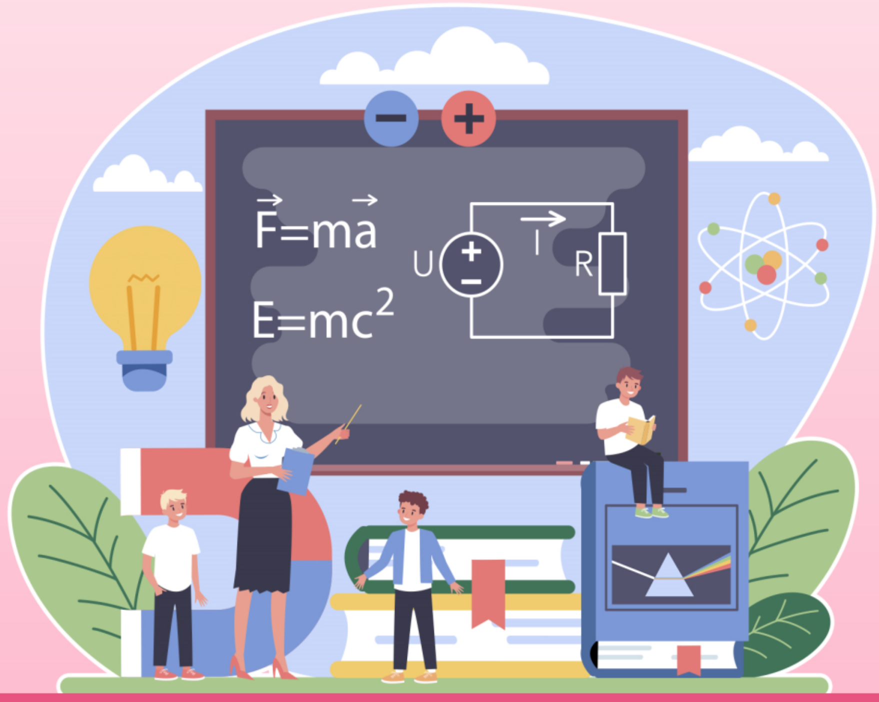
भौतिकी
Physics

कक्षा / Class XII

2025-26

विद्यार्थी सहायक सामग्री
Student Support Material



केन्द्रीय विद्यालय संगठन~Kendriya Vidyalaya Sangathan

संदेश

विद्यालयी शिक्षा में शैक्षिक उत्कृष्टता प्राप्त करना एवं नवाचार द्वारा उच्च - नवीन मानक स्थापित करना केन्द्रीय विद्यालय संगठन की नियमित कार्यप्रणाली का अविभाज्य अंग है। राष्ट्रीय शिक्षा नीति 2020 एवं पी. एम. श्री विद्यालयों के निर्देशों का पालन करते हुए गतिविधि आधारित पठन-पाठन, अनुभवजन्य शिक्षण एवं कौशल विकास को समाहित कर, अपने विद्यालयों को हमने ज्ञान एवं खोज की अद्‌भुत प्रयोगशाला बना दिया है। माध्यमिक स्तर तक पहुँच कर हमारे विद्यार्थी सैद्धांतिक समझ के साथ-साथ, रचनात्मक, विश्लेषणात्मक एवं आलोचनात्मक चिंतन भी विकसित कर लेते हैं। यही कारण है कि वह बोर्ड कक्षाओं के दौरान विभिन्न प्रकार के मूल्यांकनों के लिए सहजता से तैयार रहते हैं। उनकी इस यात्रा में हमारा सतत योगदान एवं सहयोग आवश्यक है - केन्द्रीय विद्यालय संगठन के पांचों आंचलिक शिक्षा एवं प्रशिक्षण संस्थान द्वारा संकलित यह विद्यार्थी सहायक-सामग्री इसी दिशा में एक आवश्यक कदम है । यह सहायक सामाग्री कक्षा 9 से 12 के विद्यार्थियों के लिए सभी महत्वपूर्ण विषयों पर तैयार की गयी है। केन्द्रीय विद्यालय संगठन की विद्यार्थी सहायक- सामग्री अपनी गुणवत्ता एवं परीक्षा संबंधी सामग्री संकलन की विशेषज्ञता के लिए जानी जाती है और शिक्षा से जुड़े विभिन्न मंचों पर इसकी सराहना होती रही है। मुझे विश्वास है कि यह सहायक सामग्री विद्यार्थियों की सहयोगी बनकर निरंतर मार्गदर्शन करते हुए उन्हें सफलता के लक्ष्य तक पहुँचाएगी।

शुभाकांक्षा सहित ।

निधि पांडे

आयुक्त , केन्द्रीय विद्यालय संगठन

PATRON
SMT. NIDHI PANDEY
COMMISSIONER, KVS

CO-PATRON
DR. P. DEVAKUMAR
ADDITIONAL COMMISSIONER (ACAD.), KVS (HQ)

CO-ORDINATOR
MS. CHANDANA MANDAL
JOINT COMMISSIONER (TRAINING), KVS (HQ)

COVER DESION
KVS PUBLICATION SECTION

EDITOR
MS. MENAXI JAIN
DIRECTOR, ZIET MYSURU

SUBJECT COORDINATOR & ASSOCIATE COURSE DIRECTOR

SH. MANOJ KUMAR PALIWAL, PRINCIPAL
PM SHRI KV NO. 1 MADURAI, CHENNAI REGION

RESOURCE PERSONS
Sh. P SEENIVASAN
PGT(PHYSICS) PM SHRI KV SIVAGANGA

Sh. PRAMOD KUMAR SHRIVASTAVA
PGT(PHYSICS), PM SHRI KV NO 1 BHOPAL

ZIET COORDINATOR
SHRI DINESH KUMAR, TA(PHYSICS)
ZIET MYSURU

CONTENT CREATORS

S NO.	NAME OF THE TEACHER	DESIGNATION	KV NAME	REGION
1	MAHENDRA PRASAD DABI	PGT(PHY)	PM SHRI KV NO 2 CRPF GANDHINAGAR	AHMEDABAD
2	RAJENDRA NATH U	PGT(PHY)	PM SHRI KV MEG & CENTRE	BENGALURU
3	RASHMI K	PGT(PHY)	PM SHRI KV MEG & CENTRE	BENGALURU
4	AZAD SARKAR	PGT(PHY)	PM SHRI KV IIT INDORE	BHOPAL
5	DEEPA	PGT(PHY)	PM SHRI KV MHOW	BHOPAL
6	DEEPA MALVIYA	PGT(PHY)	PM SHRI KV DHAR	BHOPAL
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9	HITENDRA SINGH	PGT(PHY)	PM SHRI KV RANIKHET	DEHRADUN
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17	ALIVELUMANGABAI N	PGT(PHY)	PM SHRI KV NELLORE	HYDERABAD
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20	MAHIPAL SWAMI	PGT(PHY)	PM SHRI KV CHURU	JAIPUR

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Student Support Material contains the following:

