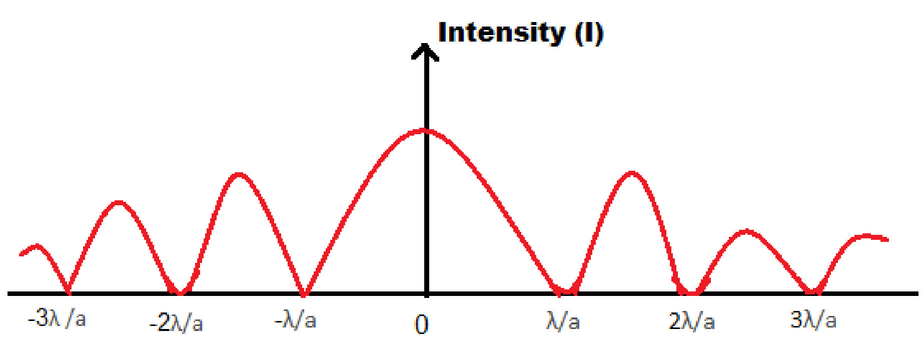
For first minima n = 1 $a \sin\theta = \lambda$ and so on

POSITION FOR SECONDARY MAXIMA

For secondary maxima, $a \sin\theta = (2n+1)\frac{\lambda}{2}$ $where\ \ n = 1,2,3 \ldots\ldots$

For first secondary maxima $n = 1$ $a \sin\theta = \frac{3\lambda}{2}$ and so on

Intensity distribution curve in diffraction

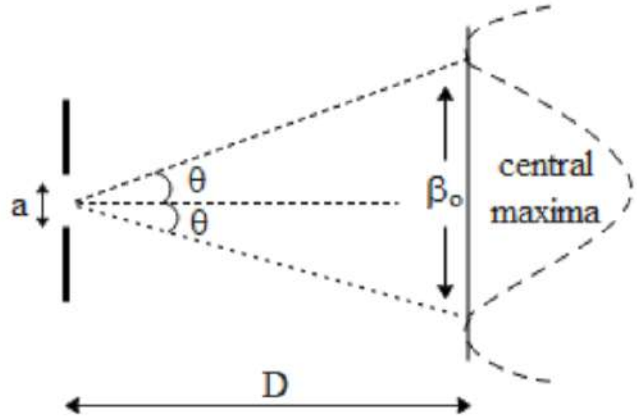


Angular width of central maximum

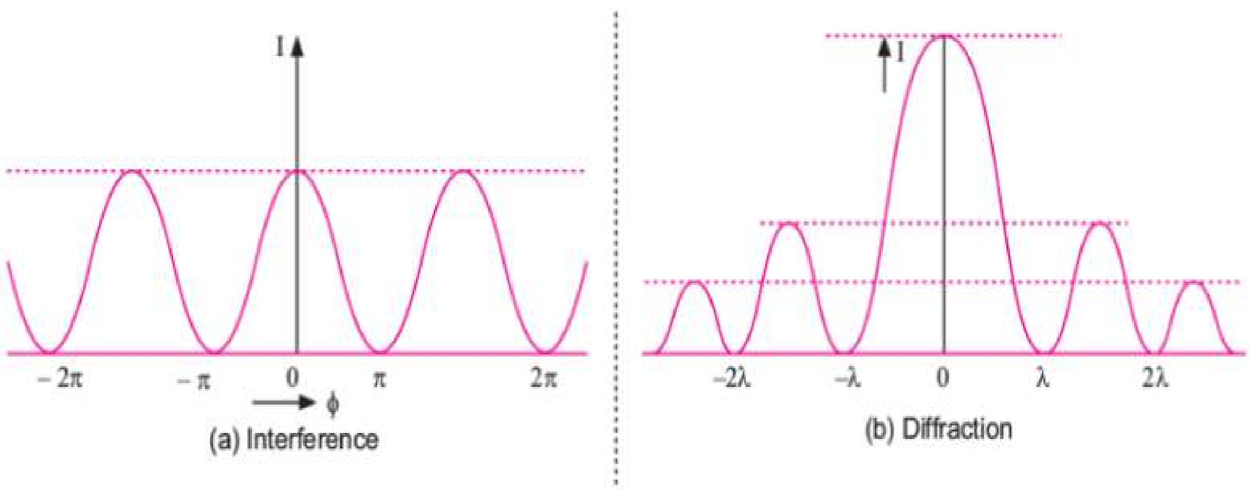
$$2\theta = \frac{2\lambda}{a}$$

Linear width of central maximum

$$\beta_o = D \times 2\theta = \frac{2D\lambda}{a}$$



Intensity distribution curve in interference and diffraction (Comparison)



Intensity Patterns

Differences between interference and diffraction

Interference	Diffraction
(*i*) It is due to the superposition of two waves coming from two coherent sources.	(*i*) It is due to the superposition of secondary wavelets originating from different parts of the same wavefront.
(*ii*) The width of the interference bands is equal.	(*ii*) The width of the diffraction bands is not the same.
(*iii*) The intensity of all maxima (fringes) is same.	(*iii*) The intensity of central maximum is maximum and goes on decreasing rapidly with increase in order of maxima.

Unit VII: Dual Nature of Radiation and Matter

CHAPTER–11: DUAL NATURE OF RADIATION AND MATTER

GIST OF CHAPTER

Dual nature of radiation, Photoelectric effect, Hertz and Lenard's observations;
Einstein's photoelectric equation-particle nature of light.
Experimental study of photoelectric effect
Matter waves-wave nature of particles, de-Broglie relation.

UNITS AND DIMENSIONS

Physical quantity	Symbol	Dimension	Unit
Plank's constant	h	$[ML^2T^{-2}]$	Js
Stopping potential	V_0	$[ML^2T^{-3}A^{-1}]$	V
Work function	ϕ_0	$[ML^2T^{-2}]$	J; eV
Threshold frequency	v_0	$[T^{-1}]$	Hz
De-Broglie wavelength	Λ	[L]	M

IMPORTANT RESULTS AND FORMULAE

1. Energy of photon:
   $E=hf=\frac{hc}{\lambda}$
2. Momentum of photon:
   $P=\frac{h}{\lambda}=\frac{hf}{c}$
3. Work function:
   $W_0=hf_0=hc/\lambda_0$
4. Cut off potential:
   $eV_0=\frac{1}{2}mv_{max}^2$
5. Einstein equation:
   $hf= W_o + K_m$
   $K_m = hf - W_0 = hf - hf_0$
6. The de-Broglie's wavelength og the particle of mass *m* and moving with velocity *v* is given by:
   $$\lambda=\frac{h}{p}=\frac{h}{mv}$$
7. The de-Broglie wavelength of a particle of mass *m* and kinetic energy K is given by:
   $$\lambda=\frac{h}{p}=\frac{h}{\sqrt{2mK}}$$

8. If a particle of mass m is carrying charge q_0 is accelerated through potential V, then its de-Broglie wavelength is given by:

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mq_0V}}$$

9. The de-Broglie wavelength associated with orbital electron in the n^{th} orbit of hydrogen atom is given by:

$$\lambda_n = \frac{12.27}{\sqrt{V}}\text{Å}$$

DEFINITION & CONCEPTS:-

Free electrons:- In metals, the electrons in the outer shell of the atoms are loosely bound. They move about freely throughout the lattice of positive ions. Such loosely bound electrons are called free electrons.

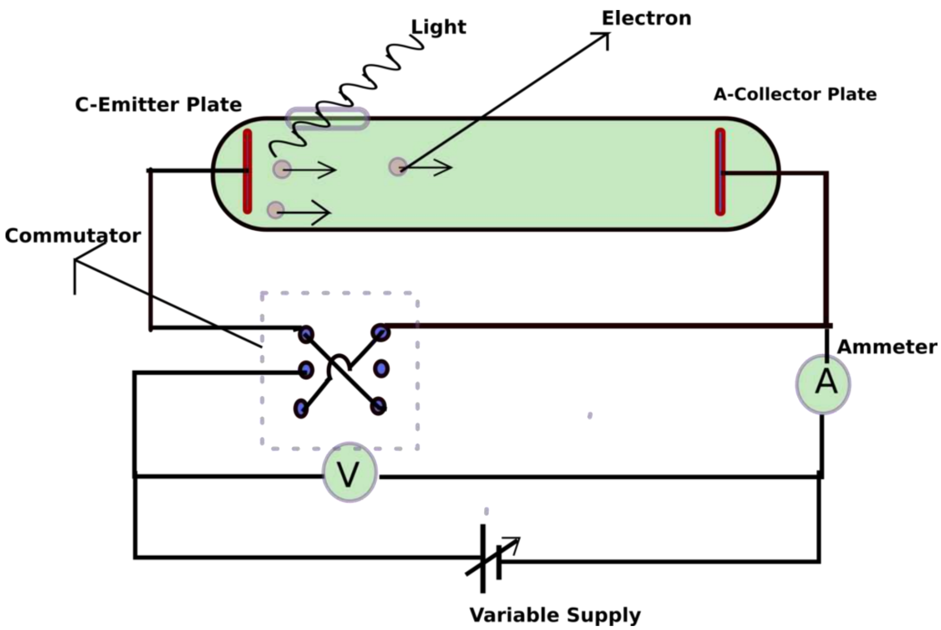
Work function of a metal. The minimum energy, which must be supplied to the electron so that it can just come out of a metal surface, is called the work function of the metal. It is denoted by W_0.

Work function depends on (i) nature of the metal (ii) the conditions of its surface.

Electron emission:- The phenomenon of ejecting out the electron from metal surface is called electron emission.

PHOTOELECTRIC EMISSION/ EFFECT :-. The phenomenon of ejection of electrons from a metal surface, when light of sufficiently high frequency falls on it, is known as photoelectric effect.