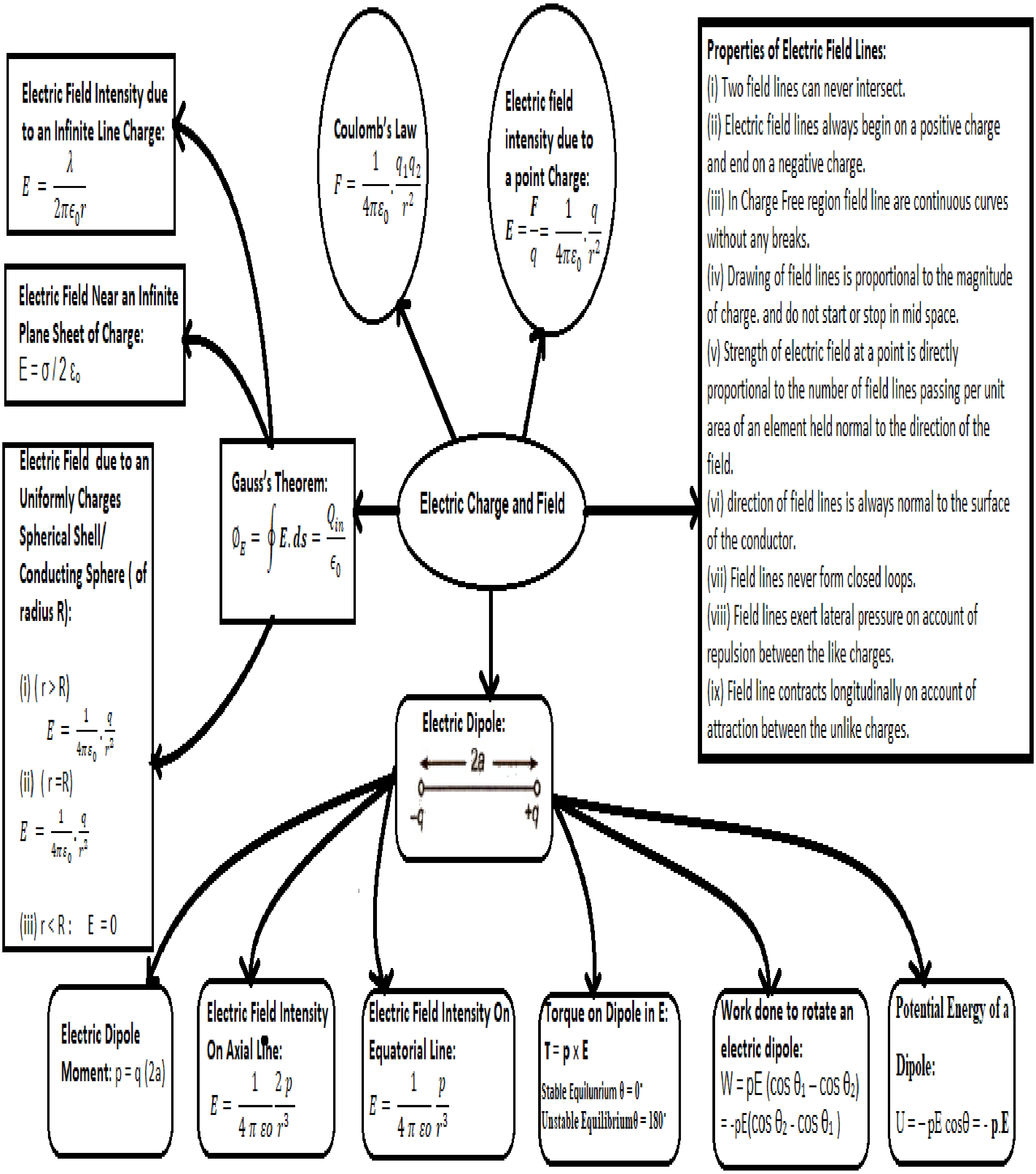
- **MCQs, ASSERTION & REASONING questions, 2 Marks, 3 Marks, Case Based Questions and 5 Marks questions.**
- **Questions are provided with solutions. Exercise questions are having only answers.**
- **Chapter wise syllabus in the beginning of each chapter**
- **The gist of each chapter audio recording QR code.**
- **Link for Previous year's CBSE question papers and answers.**
- **Chapter wise assessment (google form).**
- **Links of video lessons delivered by KVS PGT(Physics) on DIKSHA PORTAL, SWYAM.**
- **Link for three practice question paper is also included in digital resources**
- **Previous year's CBSE sample question paper.**
- **The CBSE curriculum 2025-26 is given in form of QR code**

PHYSICS CURRICULUM (2025-26)

CHAPTER1: ELECTRIC CHARGES & ELECTRIC FIELD

SYLLABUS: - 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).

MIND/CONCEPT MAP:



GIST OF THE LESSON

Electrostatic force of interaction acting between two stationary point charges is given by

$$F = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r^2}$$

where q_1, q_2 are magnitude of point charges, r is the distance between them and ε_o is permittivity of free space.

Here, $\frac{1}{4\pi\varepsilon_o} = 9 \times 10^9$ N-m^2/C^2

The value of ε_o is 8.85×10^{-12} C^2 / N-m^2.

If there is another medium between the point charges except air or vacuum, then ε_o is replaced by $\varepsilon_o K$ or $\varepsilon_o \varepsilon_r$ or ε.

where K or ε_r is called dielectric constant or relative permittivity of the medium.

$K = \varepsilon_r = \varepsilon / \varepsilon_o$ where, ε = permittivity of the medium.

For air or vacuum, K = 1 For water K = 81 For metals, K = ∞

In Medium Culomb's force becomes $F_m = \frac{F_0}{K}$

Coulomb Law implies:

Force on q_1 due to q_2 = – Force on q_2 due to q_1

$\mathbf{F}_{12} = -\mathbf{F}_{21}$

The forces due to two-point charges are parallel to the line joining point charges; such forces are called central forces and electrostatic forces are conservative forces.

Electric Field:

The space in the surrounding of any charge in which its influence can be experienced by other charges is called electric field.

Electric Field Lines:

"An electric field line is an imaginary line or curve drawn through a region of space so that its tangent at any point is in the direction of the electric field vector at that point. The relative closeness of the lines at some place gives an idea about the intensity of electric field at that point."

Properties of Field Lines:

(i) Two field lines can never intersect.

(ii) Electric field lines always begin on a positive charge and end on a negative charge.

(iii) In Charge Free region field line are continuous curves without any breaks.

(iv) Drawing of field lines is proportional to the magnitude of charge. and do not start or stop in mid space.

(v) Strength of electric field at a point is directly proportional to the number of field lines passing per unit area of an element held normal to the direction of the field.

(vi) direction of field lines is always normal to the surface of the conductor.

(vii) Field lines never form closed loops.

Electric Field Intensity (E):

The electrostatic force acting per unit positive charge on a point in electric field is called electric field intensity at that point.

Electric field intensity $\boldsymbol{E} = \frac{\boldsymbol{F}}{q}$

Its SI unit is NC^{-1} or V/m and its dimension is [MLT^{-3} A^{-1}].

It is a vector quantity and its direction is in the direction of electrostatic force acting on positive charge.

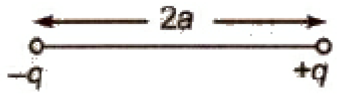
Electric field intensity due to a point Charge:

due to a point charge q at a distance r is given by

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

Electric Dipole:

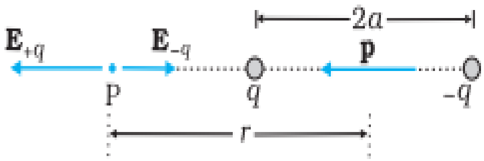
An electric dipole consists of two-point charges of equal magnitude and opposite sign separated by a very small distance. e.g., a molecule of HCL, a molecule of water etc.



Electric Dipole Moment: Product of magnitude of either charge and distance between them. i.e. $p = q\,(2a)$
Its SI unit is 'coulomb-metre' and its dimension is [LTA].
It is a vector quantity and its direction is from negative charge towards positive charge.

Electric Field Intensity and Potential due to an Electric Dipole:

(i) **On Axial Line:**



Electric field intensity

$$E = \frac{1}{4\pi\varepsilon o}\frac{2pr}{(r^2-a^2)^2}$$

If r > > 2a, then $E = \frac{1}{4\pi\varepsilon o}\frac{2p}{r^3}$ (Short Dipole)

Electric potential $V = \frac{1}{4\pi\varepsilon o}\frac{p}{r^2-a^2}$

If r > > 2a, then $V = \frac{1}{4\pi\varepsilon o}\frac{p}{r^2}$ (Short Dipole)

(ii) **On Equatorial Line:**

Electric field intensity $E = \frac{1}{4\pi\varepsilon o}\frac{p}{(r^2+a^2)^{3/2}}$

If r > > 2a, then $E = \frac{1}{4\pi\varepsilon o}\frac{p}{r^3}$ (Short Dipole)

Electric potential V = 0

(iii) At any Point along a Line Making θ Angle with Axis

Electric field intensity

Magnitude of electric field

$$E = \frac{1}{4\pi\varepsilon o}\frac{p\sqrt{1+3\cos^2\theta}}{r^3}$$

Electric potential $V = \frac{1}{4\pi\varepsilon o}\frac{p\cos\theta}{r^2-a^2\cos^2\theta}$

If r > > 2a, then $V = \frac{1}{4\pi\varepsilon o}\frac{p\cos\cos\theta}{r^2}$ (Short Dipole)

Torque on a Electric Dipole in Uniform Electric Field:

Torque acting on an electric dipole placed in uniform electric field is given by

$\tau = pE\sin\theta$

or $\boldsymbol{\tau} = \mathbf{p} \times \mathbf{E}$

When θ = 90°, then '$\tau_{max} = pE$ (Maximum)

When electric dipole is parallel to electric field, it is in stable equilibrium and when it is anti-parallel to electric field, it is in unstable equilibrium. (In this Case Torque = 0)

Electric Dipole in Non-Uniform Electric Field:

When an electric dipole is placed in a non-uniform electric field, then a resultant force as well as a torque act on it.

Net force on electric dipole = $(qE_1 - qE_2)$, along the direction of greater electric field intensity.

Therefore, electric dipole undergoes rotational as well as linear motion.

Work done to rotate an electric dipole in Uniform electric Field:

Work done is rotating an electric dipole in a uniform electric field from angle θ_1 to θ_2 is given by

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

If initially it is in the direction of electric field, then work done in rotating through an angle θ,

$W = pE(1 - \cos\theta)$.

Potential Energy of a Dipole:

Potential energy of an electric dipole in a uniform electric field is given by

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

Stable Equilibrium:

When angle between **p** and **E** is 0 degree.

Unstable Equiibrium:

When angle between p and E is 180^0 .

Electric Flux (φ_E):

Electric flux over an area is equal to the total number of electric field lines crossing this area.

Electric flux through a small area element **dS** is given by

$d\varphi_E = \mathbf{E}.\,\mathbf{dS}$

where E= electric field intensity and dS = area vector.

Its SI unit is Nm^2C^{-1}.

For a curved surface, it is divided into smaller area element and flux through each element is calculated to find total flux i.e.

$$\varphi_E = \sum_{i=1}^{n} E.\Delta s = \oint E.ds$$

Gauss's Theorem:

The electric flux over any closed surface is $1/\varepsilon_o$ times the total charge enclosed by that surface, i.e.,

$$\emptyset_E = \oint \boldsymbol{E.ds} = \frac{Q_{in}}{\epsilon_0}$$ where Q_{in} = Net Charge enclosed in the surface.

Important points regarding Gauss's Law:

(i) The law is valid for a surface of any shape and size.

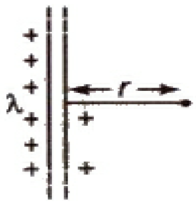
(ii) Q_{in} includes only those charges which are inside the closed surface (may be located anywhere in the surface)

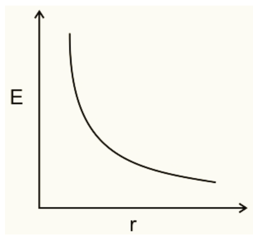
(iii) E in LHS is due to all the charges located inside or outside the surface.

(iv) Any violation of Gauss law will indicate the departure from inverse square law or Coulomb's law.

Note: If a charge q is placed at the centre of a cube, then total electric flux linked with the whole cube = q/ε_o, electric flux linked with one face of the cube = $q / 6\varepsilon_o$.

Electric Field Intensity due to an Infinite Line Charge:



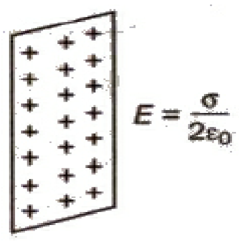


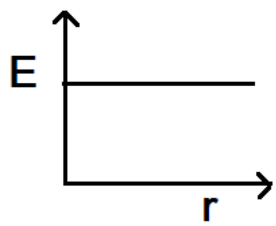
$$E = \frac{\lambda}{2\pi\epsilon_0 r}$$

(Direction –Radially outwards for q > 0 and inwards or q<0)

where λ is linear charge density and r is distance from the line charge.

Electric Field Near an Infinite Plane Sheet of Charge:





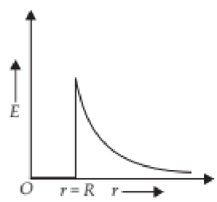
$E = \sigma / 2\varepsilon_o$

where σ = surface charge density.

If infinite plane sheet has uniform thickness, then

$\mathbf{E} = \sigma / \varepsilon_o$

Electric Field Intensity due to an Uniformly Charges Spherical Shell/ Conducting Sphere (of radius R):



(i) At a point lying outside the shell (r > R) $\quad E = \frac{1}{4\pi\varepsilon_0}.\frac{q}{r^2}$

(ii) At a point on the Surface of the shell (r =R) $\quad E = \frac{1}{4\pi\varepsilon_0}.\frac{q}{r^2}$

(iii) At a point inside the shell: $E = 0$

MULTIPLE CHOICE QUESTIONS:

1. When the distance between the charged particles is halved, the force between them becomes
(a) One-fourth (b) Half (c) Double (d) Four times

2. Two charged spheres separated at a distance d exert a force Fon each other. If they are immersed in a liquid of dielectric constant 2, then what is the force (if all conditions are same)
(a) $\frac{F}{2}$ (b) F (c) $2F$ (d) $4F$

3. A hollow insulated conducting sphere is given a positive charge of $10\mu C$. What will be the electric field at the centre of the sphere if its radius is 2 meters
(a) Zero (b) $5\mu Cm^{-2}$ (c) $20\mu Cm^{-2}$ (d) $8\mu Cm^{-2}$

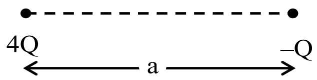
4. An electric dipole consisting of two opposite charges of $2 \times 10^{-6}C$ each separated by a distance of $3cm$ is placed in an electric field of 2×10^5 N/C. The maximum torque on the dipole will be
(a) $12 \times 10^{-1}Nm$ (b) $12 \times 10^{-3}Nm$ (c) $24 \times 10^{-1}Nm$ (d) $24 \times 10^{-3}Nm$

5. The electric field due to a dipole at a distance$r$ on its axis is
(a) Directly proportional to r^3 (b) Inversely proportional to r^3
(c) Directly proportional to r^2 (d) Inversely proportional to r^2

6. If E_a be the electric field strength of a short dipole at a point on its axial line and E_e that on the equatorial line at the same distance, then
(a) $E_e = 2E_a$ (b) $E_a = 2E_e$ (c) $E_a = E_e$ (d) None of the above

7. A charge q is located at the centre of a cube. The electric flux through any face is
(a) $\frac{4\pi q}{6(4\pi\varepsilon_0)}$ (b) $\frac{\pi q}{6(4\pi\varepsilon_0)}$ (c) $\frac{q}{6(4\pi\varepsilon_0)}$ (d) $\frac{2\pi q}{6(4\pi\varepsilon_0)}$

8. The position of the point where net electric field will be zero -



(a) (1+ a) m from 4Q (b) a m from – Q
(c) 1m from 4Q (d) Neutral point not posible

HINTS AND SOLUTIONS:

1. Answers: (d) **Sol.** $F \propto \frac{1}{r^2}$; so when r is halved the force becomes four times.

2. (a) **Sol.** $F \propto \frac{1}{K}$ i.e. $\frac{F_{medium}}{F_{air}} = K$

3. (a) **Sol.** The intensity of electric field inside a hollow conducting sphere is zero.