The electrons so emitted are called **photoelectrons**



Hertz's observation:-While demonstrating the existence of electromagnetic waves, Hertz found that high voltage sparks passed across the metal electrodes of the detector loop more easily when the cathode was illuminated by ultraviolet light from an arc lamp. The uv light falling on metal surface caused the emission of negatively charged particles (electrons) into surrounding space and enhance the high voltage sparks**.**

Hallwachs and Lenard Observation:- It was observed that if the frequency of incident light is less than certain minimum value (Threshold frequency) emission of photo electrons do not takes place.

Threshold frequency. The minimum frequency (ν_0), which the incident light must possess so as to eject photoelectrons from a metal surface, is called threshold frequency of the metal.
Mathematically- Work function of metal W = hν_0

Laws of photoelectric effect.

1. Photoelectric emission takes place from a metal surface, when the frequency of incident light is above its threshold frequency.

2. The photoelectric emission starts as soon as the light is incident on the metal surface.

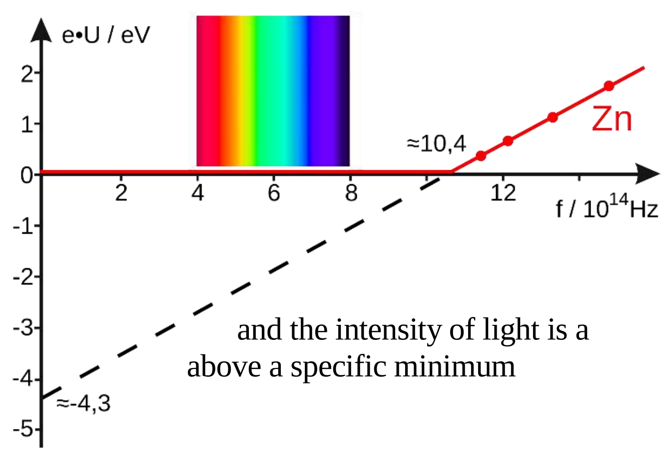
3. The maximum kinetic energy with which an electron is emitted from a metal surface is independent of the intensity of light and depends upon its frequency.

4. The number of photoelectrons emitted is independent of the frequency of the incident light and depends only upon its intensity.

The Effect of Intensity

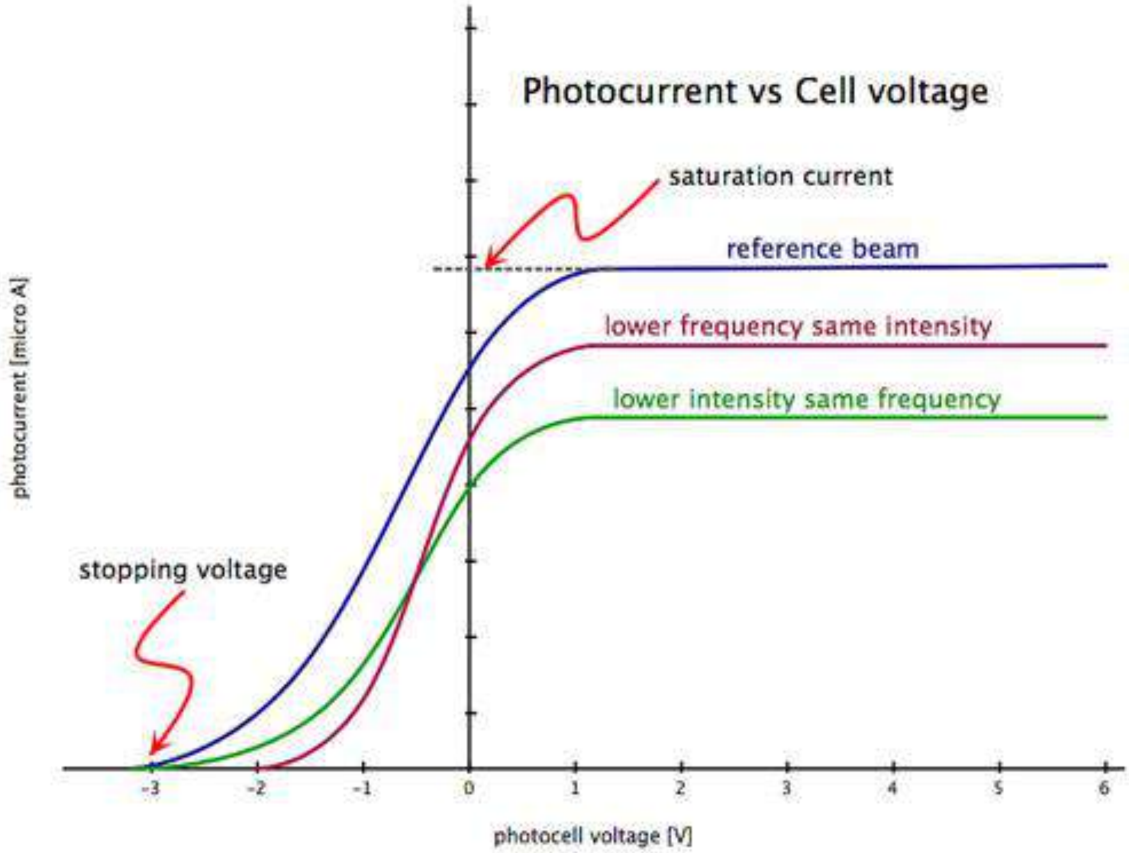
The number of electrons emitted per second is observed to be directly proportional to the intensity of light.

This happens above the threshold frequency. Below this threshold frequency there is no photocurrent at all, howsoever high the intensity of light is.



The graph between the photoelectric current and the intensity of light is a straight line when the frequency of light used is above a specific minimum threshold value.

The Effect of the Potential



The photoelectric current increases with increase in accelerating (positive) potential of collector plate.
For a certain positive potential of plate A, the photoelectric current becomes maximum and constant or saturates. *This maximum value of the photoelectric current is called **saturation current**.*
Saturation current corresponds to the case when all the photoelectrons emitted by the emitter plate C reach the collector plate A.
Saturation current **increases with increase in intensity** of incident radiation.
The photoelectric current **decreases with nega tive potential** of collector plate.

STOPPING POTENTIAL V_0
At certain negative potential of the collector plate the photocurrent becomes zero. This negative potential is called **STOPPING POTENTIAL V_0**.
The stopping potential is measure of maximum kinetic energy of photoelectron.

$$Max.KE\ of\ photo\ electron = e\,V_o = \frac{1}{2}mv_{max}{}^2$$

Where v_{max} is the maximum velocity with which the photoelectrons are emitted

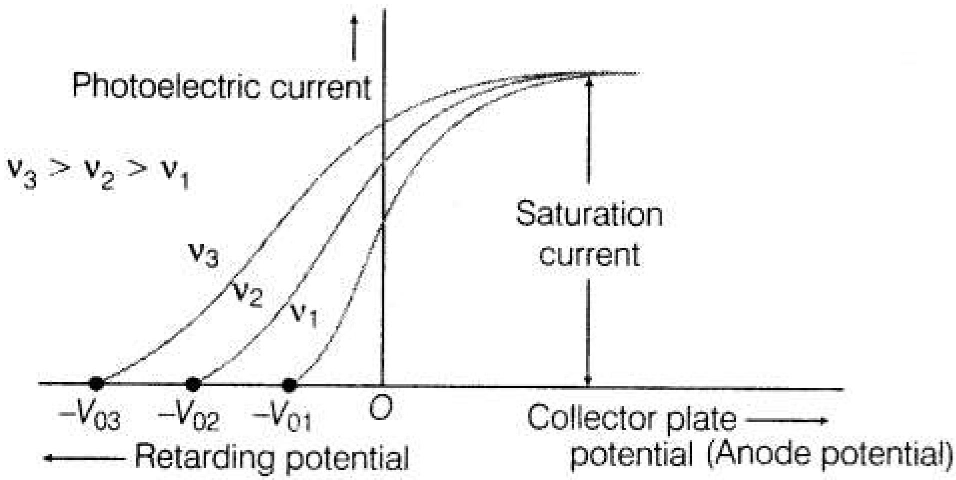
Effect of intensity of incident radiation on stopping potential

- Stopping potential **does not change** on changing the intensity of incident radiation.
- The maximum kinetic energy of photoelectron **thus does not depend on intensity of incident radiation.**

EFFECT OF FREQUENCY:

Effect of frequency on photocurrent

- Saturation Photocurrent **does not change** on changing frequency of incident radiation.
- The rate of emission of photoelectron does not depend on frequency of incident radiation.

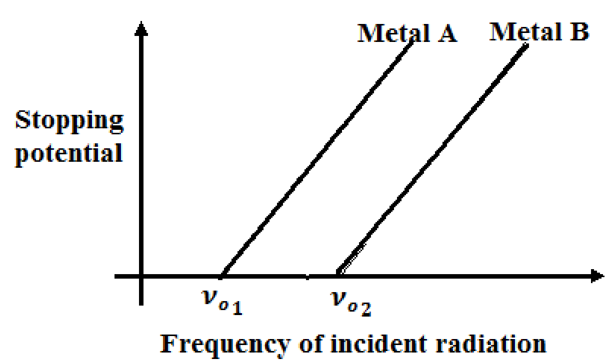


Effect of frequency on stopping potential

- Stopping potential increases on increasing frequency of incident radiation. maximum kinetic energy of photoelectron thus depends on frequency of incident radiation

Graph between stopping potential and frequency

- Graph between stopping potential and frequency of incident radiation is always a straight line.
- Slope of this graph is constant and its value *is* $\frac{h}{e}$.
- Thus **maximum kinetic energy of photoelectron** vary linearly with frequency of incident radiation.
- There exists a certain minimum cut-off frequency ν_o for which the stopping potential is zero.



EINSTEIN'S PHOTOELECTRIC THEORY

Electromagnetic Radiation energy is built up of discrete units PHOTONS – the so called quanta of energy of radiation
In interaction of Electromagnetic Radiation with matter, radiation behaves as if it is made up of particles called photons.