4. (b) **Sol.** Maximum torque = pE = $2 \times 10^{-6} \times 3 \times 10^{-2} \times 2 \times 10^5 = 12 \times 10^{-3}$ N-m.

5. (b) **Sol.** $E = \frac{1}{4\pi\varepsilon_0}.\frac{2p}{r^3}$

6. (b) **Sol.** We have $E_a = \frac{2kp}{r^3}$ and $E_e = \frac{kp}{r^3}$; $\therefore E_a = 2E_e$

7. (a) **Sol.** $\varphi_{face} = \frac{q}{6\varepsilon_0} = \frac{4\pi q}{6(4\pi\varepsilon_0)}$

8. (b)

ASSERTION AND REASON QUESTIONS

In the following questions, two statements are given –one labelled Assertion (A) and other labeled Reason (R).

Select the correct answer to these questions from the options as given below.

A. If both Assertion and Reason are true and Reason is the correct explanation of Assertion.
B. If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.
C. If Assertion is true but Reason is false.
D. If both Assertion and Reason are false.

1. ASSERTION : When charged balloon is put against on insulating wall, it get stick to the wall.
REASON : Wall acquire a net negative charge & thus attract balloon.

2. ASSERTION (A): In a non-uniform electric field, a dipole may have translatory as well as rotational motion.

REASON (R): In a non-uniform electric field, a dipole experiences a force as well as torque.

3.ASSERTION (A): Gauss law is applicable only for symmetric charge distribution.

REASON (R): In gauss law, electric field is due to only those charges which are present inside the closed surface.

4. ASSERTION: A point charge q_0 is kept outside a solid metallic sphere, the electric field inside the sphere is zero.

REASON : Induced charge does not contribute to electric field or potential at a given point.

5. ASSERTION (A): No torque acts on an electric dipole when its dipole moment is in a direction opposite to the electric field.

REASON (R): An electric dipole is in stable equilibrium when placed in a uniform electric field with its dipole moment opposite to the field.

6. ASSERTION (A): Charge cannot exist without mass.

REASON: The particles such as photon or neutrino which have no (rest) mass are uncharged.

7. ASSERTION (A) : An electron has a negative charge.

REASON (R) : Electrons move away from a region of lower potential to a region of higher potential.

8. ASSERTION (A) : If a point charge q is placed in front of an infinite grounded conducting plane surface, the point charge will experience a force.

REASON (R): This force is due to the induced charge on the conducting surface which is at zero potential.

HINTS AND SOLUTIONS:

1.	**C**	**2.**	**A**	**3.**	**D**	**4.**	**C**	**5.**	**C**
6.	**B**	**7.**	**B**	**8.**	**A**				

VERY SHORT ANSWER TYPE QUESTIONS

1. If a dipole is kept in uniform electric field E, diagrammatically represent the position of the dipole in stable and unstable equilibrium and write the expression for the torque acting on the dipole in both the cases.

Solution: - Stable Equilibrium:

The dipole is aligned parallel to the electric field (angle $\theta = 0°$).

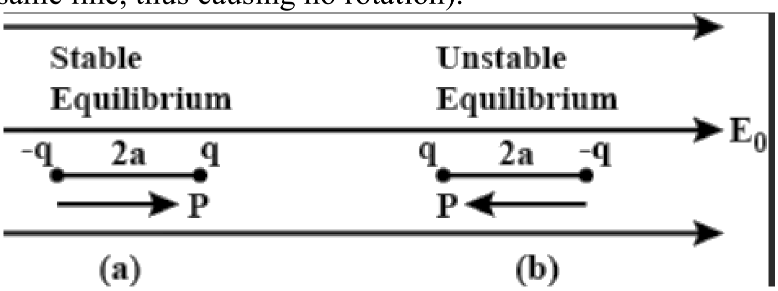
Torque: $\tau = 0$ (The torque is zero because the forces on the positive and negative charges are equal and opposite, and they act along the same line, thus causing no rotation).

Unstable Equilibrium:

The dipole is aligned anti-parallel to the electric field (angle $\theta = 180°$).

Torque:

$\tau = 0$ (The torque is zero because the forces on the positive and negative charges are equal and opposite, and they act along the same line, thus causing no rotation).



2. A spherical balloon carries a charge that is uniformly distributed over its surface. As the balloon is blown up and increases in size, how does the electric flux come out of the surface change? Give reason.

Solution:- The electric flux coming out of the balloon's surface remains unchanged as the balloon is blown up and increases in size. This is because the electric flux is directly proportional to the enclosed charge, and the total charge on the balloon's surface remains constant.

3. An electric dipole of length 10 cm having charges ± 6 x 10^{-3}, placed at 30˚ with respect to a uniform electric field, experiences a torque of 6√3 Nm. Calculate the magnitude of the electric field.

Solution: so, dipole moment of dipole, P = qd = 6 × 10^{-3} C × (10cm)

= 6 × 10^{-3} C × (10/100) m = 6 × 10^{-3} C.m

and angle between dipole , P and external electric field , E is , θ = 30°

we know, torque = P.E sinθ = 6√3 = 6 × 10^{-4} × E × sin30° = √3 × 10^4 = E × (1/2)

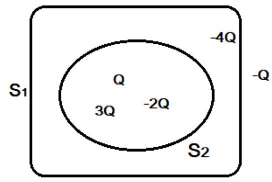
or, E = 2√3 × 10^4 N/C

4. (a) Define electric flux. Write its SI unit. Is it a scalar or vector?

Solution: Electric flux: It is the number of electric field lines passing through a surface normally which is give as $\varphi = E\Delta S\cos\theta$

S.I unit of flux = $Nm^2 C^{-1}$ .It is a Scalar quantity.

5. Find ratio of electric flux through the surface S_1 and S_2 as shown in figure



Answer: $\varphi_1 = \frac{2Q}{\varepsilon_0}$ and $\varphi_2 = \frac{-2Q}{\varepsilon_0}$ and $\frac{\varphi_1}{\varphi_2} = 1:-1$

6. Two small balls, each with a charge Q, hang from the same point by insulating strings of length L from a fixed support. Consider the setup in a region of zero gravity and in equilibrium.

(a) What will be the angle between the two strings?

(b) What will be the tension in each of the strings?

Solution – (a) The angle between the two strings will be 180°.

(b) Tension in each string will be equal to the electrostatic force of repulsion between the two charged balls. $F = \frac{Q^2}{4\pi\epsilon_0(2L)^2}$

7. A thundercloud carries a charge of +50 C at a height of 4000 m and a charge of -50 C at a height of 2000 m from the ground. An airplane crosses through the charged thundercloud at a height of 3000 m from the ground. Find the magnitude and the direction of the electric field acting on the airplane as its crosses through the charged-up thundercloud.