Photo electric emission: Each Photon of incident radiation interacts with a single electron and if energy of photon ($h\nu$) is equal to or greater than work function, the electron is emitted.

When light of frequency ν is incident on a metal surface, whose work function is W (i.e. h), then the maximum kinetic energy of the emitted photoelectrons is given by

$$E_K = \frac{1}{2} m v_{max}{}^2 = h\nu - \phi_o = h(\nu - \nu_o)$$

This is called **EINSTEIN'S PHOTOELECTRIC EQUATION**. It can explain the laws of photoelectric emission.

Properties of Photon :-

(i) In interaction of radiation with matter, radiation behaves as if it is made of particles like photons.

(ii) Each photon has energy (E= $h\nu$) and momentum (p=$h\nu$/c)

(iii) All photons of a particular frequency ν or wavelength have same energy (E= $h\nu$=h c/ λ) and same momentum(p=$h\nu$/c= h/ λ) irrespective of intensity of radiations.

(iv) Velocity of photon in different media is different due to change in it's wave length.

(v) Rest mass of photon is zero.

(vi) During collision of photon and electron energy and momentum are conserved.

If stopping potential is V_o then , $Max. KE\ of\ photo\ electron = e\, V_o$

$$\Rightarrow e\, V_o = h\nu - \phi_o = h(\nu - \nu_o)$$

$$\Rightarrow V_o = \frac{h\nu}{e} - \frac{\phi_o}{e} = \frac{h}{e}(\nu - \nu_o)$$

This explains why the V_o versus ν curve is a straight line with slope = (h/e), independent of the nature of the material.

DE-BROGLIE HYPOTHESIS.
Both radiation and matter have dual nature. A moving particle of momentum p is associated with a wave called de-Broglie wave of wavelength λ .

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

This is De-Broglie wave equation the wavelength of the wave associated is called de-Broglie wavelength of the particle.

De-Broglie wavelength of electron. Consider an electron having mass m moving with final velocity v when accelerated through potential V. Kinetic energy gained by electron due to work done by electric field is eV. Then

$$K.E. = eV = \frac{p^2}{2m} = \frac{1}{2}mv^2 \Rightarrow P = \sqrt{2mK} = \sqrt{2meV}$$

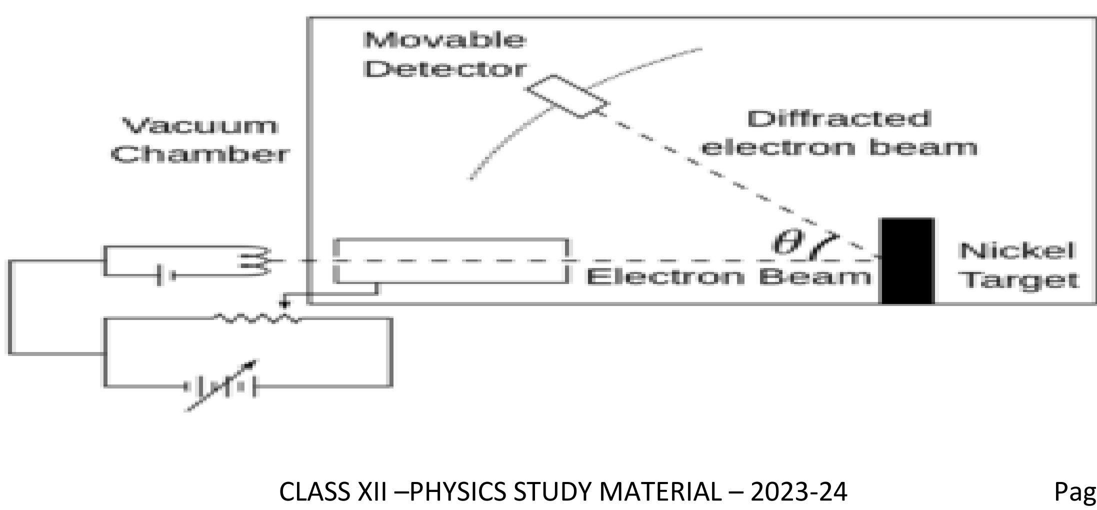
So, If an electron accelerated through a potential difference V acquires kinetic energy E possesses de-Broglie wavelength,

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}} = \frac{12.27}{\sqrt{V}} \text{Å}$$

DAVISSON AND GERMER EXPERIMENT - Experimental Demonstration of wave nature of electrons.

The experimental setup for the Davisson and Germer experiment is enclosed within a vacuum chamber. Thus the deflection and scattering of electrons by the medium are prevented. The main parts of the experimental setup are as follows:

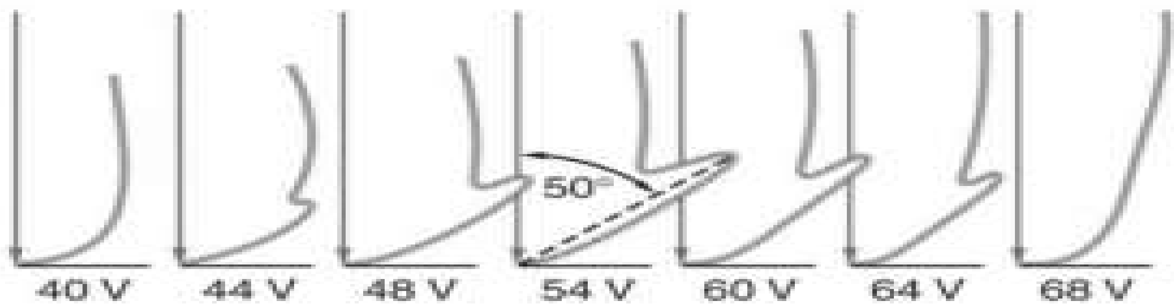
- **Electron gun**: An electron gun is a Tungsten filament that emits electrons via thermionic emission i.e. it emits electrons when heated to a particular temperature.
- **Electrostatic particle accelerator**: Two opposite charged plates (positive and negative plate) are used to accelerate the electrons at a known potential.
- **Collimator**: The accelerator is enclosed within a cylinder that has a narrow passage for the electrons along its axis. Its function is to render a narrow and straight (collimated) beam of electrons ready for acceleration.
- **Target**: The target is a Nickel crystal. The electron beam is fired normally on the Nickel crystal. The crystal is placed such that it can be rotated about a fixed axis.
- **Detector**: A detector is used to capture the scattered electrons from the Ni crystal. The detector can be moved in a semicircular arc as shown in the diagram



Observations of the Davisson and Germer Experiment

The intensity (strength) of this electronic current received by the detector and the scattering angle is studied. This current is called the electron intensity.

The intensity of the scattered electrons is not continuous. It shows a maximum and a minimum value corresponding to the maxima and the minima of a diffraction pattern produced by X-rays. It is studied from various angles of scattering and potential difference



Plots between I *– the intensity of scattering (X-axis) and the angle of scattering θ for given values of Potential difference.*

Results of the Davisson and Germer Experiment

From the Davisson and Germer experiment, we get a value for the scattering angle θ and a corresponding value of the potential difference V at which the scattering of electrons is maximum. From these two values from the data collected by Davisson and Germer, the λ. Is obtained.

If an electron is accelerated by potential difference V then using De-Broglie Hypothesis

$$\lambda = \frac{12.27}{\sqrt{V}}\text{Å} = \frac{12.27}{\sqrt{54}}\text{Å} = 1.67\ \text{Å}$$

Now the value of 'd' from X-ray scattering is 0.092 nm. Therefore for V = 54 V, the angle of scattering is 50^0, using condition for maxima, we have:

$$n\lambda = 2d\ \sin(90^0 - 50^0) \Rightarrow\ for\ n = 1, \qquad \lambda = 2(0.092)\sin(90^0 - 50^0) = 1.65\text{Å}$$

Therefore the experimental results are in a close agreement with the theoretical values got from the de Broglie equation.

Unit VIII: Atoms and Nuclei

CHAPTER–12: ATOMS

GIST OF CHAPTER

Alpha-particle scattering experiment; Rutherford's model of atom; Bohr model, energy levels, hydrogen spectrum.

DEFINITIONS AND CONCEPT:

Atomic models

As atom is electrically neutral the discovery of electron led by J.J. Thomson established that it should also have positive charge. Hence, he proposed first model of atom- Plum- Pudding model.

Plum – Pudding Model

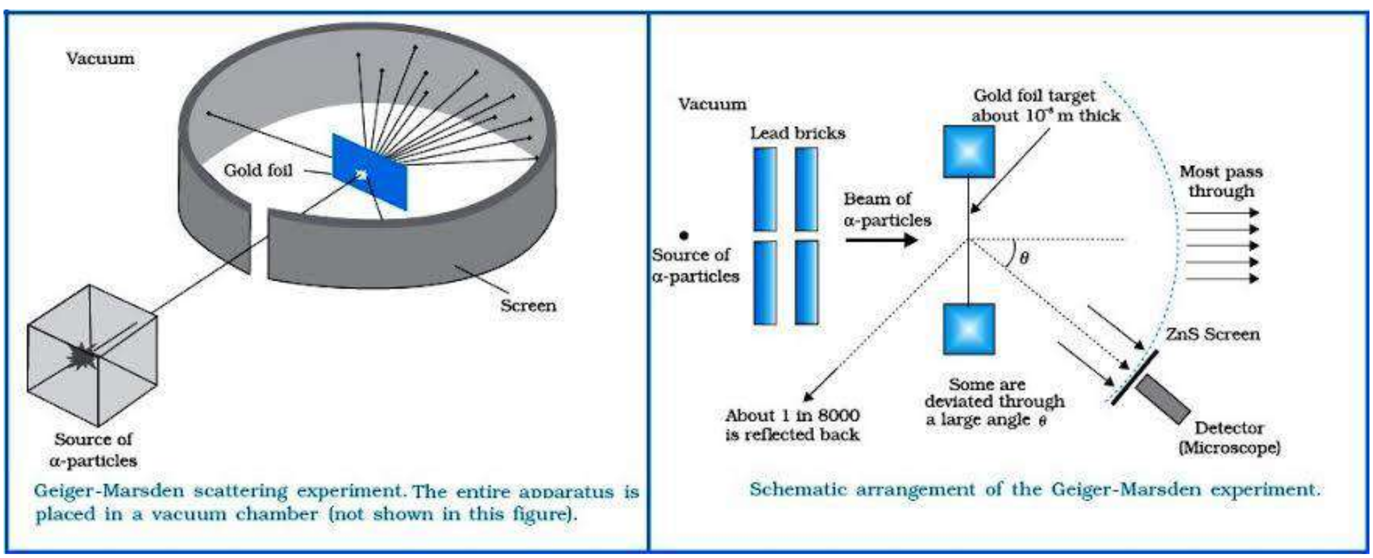
According to plum pudding model," the positive charge of the atom is uniformly distributed throughout the volume of the atom and the negatively charged electrons are embedded in it like seeds in a watermelon."
But subsequent studies on atom showed the results very different from this atomic model.