Solution: Electric field due to +50 C above the airplane: $\frac{kq}{r^2} = 9\,x10^9\left(\frac{50}{1000^2}\right)$

= 4.5 x 10^5 N/C, acting downwards.

Electric field due to -50 C above the airplane: $\frac{kq}{r^2} = 9\,x10^9\left(\frac{50}{1000^2}\right)$

= 4.5 x 10^5 N/C, acting downward

So, the total electric field acting on the airplane = 4.5 x 10^5 N/C + 4.5 x 10^5 N/C

= 9 x 10^5 N/C, acting downwards.

8. Two charged conducting spheres of radii a and b are connected to each other by a wire. Find the ratio of the electric fields at their surfaces.

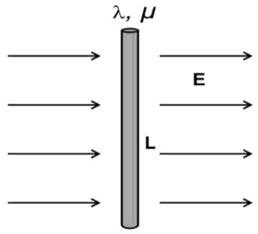
Solution - The electric potential V at the surface of a sphere is given by: V = KQ/r

When connected by a wire, the spheres reach the same potential.

i.e. $V_1 = V_2$ or $kQ_1/a = kQ_2/b$

or Q_1/Q_2 = a/b

Now ratio of electric field $\frac{E_1}{E_2} = \frac{\frac{kQ_1}{a^2}}{\frac{kQ_2}{b^2}} = \frac{Q_1}{Q_2}\frac{b^2}{a^2}$ or $\frac{E_1}{E_2} = = \frac{a}{b}\frac{b^2}{a^2} = \frac{b}{a}$



SHORT ANSWER TYPE QUESTIONS

1. Define electric dipole moment. Is it a scalar or vector ? Derive the expression for the electric field of a dipole on the equatorial plane of the dipole.

Solution: Electric dipole moment is defined as the product of any one of the charges and the length of the electric dipole. **p** = q (**2a**)

q = One of the charges and 2*a* = Length of the electric dipole.

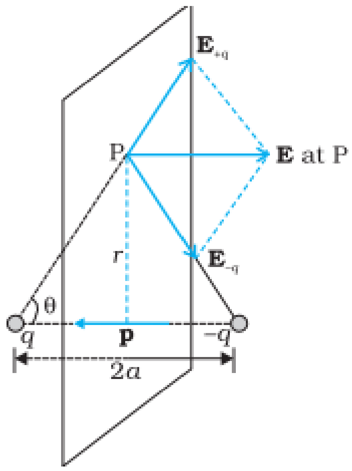
Its direction is from negative charge to positive charge. Its SI unit is coulomb metre.

Electric field of a dipole on the equatorial plane of the dipole:

The magnitudes of the electric fields at point 'P' due to the two charges +q and –q are given by

$$E_q = \frac{kq}{(r^2+a^2)} \quad \& \quad E_{-q} = \frac{kq}{(r^2+a^2)}$$

which are equal in magnitude.



The directions of **E+q** and **E–q** are as shown in Fig.

Clearly, the components normal to the dipole axis cancel away.

The components along the dipole axis add up.

The total electric field is opposite to dipole moment **p**.

Net electric field at point P is

$$E = E_q cos\theta + E_{-q}\, cos\theta$$
$$= 2\, E_q cos\theta$$

Or E = **2 x** $\frac{kq}{(r^2+a^2)}$ **x** $\frac{a}{(r^2+a^2)^{\frac{1}{2}}}$

Or E = $\frac{2kp}{(r^2+a^2)^{\frac{3}{2}}}$ **(Direction – Opposite to direction of p)**

At large distances (r >> a) (or for short dipole), this reduces to

E = $\frac{2kp}{r^3}$ In vector form E = $-\frac{2kp}{r^3}$

2. Using Gauss's law deduce the expression for the electric field due to a uniformly charged spherical conducting shell of radius R at a point (i) outside and (ii) inside the shell.

Plot a graph showing variation of electric field as a function of r > R and r < R (r being the distance from the centre of the shell

Solution : Let σ be the uniform surface charge density of a thin spherical shell of radius R . The situation has spherical symmetry. The field at any point P, outside or inside, can depend only on r (the radial distance from the centre of the shell to the point) and must be radial (i.e., along the radius vector).

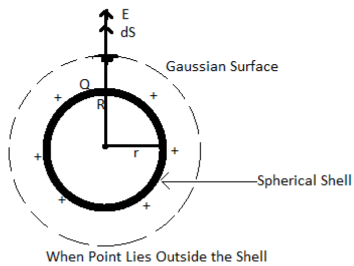
(i) **Field outside the shell:**

Consider a point P outside the shell with radius vector r.

To calculate E at P, we take the Gaussian surface to be a sphere of radius r and with centre O, passing through P.

All points on this sphere are equivalent relative to the given charged configuration. (That is what we mean by spherical symmetry.) The electric field at each point of the Gaussian surface, therefore,

has the same magnitude E and is along the radius vector at each point.



Thus, E and dS at every point are parallel and the flux through each element is E dS.

Summing over all dS, the flux through the Gaussian surface is E × 4πr2 .

The charge enclosed is $\sigma\ (4\pi R^2\ )$.

By Gauss's law $\varphi = \frac{q_{in}}{\epsilon_0}$

Or $E \times 4\pi r^2 = \frac{\sigma\ (4\pi R^2\ )}{\epsilon_0}$

Or $E = \frac{\sigma R^2}{\epsilon_0 r^2} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$ where $\sigma = q(4\pi R^2)$ is surface charge density.

The electric field is directed outward if q > 0 and inward if q < 0. This, however, is exactly the field produced by a charge q placed at the centre O. Thus for points outside the shell, the field due to a uniformly charged shell is as if the entire charge of the
shell is concentrated at its centre.

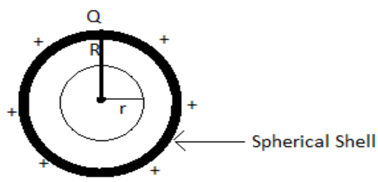
(ii) **Field inside the shell:** In this case the Gaussian surface is again a sphere through P centred at O.

The flux through the Gaussian surface, calculated as before, is $E \times 4\pi r^2$.

However, in this case, the Gaussian surface encloses no charge.

Gauss's law then gives $E \times 4\pi r^2 = 0$ i.e., $E = 0$ (r < R)

that is, the field due to a uniformly charged thin shell is zero at all points inside the shell



When Point Lies Inside the Shell

3. State Gauss's law in electrostatic. Use this law to derive an expression for the electric field due to a uniformly charged infinite plane sheet having uniform charge density $+\sigma$. Obtain the expression for the amount of work done in bringing a point charge q from infinity to a point, distance r, in front of the charge sheet.

Solution: Gauss's Law:

Electric flux of electric field through a close surface held in vacuum is 1 upon ε_0 times total charge enclosed by the surface.

i.e. $\varphi = \frac{q_{in}}{\epsilon_0}$

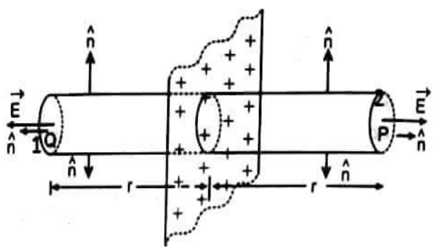
Direction of E:- Let σ be the uniform surface charge density of an infinite plane sheet . We take the x-axis normal to the given plane. By symmetry, the electric field will not depend on y and z coordinates and its direction at every point must be parallel to the x-direction.