Rutherford's atomic model

According to this model " The entire positive charge and most of the mass of an atom is concentrated in a small volume called the nucleus, with electrons revolving around the nucleus."

Geiger and Marsden experimentally proved Rutherford's atomic model.

Alpha particle scattering Experiment



Geiger-Marsden scattering experiment. The entire apparatus is placed in a vacuum chamber (not shown in this figure).

Schematic arrangement of the Geiger-Marsden experiment.

- Radioactive element $^{214}_{83}Bi$ was taken as α-particles generating source
- Gold was taken as target metal. The selection of gold was based upon its two important characteristics:

a) Gold has the highest malleability. Gold foil that was used in the experiment was almost transparent.

b) Gold is a heavy metal, hence it helped in discovery of the nucleus.

- Lead bricks absorbed the α-particles which were not in the direction of gold foil. They worked as collimator.
- The detector was made from ZnS.

Experimental Observations:

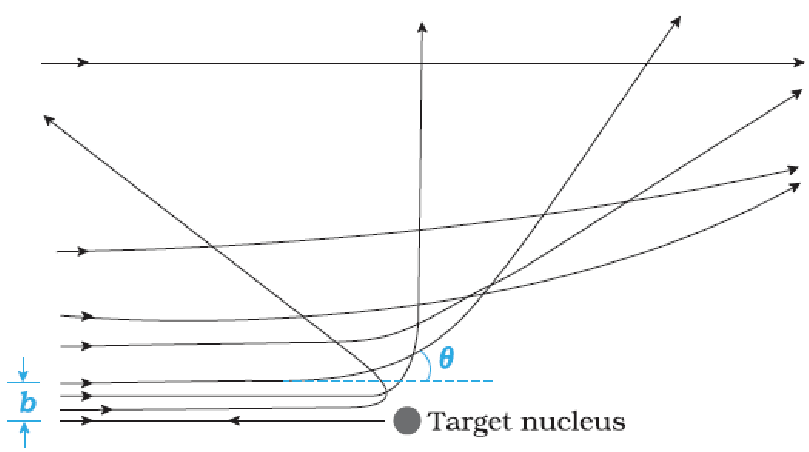
- When α-particles hit ZnS screen, it absorbs and glows. Hence the number of α-particles can be counted by intensity variation.
- Most of the α-particles passed roughly in a straight line (with in 1̊) without deviation. This showed that no force was acting upon most of the α-particles.
- A very small number of α-particles were deflected. (1 out of 8000)

Conclusions:

- Most of the space in the atom is mostly empty(only 0.14% scatters more than 1̊)
- Experiment suggest that all positively charged particles are together at one location at centre. It was called nucleus. So, nucleus has all the positive charges and the mass. Therefore, it has the capability to reflect heavy positive α-particles.
- Size of nucleus is calculated to be about 10^{-15}m to 10^{-14}m. According to kinetic theory, size of atom is of the order of 10^{-10}m.
- Force between α-particles and gold nucleus $F = \frac{1}{4\pi\varepsilon_0}\frac{(2e)(Ze)}{r^2}$

Alpha-particle trajectory:

- Impact parameter: It is the perpendicular distance between the directions of given α-particle and the centre of the nucleus. It is represented by ‘b’.



- Distance of closest approach: It is the distance between centre of nucleus and the α-particle when it stops and reflects back. It is represented by 'd'. This distance gives an approximation of nucleus size.

Electron Orbits:

- We can calculate the energy of an electron and the radius of its orbit based upon Rutherford model.
- The electrostatic force of attraction, F_e between revolving electron and the nucleus provides the requisite centripetal force (F_c) to keep them in their orbits.
  $F_e=F_c$
  For hydrogen atom, $\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} = \frac{mv^2}{r}$
  $$r = \frac{e^2}{4\pi\varepsilon_0 mv^2}$$
  Electron has kinetic energy, $K = \frac{1}{2}mv^2$. Putting the value of mv^2 in the above equation
  $$K = \frac{e^2}{8\pi\varepsilon_0 r}$$
  And $v = \frac{e}{\sqrt{4\pi\varepsilon_0 mr}}$
  P.E. of an electron, $U = -\frac{1}{4\pi\varepsilon_0}\frac{e}{r}$ negative sign shows that it is due to attractive force.
  Total Energy , E=K+U
  $$E= \frac{e^2}{8\pi\varepsilon_0 r} + \left[-\frac{1}{4\pi\varepsilon_0}\frac{e2}{r}\right]$$
  $$= -\frac{e^2}{8\pi\varepsilon_0 r}$$
- Due to this negative energy, the electron is bound to the nucleus and revolves around it. This energy is known as the binding energy of an electron.
- From the equation, it is clear that if energy is zero, then radius is infinity. Practically, if we provide this amount of energy to this electron, it gets free.

Atomic Spectra:

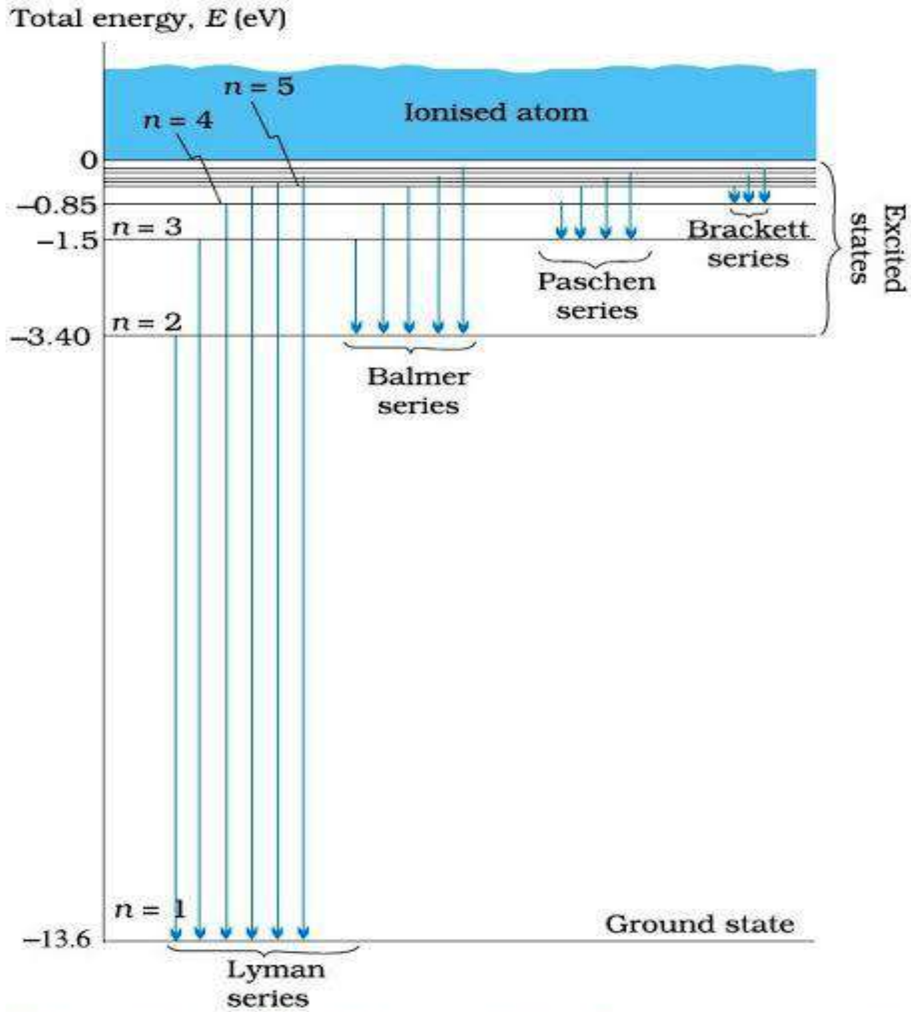
- Each element has a characteristics spectrum of radiation, which it emits. There are two types of atomic spectra: Emission atomic spectra and absorption atomic spectra.
- Emission atomic spectra: Due to excitation of atom usually by electricity, light of particular wavelength is emitted. This atomic spectra is known as emission spectra.
- Absorption atomic spectra: If atoms are excited in presence of white light, it absorbs it absorbs its emission spectral colours and black lines appear in the same places of that atoms emission spectra. This type of spectra is known as absorption spectra.

Spectral Series:

- The atom shows range of spectral lines. Hydrogen is the simplest atom and has the simplest spectrum.
- The spacing between lines within certain sets of the hydrogen spectrum decreases in a regular way. Each of these sets is called a spectral series.
- Balmer Series: Balmer observed the first hydrogen spectral series in visible range of the hydrogen spectrum. It is known as Balmer Series.

  $\frac{1}{\lambda}=R\left[\frac{1}{2^2}-\frac{1}{n^2}\right]$ where n=3,4,5… and R is Rydberg's constant.

  The value of R is $1.097\times10^7 m^{-1}$;



Line spectra originate in transitions between energy levels.