Magnitude of E: We take the Gaussian surface to be a cylindrical surface of cross-sectional area A, as shown.

(A rectangular parallelepiped will also do.) As seen from the figure,

only the two faces 1 and 2 will contribute to the flux;

electric field lines are parallel to the other faces and they, therefore, do not contribute to the total flux.



The unit vector normal to surface 1 is in –x direction while the unit vector normal to surface 2 is in the +x direction. Therefore, flux E.ΔS through both the surfaces are equal and add up. Therefore the net flux through the Gaussian surface is 2 EA. The charge enclosed by the closed surface is σA.

Therefore by Gauss's law, $\varphi = \frac{q_{in}}{\epsilon_0}$

$2\ EA = \sigma A/\varepsilon_0$

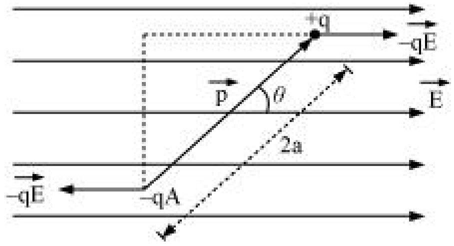
or, $E = \sigma/2\varepsilon_0$

Vectorically, **E** = $\sigma/2\varepsilon_0$ **n** where **n** is a unit vector normal to the plane and going away from it.

Work Done: $W = q\ [V(r) - \ V\ (\infty)] = q\ [E\ r - 0] = \ q\frac{\sigma}{2\epsilon_0}r$

4. Show that an electric dipole held in uniform electric field will not undergo any translator motion. Hence derive an expression for the torque experienced by the dipole.

Solution:



Let us consider an electric dipoleof dipole moment

p = q(2a)

Where, p = Electric dipole moment ,

q = One of the charges and

2a = Length of the electric dipole.

It makes an angle θ with the direction of electric field as shown.

Net force on the dipole = qE – qE = 0

Hence dipole will not undergo translator motion.

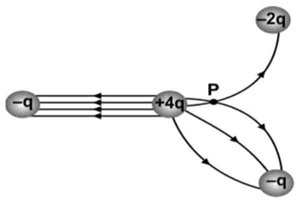
Due to different line of action of force , it experiences a torques which is given by

τ = magnitude of either force × Perpendicular distance between the two forces

= q E (2a sin θ)

or τ = p E sin θ or **τ** = **p** x **E**

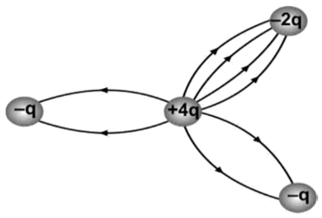
5. The figure below shows an arrangement of four charges along with some electric field lines drawn between the charges.



(a) Identify three things that are incorrect in this figure.

(b) Draw a correct diagram representing the electric field lines for this system of charges..

Solution:

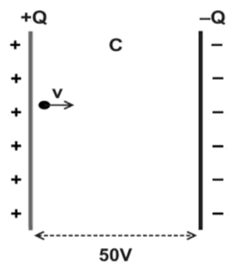


(a) Electric field lines cross each other as shown at point P.

Number of field lines that end on the negative charges is not proportional to their charges.The field lines drawn between +4q and –q are shown as parallel and equidistant.

(b) The correct representation: (shown in fig)

6. A small ball of mass 2 x 10^{-16} kg carrying a charge q = - 2 μC is fired from the positive conducting plate towards the negative conducting plate with a speed of 3 x 10^6 m/s. (figure)



Will the ball strike the negative plate? Give mathematical working for the answer.

Solution : The Ball hits the negative plate if KE of the ball is greater then Work done against the field .

Now KE of the Ball E = $mv^2/2$ = 9 x 10^{-4} J

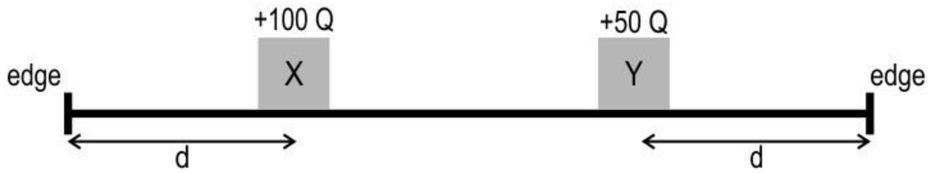
& work to be done against the electric field is W = U = qV = 2 x 10^{-6} x 50 = 10^{-4} J

Since the KE of the ball > Energy required to move through the field between the plates of conducting sheets, the ball will strike the negative plate.

SOURCE BASED QUESTION:

1. Read the following passage carefully and answer the questions that follow after paragraph-

Two small metal blocks (X and Y) of the same mass m are placed on an insulated frictionless surface such that both of them are at the same distance from the edge of the surface as shown in the image below. The charge on block X is +100 Q and that on Y is +50 Q. The two blocks are held in position by an external force.



(i) The external force is require to held them in position since

(a) Both will attract each other with equal magnitude of electrostatic force.

(b) Both will repel each other with equal magnitude of electrostatic force.

(c)X will repel Y with greater magnitude of electrostatic force.

(d) Y will repel X with greater magnitude of electrostatic force.

(ii) If the external force holding the blocks in their respective positions is removed, then which of the following will happen?

(a) Block X will reach the edge first.

(b) Block Y will reach the edge first.

(c) Both the blocks will reach the edge at the same time.

(d) The blocks will NOT move from their positions.

(iii) . If block Y is replaced with another block Z with the same charge but mass 2m, which of the following will happen when the external force holding the blocks in their respective positions is removed?

(a) Block X will reach the edge first.

(b) Block Z will reach the edge first.

(c) Both blocks will reach the edge at the same time.

(d) The blocks will NOT move from their positions.

(iv) . The two blocks X and Y are momentarily brought in contact and placed again in the same initial position as shown in the image.

Which block will reach the edge first, once the external force holding them in their positions is removed?

(a) Block X will reach the edge first.

(b) Block Y will reach the edge first.

(c)Both blocks will reach the edge at the same time.

(d) The blocks will NOT move from their positions.

(v) If nature of charge on Y is altered and they are released, what will be the velocity of their centre of mass ?

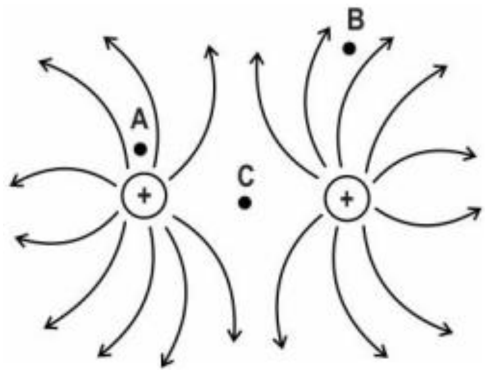
(a) 10 m/s towards right (b) 10 m/s towards left (c) zero (d) none of these

Ans – (i) (b) (ii) (c) (iii) (a) (iv) (c) (v) (c)

2. Read the following passage carefully and answer the questions that follow after paragraph-

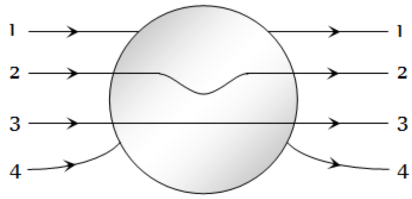
A field line is a graphical visual aid for visualizing vector fields. It consists of an imaginary integral curve which is tangent to the field vector at each point along its length. A diagram showing a representative set of neighbouring field lines is a common way of depicting a vector field in scientific and mathematical literature; this is called a field line diagram. They are used to show electric fields, magnetic fields, and gravitational fields among many other types.