Other series of spectra for hydrogen were as follows

- Lyman Series : $\frac{1}{\lambda}=R\left[\frac{1}{1^2}-\frac{1}{n^2}\right]$ n=2,3,4,5….This is in UV range

- Paschen Series: $\frac{1}{\lambda}=R\left[\frac{1}{3^2}-\frac{1}{n^2}\right]$ n=4,5,6….This is in IR range
- Brackett Series: $\frac{1}{\lambda}=R\left[\frac{1}{4^2}-\frac{1}{n^2}\right]$ n=5,6,7….This is in IR range
- Pfund Series: $\frac{1}{\lambda}=R\left[\frac{1}{5^2}-\frac{1}{n^2}\right]$ n=6,7,8….This is in IR range

Limitations of Rutherford model:

- **It could not explain the stability of the atom:** The electron orbiting around the nucleus radiates energy. As a result, the radius of electron orbit should continuously decrease and ultimately the electron should fall into the nucleus.
- **It could not explain the nature of energy spectrum:** According to the Rutherford's model, the electron can revolve around the nucleus in all possible orbits. Hence, the atom should emit radiations of all possible wavelengths or in other words, it should have a continuous spectrum. However, in practice, the atoms are found to have a line spectrum or discrete spectrum.

BOHR'S MODEL AND POSTULATES:

- An electron can revolve in certain stable orbits without emission of radiant energy. These orbits are called stationary states of the atom.
- Electron revolves around nucleus only in those orbits for which the angular momentum is the integral multiple of $\frac{h}{2\pi}$, where, h is Planck's constant.

  Hence, angular momentum, $L=\frac{nh}{2\pi}$
- An electron may make a transition from one of its specified non-radiating orbit to another of lower energy. When it does so, a photon of energy $h\upsilon$ is radiated having energy equal to energy difference between initial and final state.

$$h\upsilon = E_i - E_f \quad \text{(where, } \upsilon \textit{ is frequency}\text{)}$$

Angular momentum, $L = mv_n r_n = \frac{nh}{2\pi}$ $\quad \Rightarrow mr_n = \frac{nh}{2\pi v_n}$

For hydrogen atom, orbital velocity of electron $v = \frac{e}{\sqrt{4\pi\varepsilon_0 mr}}$

Combining these two equations, we get $v_n = \frac{1}{n}\frac{e^2}{4\pi\varepsilon_0}\frac{1}{h/2\pi}$

This equation depicts that electron speed in n^th orbit falls by a *n* factor

$$r_n = \left[\frac{n^2}{m}\right]\left[\frac{h^2}{2\pi^2}\right]\left[\frac{4\pi\varepsilon_0}{e^2}\right]$$

For innermost orbit n=1; value of r_1 is known as Bohr's radius a_0

$$a_0 = \frac{h^2 \varepsilon_0}{\pi m e^2}$$

If we put the values of all constants, we get **$a_0 = 5.29 \times 10^{-11}$ m**

It can also be observed that radii of n^{th} orbit increases by n^2 times

By putting this value in total energy of electron and convert the unit in eV, we get

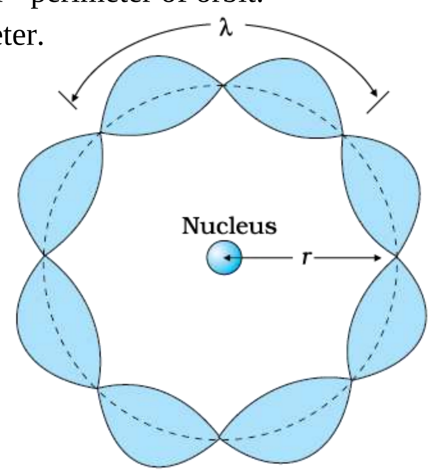
$E_n = \frac{-13.6}{n^2}.\,eV$. Negative value shows that electron is bound to nucleus.

De-Broglie's explanation of Bohr's second postulate by quantization theory:

- According to Bohr's postulate, an electron in a hydrogen atom can revolve in a certain orbit only in which its angular momentum, $L = \frac{nh}{2\pi}$ In these stationary orbits, an electron does not radiate energy.
- De-Broglie proved it with the help of the wave nature of electron.
- Travelling wave propagates energy but stationary wave does not propagates energy. In analogy to waves travelling on a string, particle waves can lead to standing waves under resonant conditions. Resonant condition is $l = 2\pi r$ where, l= perimeter of orbit.

For a hydrogen atom, length of the innermost orbit is its perimeter.

Hence $2\pi r = n\lambda$ ……..(i)



According to de-Broglie's wavelength of electron,

$$\lambda = \frac{h}{p}$$

Here $p=mv$, Now equation (i) can be written as

$$2\pi r = n\frac{h}{p} = n\frac{h}{mv} ----(ii)$$

Hence, equation (ii) can be reduced as,

$$mvr = n\frac{h}{2\pi} \quad \Rightarrow \quad L = \frac{nh}{2\pi}$$

This is Bohr's second postulate.

Limitation of Bohr's atomic model:

Bohr's model is for hydrogenic atoms. It does not hold true for a multi-electron model.

Formulae:-

- Radius of orbit $r = \frac{e^2}{4\pi\varepsilon_0 mv^2}$
- Kinetic energy of electron in its orbit $K = \frac{e^2}{4\pi\varepsilon_0 r}$
- Potential energy of an electron $U = -\frac{e^2}{4\pi\varepsilon_0 r}$
- Velocity of electron in its orbit $v = \frac{e}{\sqrt{4\pi\varepsilon_0 mr}}$
- Total energy of an electron in an orbit $E = \frac{e^2}{8\pi\varepsilon_0 r}$
- Balmer Series : $\frac{1}{\lambda}=R\left[\frac{1}{2^2}-\frac{1}{n^2}\right]$ n=3,4,5…. This is in Visible range
- Lyman Series : $\frac{1}{\lambda}=R\left[\frac{1}{1^2}-\frac{1}{n^2}\right]$ n=2,3,4,5….This is in UV range
- Paschen Series: $\frac{1}{\lambda}=R\left[\frac{1}{3^2}-\frac{1}{n^2}\right]$ n=4,5,6….This is in IR range
- Brackett Series: $\frac{1}{\lambda}=R\left[\frac{1}{4^2}-\frac{1}{n^2}\right]$ n=5,6,7….This is in IR range
- Pfund Series: $\frac{1}{\lambda}=R\left[\frac{1}{5^2}-\frac{1}{n^2}\right]$ n=6,7,8….This is in IR range
- Relation between speed, total energy of an electron and its radius with respect to orbital number n: $Speed\ of\ electron \quad v_n = \frac{1}{n}\frac{e^2}{4\pi\epsilon_0}\frac{1}{h/2\pi}$

  $$Radius\ of\ orbit \quad r_n = \frac{n^2}{m}\frac{h}{2\pi}\frac{4\pi\varepsilon_0}{e^2}$$

  Bohr radius, $a_0 = \frac{h^2\epsilon_0}{\pi me^2} \quad = 0.53\dot{A}$

Energy for n[th] orbit electron, $E_n = \frac{-13.6}{n^2}eV$

MNEMONICS for Concept: Hydrogen Spectra

Mnemonics:	**P**apa	**B**rings	**P**astry for	**B**abu and	**L**al
	Pfund	**B**rackett	**P**aschen	**B**almer	**L**yman
	n_1=5	n_1=4	n_1=3	n_1=2	n_1=1

MNEMONICS for Concept: Range of each series of Hydrogen Spectra

1 is **U**nimportant,	**2** is **V**ery important,	**R**est are **I**mportant
n_1=**1** **U**V range	n_1=**2** **V**isible range	n_1=3,4,5 **I**R range

Unit VIII: Atoms and Nuclei

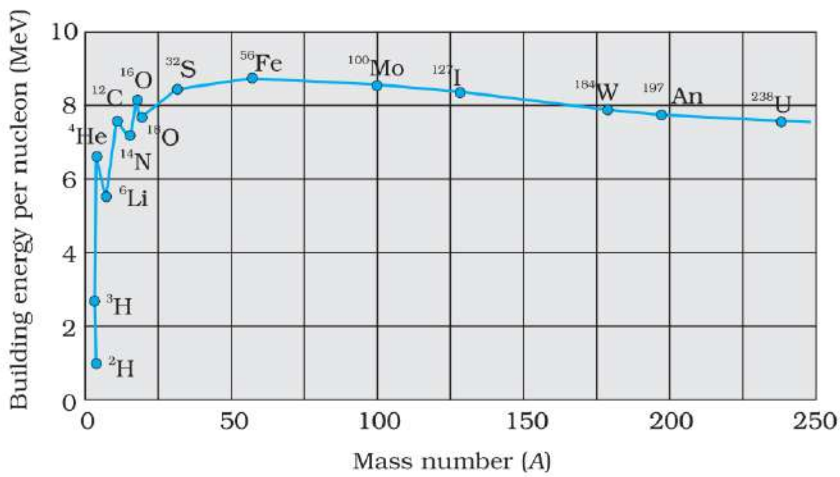
CHAPTER–13: NUCLEI

GIST OF CHAPTER:

Composition and size of nucleus, nuclear force , Mass-energy relation, mass defect; binding energy per nucleon and its variation with mass number; nuclear fission, nuclear fusion.

DEFINITIONS AND CONCEPTS:

1) **Composition of Nucleus:** Nucleus consists of two particles Protons and Neutrons. Protons are positively charged and Neutrons and neutral particles.
2) **Size of Nucleus:** Size of nucleus depends on number of nucleons (Protons and Neutrons). It increases with increase in number of nucleons.
   Size of nucleus $R = R_0 A^{1/3}$
3) **Nuclear force:** The force existing between nucleons (Proton – Proton, Neutron - Neutron, Proton – Neutron) inside the nucleus is called nuclear force. It is strongest force of in nature.
4) **Mass Defect:** Experimentally it has been found that the actual (Practical) mass of a nucleus is less than the expected theoretical mass of nucleus. This difference in Theoretical mass and practical mass is called as mass defect.
   Mass defect ΔM = Theoretical mass – Practical mass
   $\Delta M = [Zm_p + (A - Z)\, m_n] - M$
5) **Binding Energy:** If a certain number of neutrons and protons are brought together to form a nucleus of a certain charge and mass, an energy E_b will be released in the process. The energy E_b is called the binding energy of the nucleus.
   Binding Energy $E_b = \Delta Mc^2$
   Binding Energy per nucleon $E_{bn} = E_b/A$
   Binding energy per nucleon v/s Mass number



6) **Nuclear fission:** When neutron is bombarded on nucleus of heavy elements like uranium, it breaks into two nuclei. This process of breaking nucleus into fragments is called Nuclear fission.
7) **Nuclear fusion:** When two light nuclei combine together to form a larger nucleus, energy is released in this process. This is called as nuclear fusion.
8) **Q-Value:** Energy liberated during fission reaction is called as Q - value.

FORMULAE

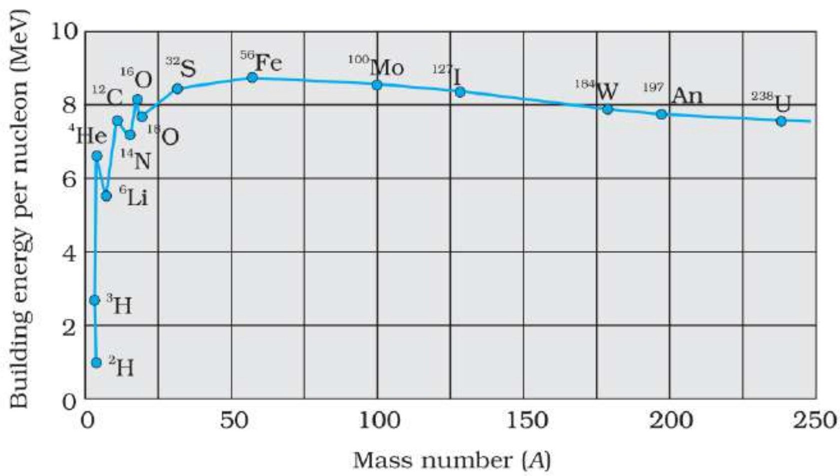
- Size of nucleus — $R = R_0 A^{1/3}$
- Mass energy relation — $E = mc^2$
- Mass defect — ΔM = Theoretical mass – Practical mass
  $\Delta M = [Zm_p + (A - Z) m_n] - M$
- Binding Energy — $E_b = \Delta Mc^2$
- Binding Energy per nucleon — $E_{bn} = E_b/A$

UNITS

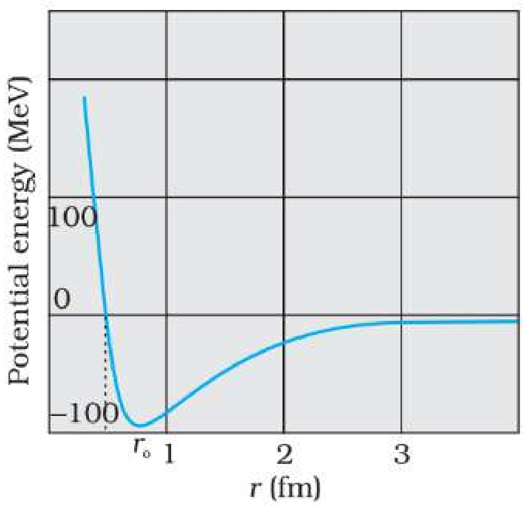
- Size of nucleus — m (metre) or fm (fermi or fempto metre)
- Mass defect — kg (kilogram)or u (unified mass) (1 u = 1.660563 × 10^{-27} kg)
- Binding Energy — J (joule) or MeV (mega electron volt)
- Binding Energy per nucleon — J (joule) or MeV (mega electron volt)

GRAPHS

- Binding energy per nucleon v/s Mass number



- Potential energy of pair of nucleons as a function of separation between them



Unit IX: Electronic Devices 10 Periods

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

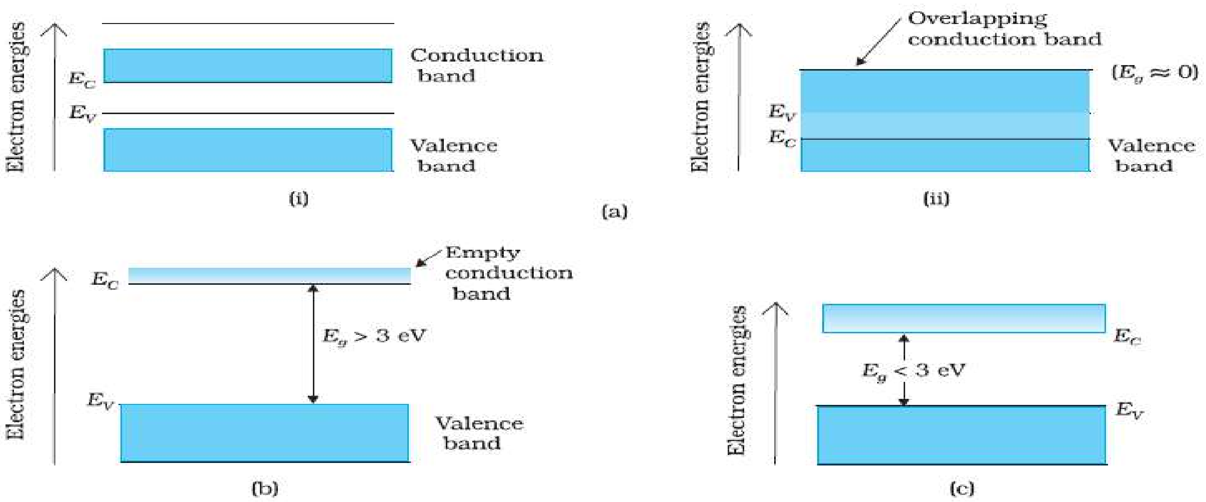
GIST OF THE CHAPTER:

Energy bands in conductors, semiconductors and insulators (qualitative ideas only) Intrinsic and extrinsic semiconductors- p and n type, p-n junction Semiconductor diode - I-V characteristics in forward and reverse bias, application of junction diode -diode as a rectifier.

Energy bands in solids:

- Due to influence of high electric field between the core of the atoms and the shared electrons, energy levels are split-up or spread-out forming energy bands.
- The energy band formed by a series of levels containing valance electrons is called valance band and the lowest unfilled energy level just above the valance band is called conduction band.
- Filled energy levels are separated from the band of unfilled energy levels by an energy gap called **forbidden gap** or energy gap or band gap.

Energy band diagram for, Conductors Semiconductors and Insulators



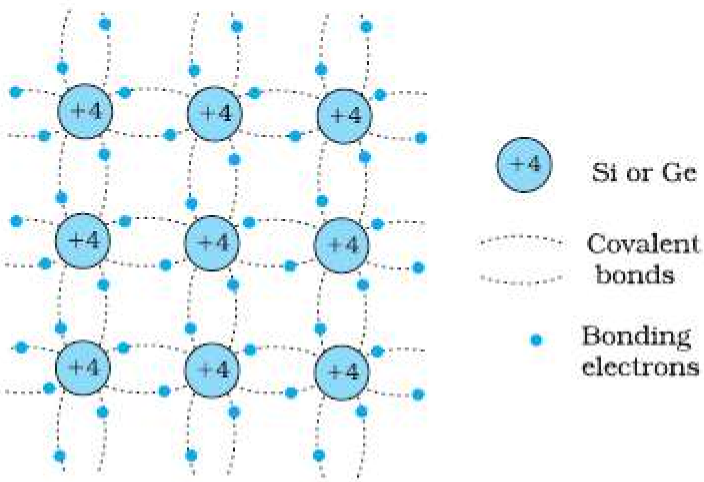
Conductors (Metals): The conduction band and valance band partly overlap each other and there is no forbidden energy gap in between.Large number of electrons are available for electrical conduction , hence the resistance is low of such materials.Even if a small electric field is applied across the metal, these free electrons start moving.Hence metals behave as a conductor.

Semiconductors: The conduction and valance bands are separated by the small energy gap (1 eV) called forbidden energy gap. The valence band is completely filled, while the conduction band is empty at zero kelvin. The electrons cross from valence band to conduction band even when a small amount of energy is supplied. The semiconductor acquires a small conductivity at room temperature.

Insulators: Electrons, however heated, cannot practically jump to conduction band from valence band due to a large energy gap (>3 eV). Therefore, conduction is not possible in insulators.

INTRINSIC SEMICONDUCTORS:

- Intrinsic Semiconductor is a pure semiconductor.
- The energy gap in Si is 1.1 eV and in Ge is 0.74 eV.
- Si: $1s^2, 2s^2, 2p^6, 3s^2, 3p^2$. (Atomic No. is 14)
- Ge: $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^{10}, 4s^2, 4p^2$. (Atomic No. is 32)
- Both Si and Ge have four valance electrons. The four valance electrons form four covalent bonds by sharing the electrons with neighbouring four atoms.
- In intrinsic semiconductor, the number of thermally generated electrons always equals the number of holes. So, if n_i and p_i are the concentration of electrons and holes respectively, then $n_i = p_i$. The quantity n_i or p_i is referred to as the 'intrinsic carrier concentration'.
- At 0 K, a semiconductor is an insulator i.e., it possesses zero conductivity. When temperature is increased, a few covalent bonds break up and release the electrons. These electrons move to conduction band leaving behind equal number of holes in valence band. The conductivity of an intrinsic semiconductor is due to both electrons and holes.