(i) Study the given electric field representation and identify one **INCORRECT** qualitative impression given by this representation.



(a) The electric field at point A is stronger than at point B.
(b)The electric field distribution is two-dimensional.
(c)The electric field at point C is zero.
(d)The electric field always points away from a positive charge.

(ii) A metallic solid sphere is placed in a uniform electric field. The electric field lines follow the path(s) shown in the figure. Which among the four correctly describes electric field line-



(a) 1 (b) 2 (c) 3 (d) 4

(iii) Which of the following is not the property of electric field lines
(a) Electric field line form closed loop.
(b) Electric field line emerges from positive charge.
(c) Electric field line can not have sudden breaks in charge free Region.
(d) No two Electric field lines can intersect each other.

(iv) Electric field lines about negative point charge are
(a) Circular, anticlockwise (b) Circular, clockwise
(c) Radial, inward (d) Radial, outward

Answer: (i) (B)The electric field distribution is two-dimensional.
(ii) (d) 4
(iii) (a)Electric field line form closed loop.
(iv) (c) Radial, inward

3. **Read the following passage carefully and answer the questions that follow after paragraph-**

Gauss Theorem: Electric flux of electric field through a close surface held in vacuum is one upon ε_0 times total charge enclosed by the surface.

i.e. $\boldsymbol{\varphi} = \frac{q_{in}}{\epsilon_0}$

where q_{in} included only those charges which are located inside the closed surface. Gauss theorem can be conveniently applied to find electric field due to the given charge distribution by assuming any closed surface imagined around the charge distribution called Gaussian Surface. The law is applicable for a Gaussian Surface of any shape and Size.

(i) Two charges of magnitude -2Q and +Q are located at points (a, 0) and (4a, 0) respectively. What is the electric flux due to these charges through a sphere of radius '3a' with its Centre at origin?
(a) Q/ϵ_0 (b) $-2Q/\epsilon_0$ (c) $3Q/\epsilon_0$ (d) $-3Q/\epsilon_0$

(ii) A charge q is placed at the Centre of a cube of side l. What is the electric flux passing through each face to the cube?
(a) $q/5\epsilon_0$ (b) $q/9\epsilon_0$ (c) $q/6\epsilon_0$ (d) q/ϵ_0

(iii) Chares outside the Closed surface does not contribute in electric flux through the surface since due to outside charges

(a) number of filed lines are countless
(b) no field lines can get through the surface
(c) number of field lines entering the surface is equal to number of field lines leaving the surface.
(d) no field lines are emitted.

(iv) SI unit of electric flux is
(a) N^2mC (b) V m (c) Nm^2C^{-1} (d) both (b) and (c)

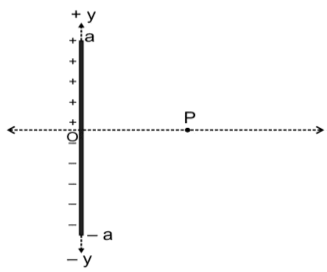
Answer: (i) (B) $-2Q/\epsilon_0$ **(ii)** (C) $q/6\epsilon_0$ **(iii) (C)** **(iv)** (D) both (b) and (c)

LONG ANSWER TYPE QUESTIONS:

1. A spherical Gaussian surface encloses a positive charge q. Find net electric flux through the surface. Explain with a reason what happens to the net electric flux through the Gaussian surface if:
(a) the charge is tripled.
(b) the volume of the sphere is tripled.
(c)the shape of the Gaussian surface is changed into a cuboid.
(d) the charge is moved into another location inside the Gaussian surface

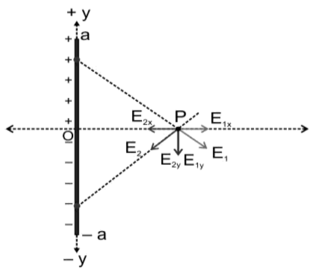
Solution: electric flux through the surface is $\varphi = \frac{q}{\epsilon_0}$
(a) The net flux is also tripled because as per Gauss law the net flux is proportional to the net charge enclosed.
(b) Regardless of the volume of the enclosed surface, if the net charge enclosed is the same, the net flux remains the same as per Gauss law.
(c)No change in the net flux as it doesn't depend upon the shape of the closed surface.
(d) As long as the new location of the charge remains inside the Gaussian surface, there is no change in net flux.

2. (a) Given is a line of charge of uniform linear density. A charge +q is distributed uniformly between y = 0 and y = a and charge –q is distributed uniformly between y = 0 and y = -a.



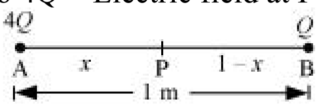
Explain how the direction of the resultant electric field at point P can be obtained. Represent using a vector diagram.
(b) Two point charges 4*Q*, *Q* are separated by 1 m in air. At what point on the line joining the charges is the electric field intensity zero?

Solution
(a) The x-components of E_1 and E_2, due to two equidistant points on either side of O, cancel each other. The resultant electric field is due to the superposition of the y-components of E_1 and E_2.
The direction of the net electric field is along the negative y-axis. This is true for all pairs of equidistant points on either side of O.



(b) Let the point be at a distance x from 4Q charge.
Electric field at P due to 4Q = Electric field at P due to Q

$$\frac{k(4Q)}{x^2} = \frac{kQ}{(1-x)^2}$$



$$\frac{2}{x} = \mp \frac{1}{1-x}$$

Therefore x = 2/3 m or 2m.
Since 2m is not possible so answer is 2/3 metre from charge 4Q.

3. (a) State Gauss's law in electrostatic. Use this law to derive an expression for the electric field due to an infinitely long straight uniformly charged wire having linear charge density λ C/m.

(b) Obtain the expression for the amount of work done in bringing a point charge q from infinity to a point, distance r, in front of the line charge.
(c) An infinite line charge produces a field of 9×10^4 N/C at a distance of 2 cm. Calculate the linear charge density.

Solution:

(a) Gauss's Law:

Electric flux of electric field through a close surface held in vacuum is 1 upon ε_0 times total charge enclosed by the surface.

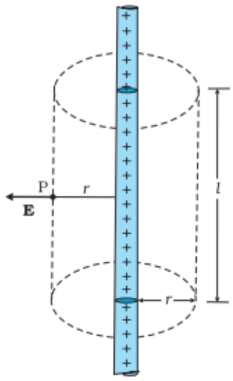
i.e. $\varphi = \frac{q_{in}}{\epsilon_0}$

Electric field due to an infinitely long straight uniformly charged wire:

For a wire of infinite length, the electric field is everywhere radial in the plane cutting the wire normally, and its magnitude depends only on the radial distance r.

To calculate the field, we imagine a cylindrical Gaussian surface, as shown in the.

Since the field is everywhere radial, **Electric flux through the two ends of the cylindrical Gaussian surface is zero**. At the cylindrical part of the surface, E is normal to the surface at every point, and its magnitude is constant, since it depends only on r. The surface area of the curved part is 2πrl, where l is the length of the cylinder.



Using Gauss Law on surface S , $\varphi = \frac{q_{in}}{\epsilon_0}$

$$E.2\pi rl = \frac{\lambda l}{\epsilon_0}$$

$$E = \frac{\lambda}{2\pi\epsilon_0} = \frac{2k\lambda}{r}$$

In Vector form $\boldsymbol{E} = \frac{\lambda}{2\pi\epsilon_0}\boldsymbol{n} = \frac{2k\lambda}{r}\boldsymbol{n}$

Where **n** is the radial unit vector in the plane normal to the wire passing through the point.