DOPING:

- Doping a Semiconductor: Doping is the process of deliberate addition of a very small amount of impurity (1% of crystal atoms) into an intrinsic semiconductor.
- The impurity atoms are called dopants.
- The semiconductor containing impurity is known as '**Extrinsic semiconductor**'.
- Doping of a semiconductor increases its electrical conductivity to a great extent.
- The pentavalent impurity atoms are called donor atoms, while the trivalent impurity atoms are called acceptor atoms

Extrinsic semiconductor.

A semiconductor doped with a suitable impurity (pentavalent or trivalent), so as to possess conductivity much higher than the semiconductor in pure form is called an extrinsic semiconductor.

Extrinsic semiconductors are of two types:

1) n-type semiconductor
2) p-type semiconductor

1) n-type semiconductor:

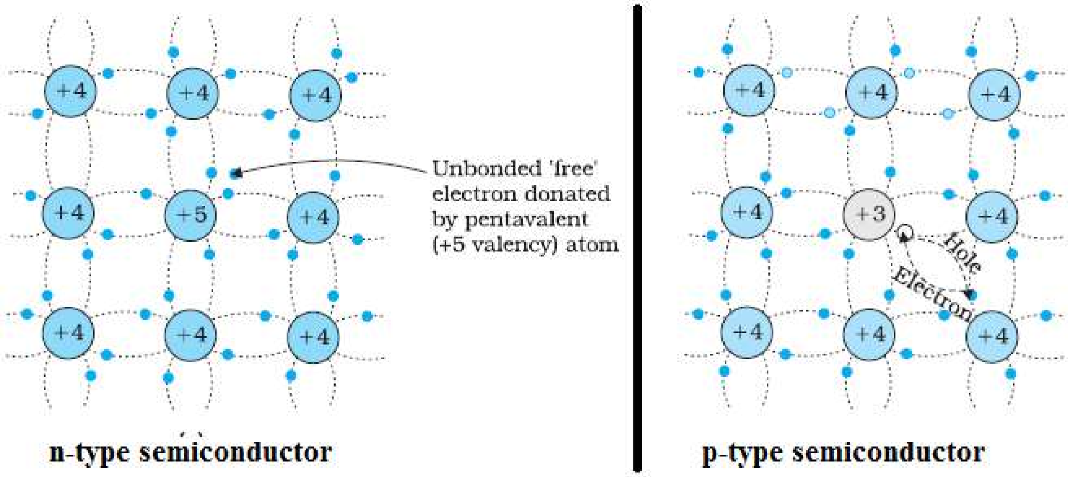
When a pentavalent impurity, such as arsenic or antimony or phosphorus is added to a pure semiconductor, the four of the five valance electrons of the impurity atoms form covalent bonds by sharing the electrons with the adjoining four silicon atoms, while the fifth electron is very loosely bound with the parent impurity atom and is comparatively free to move.

The number of free electrons become more than the holes in the semiconductor and such an extrinsic semiconductor is called n-type semiconductor. In other words, in a n-type semiconductor, electrons are majority carriers and holes are minority carriers.

2) p-type semiconductor:

When a trivalent impurity, such as indium or gallium or boron is added to a pure semiconductor, three valance electrons of the impurity atoms form covalent bonds by sharing the electrons with the adjoining three silicon atoms.

Due to the deficiency of an electron, there is one incomplete covalent bond.The vacancy that exists with the fourth covalent bond with fourth Si atom constitutes a hole.
The semiconductor becomes deficient in electrons i.e. number of holes become more than the number of electrons. Such a semiconductor is called p-type semiconductor. It has holes as majority carriers and electrons as minority carriers.



n-type semiconductor

p-type semiconductor

Electrical conductivity of a semiconductor:

The conductivity of a semiconductor is determined by the mobility (μ) of both electrons and holes and their concentration. Mathematically- $\sigma = e\,(n_e\mu_e + n_h\mu_h)$

P-N JUNCTION.

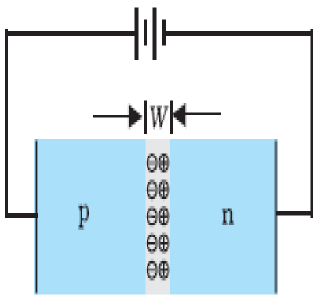
The device obtained by bringing a p-type semiconductor crystal into close contact with n-type semiconductor crystal is called a p-n junction. It conducts in one direction only. It is also called a junction diode

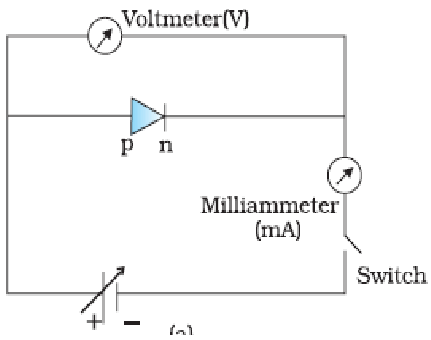
Depletion layer. It is a thin layer formed between the p and n-sections and devoid of holes and electrons. Its width is about 10^{-8} m. A potential difference of about 0.7 V is produced across the junction, which gives rise to a very high electric field (= 10^6 V/ m).

Potential Barrier: The difference in potential between p and n regions across the junction makes it difficult for the holes and electrons to move across the junction. This acts as a barrier and hence called 'potential barrier'.**Potential barrier for Si is nearly 0.7 V and for Ge is 0.3 V.The potential barrier opposes the motion of the majority carriers.**

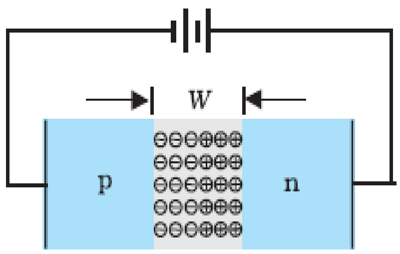
Forward biasing:

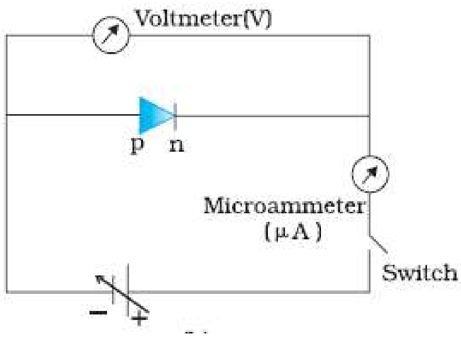
The p-n junction is said to be forward biased, when the positive terminal of the external battery is connected to p-section and the negative terminal to n-section of the junction diode.





Reverse biasing: The p-n junction is said to be reverse biased, when the positive terminal of the battery is connected to n-section and the negative terminal to p-section of the junction diode.

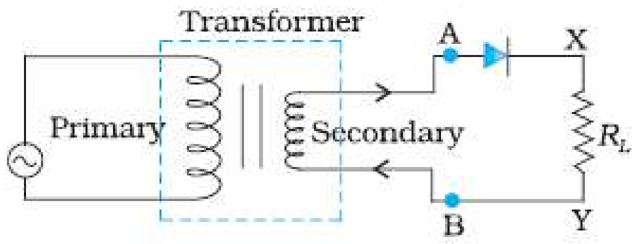




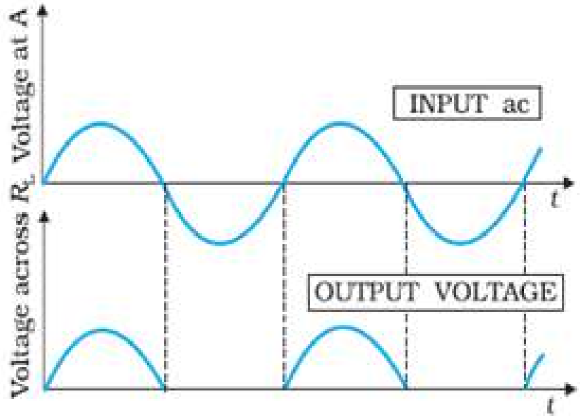
Junction diode as rectifier:

Because of its unidirectional conduction property, the p-n junction is used to convert an a,c. voltage into d. c, voltage, It is, then, said to be acting as a rectifier.

1. **Half wave rectifier:** A rectifier, which rectifies only one half of each a.c. input supply cycle, is called a half wave rectifier. A half wave rectifier gives discontinuous and pulsating d.c. output. As alternative half cycles of the a.c. input supply go waste, its efficiency is very low.

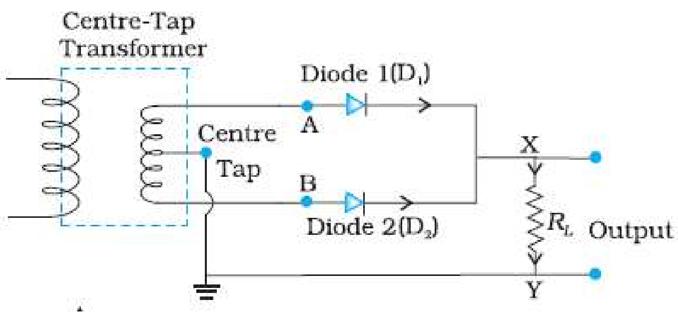


Circuit Diagram

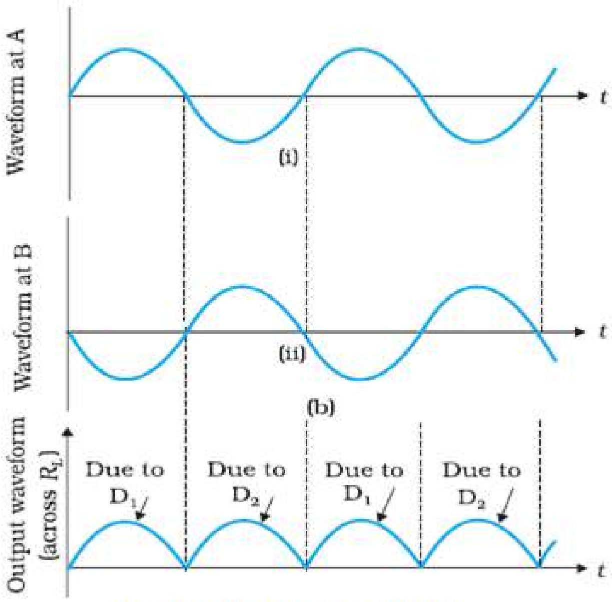


Input- Output Waveform

2. **Full wave rectifier:** A rectifier which rectifies both halves of each a.c. input cycle is called a full wave rectifier. The output of a full wave rectifier is continuous but pulsating in nature. However, it can be made smooth by using a filter circuit.



Circuit Diagram

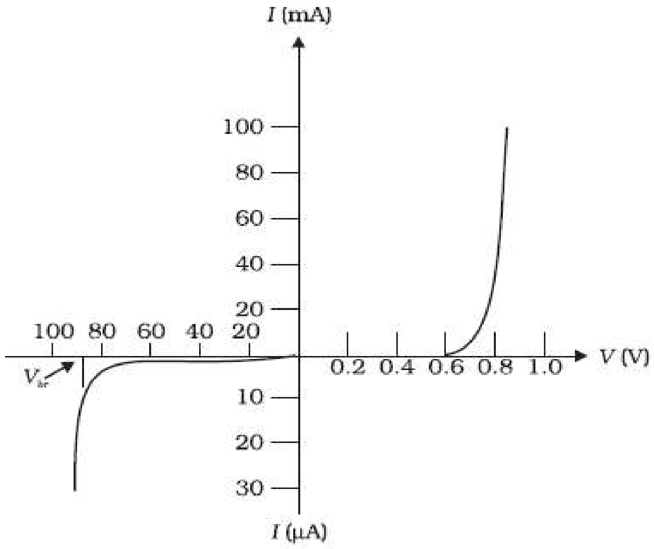


Input- Output Waveform

GRAPHS

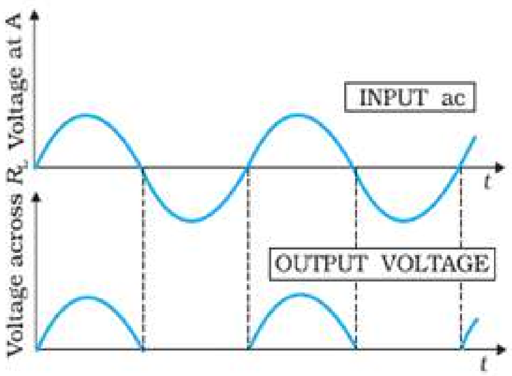
1) I -V CHARACTERISTICS:

Forward Bias & Reverse Bias Characteristics of a P-N Junction Diode

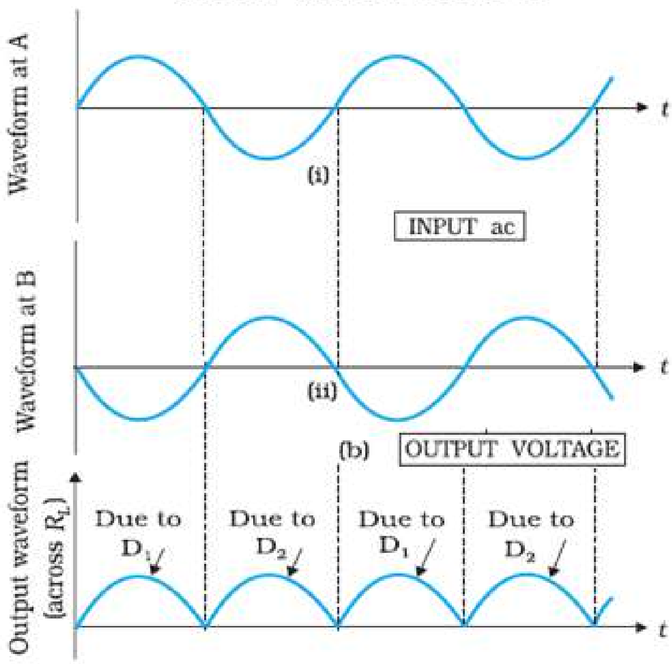


2) INPUT AND OUTPUT VOLTAGE GRAPHS OF

A HALF WAVE RECTIFIER

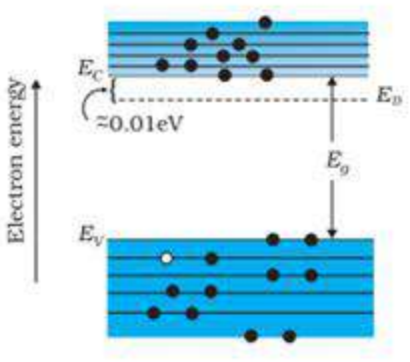


A FULL WAVE RECTIFIER

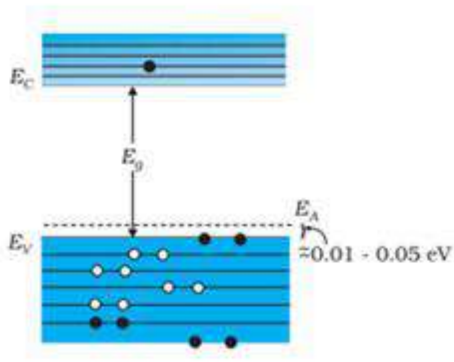


ENERGY BAND DIAGRAMS IN EXTRINSIC SEMICONDUCTORS

1) **n-TYPE SEMICONDUCTOR**



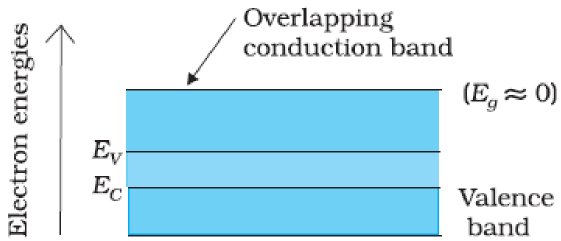
2) **p-TYPE SEMICONDUCTOR**



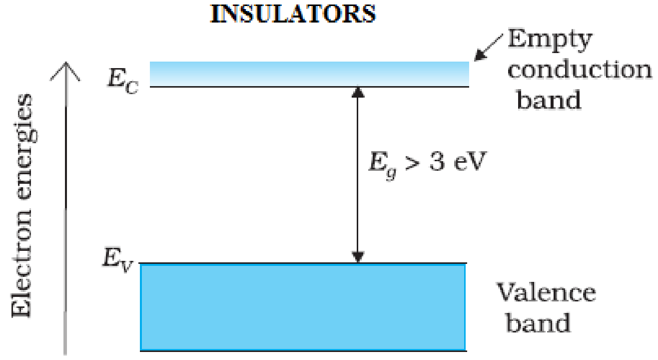
ENERGY BAND DIAGRAMS IN CONDUCTORS, INSULATORS AND SEMICONDUCTOS

CONDUCTORS HAVING PARTIALLY FILLED CONDUCTION BAND

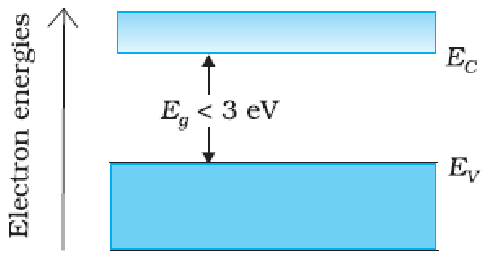
CONDUCTORS WITH OVERLAPPING CONDUCTION AND VALENCE BAND



INSULATORS



SEMICONDUTORS



TABLES

1) DIFFERENCE BETWEEN INTRINSIC AND EXTRINSIC SEMICONDUCTORS

S.NO	INRINSIC SEMICONDUCTOR	EXTRINSIC SEMICONDUCTOR
1	Pure form of semiconductor.	Impure form of semiconductor.
2	Conductivity is low	Conductivity is higher than intrinsic semiconductor.
3	The no of holes is equal to no of free electrons	In n-type, the no. of electrons is greater than that of the holes and in p-type, the no. holes is greater than that of the electrons.
4	The conduction depends on temperature.	The conduction depends on the concentration of doped impurity and temperature.

2) DIFFERENCE BETWEEN HALF WAVE AND FULL WAVE RECTIFIER

S.NO	HALF WAVE RECTIFIER	FULL WAVE RECTIFIER
1	Only half cycle of AC is rectified.	Both cycles of AC are rectified.
2	Requires only one diode	Requires two diodes.
3	The output frequency is equal to input supply frequency. (F)	The output frequency is double of the input supply frequency. (2F)
4	The electric current through the load is not continuous	A continuous electric current flow through the load.

FORMULAE

1) **Electron and hole concentration in a semiconductor in thermal equilibrium**
   $\mathbf{n_e n_h = n_i^{\,2}}$
2) Resistance of a Diode:
   a) Static or DC Resistance $R_{dc} = V/I$
   b) Dynamic or AC Resistance

   $R_{a.c} = \Delta V / \Delta I$

MNEMONICS

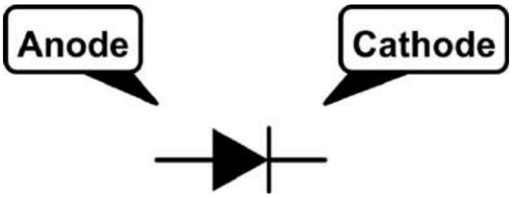
1) **TO REMEMBER NAMES OF IMPURITIES IN SEMICONDUCTORS**

   BIG PAA

   Boron**, I**ndium**, G**allium **(all three are trivalent impurities)**

   Phosphorus**, A**ntimony**, A**rsenic **(all three are pentavalent impurities)**

2) **TO REMEMBER THE P AND N SECTIONS OF A DIODE.**
   The arrow in the schematic symbol for diodes points in the direction of Conventional (positive) current flow.



P **N**

3) Current is **unidirectional** in a diode**. It flows from anode to cathode only.** To remember this, remember the mnemonics **'ACID' (ANODE CURRENT IN DIODE)**