E is directed outward if λ is positive and inward if λ is negative.

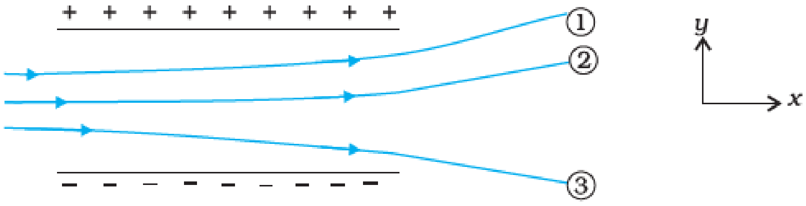
(b) $W = \int_{\infty}^{r} \boldsymbol{E}.\boldsymbol{dr} = \int_{\infty}^{r} \boldsymbol{Edrcos\pi} = -\int_{\infty}^{r} \frac{2k\lambda}{r}\boldsymbol{dr} = -\boldsymbol{2k}\lambda \log_e r$

(c) Using

$E = \frac{\lambda}{2\pi\epsilon_0} = \frac{2k\lambda}{r}$ or $\lambda = \frac{Er}{2k}$

Substituting the values we get $\lambda = \frac{9 \times 10^4 \times 2 \times 10^{-2}}{2 \times 9 \times 10^9} = 10^{-7}$ N/C

4. (a) Figure shows tracks of three charged particles in a uniform electrostatic field. Give the sign of these charges.



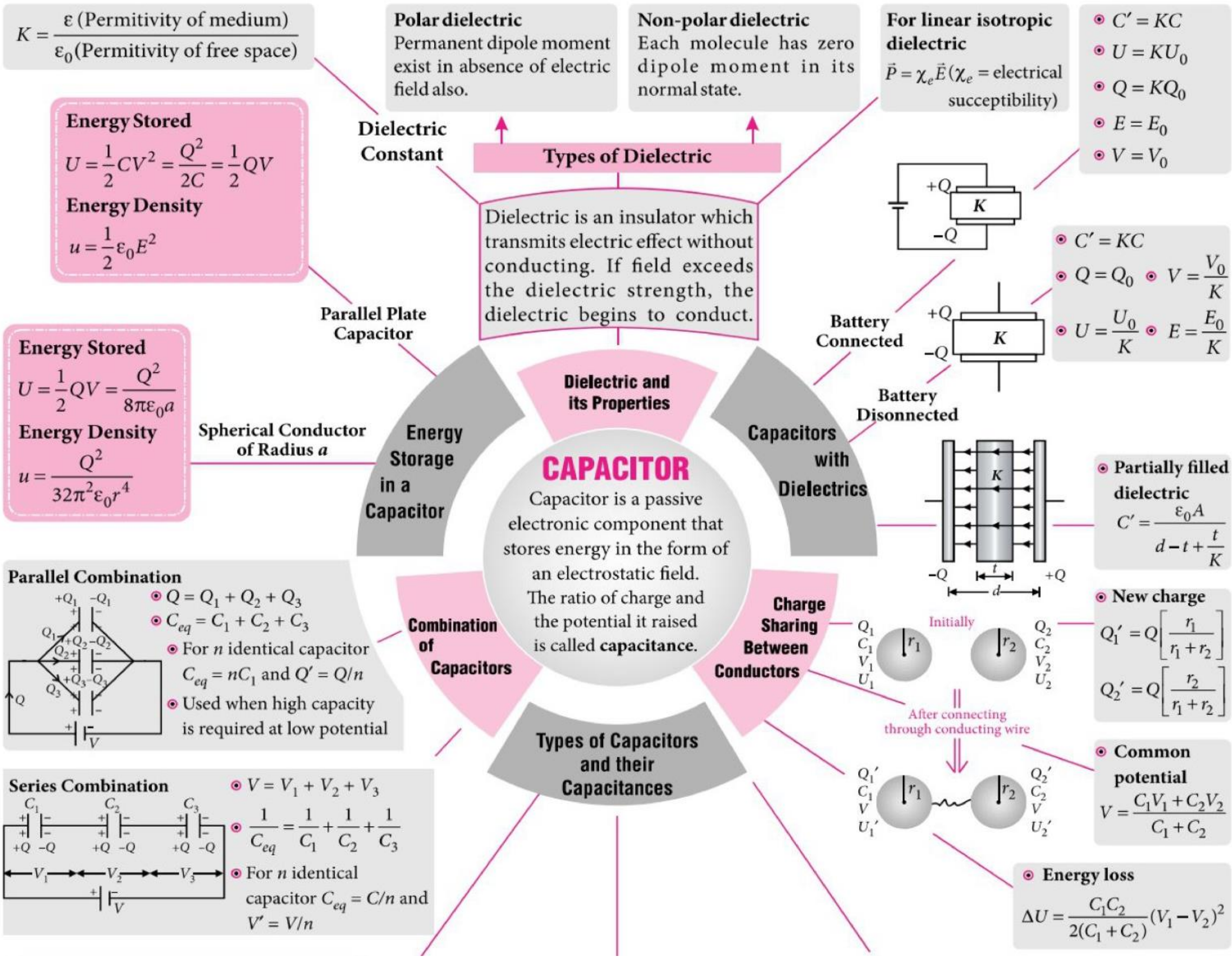
Solution : (a) Charge 1 - negative charge, charge 2 – negative charge , charge 3 - positive charge.

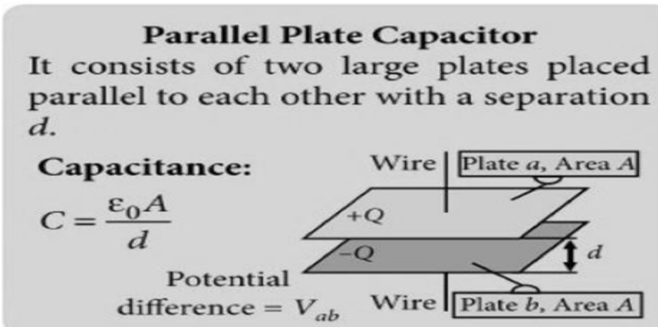
CHAPTER–2: ELECTROSTATIC POTENTIAL AND CAPACITANCE

Syllabus:- 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)

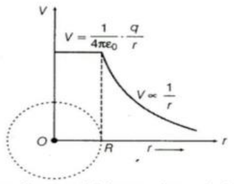
MIND MAP





GIST OF THE CHAPTER

The concept of electric potential and capacitor used in daily life as



Variation of potential due to charged shell with distance r from its centre

1. **Power Distribution**: Electric potential, or voltage, is what drives current flow in electrical circuits, ensuring that power is delivered to devices.
2. **Electronic Devices**: Electric potential is used to control the movement of charges, as seen in TV screens, electron microscopes, and other devices.
3. **Lightning Rods**: Lightning rods are designed to facilitate the transfer of charge, preventing damage during lightning strikes
4. **High-Voltage Transmission Lines**: Smooth surfaces are used on high-voltage transmission lines to prevent charge leakage
5. **Household Appliances**: In refrigerators, air conditioners, and other appliances, capacitors help start motors efficiently and reduce power consumption.
6. **Audio Equipment**: Capacitors are crucial in audio equipment for filtering out unwanted noise and stabilizing signals, ensuring clear and reliable sound.
7. **Camera Flashes**: Capacitors store energy to provide a burst of power for camera flashes, allowing them to capture images in low-light conditions.
8. **Automotive Systems**: In hybrid and electric vehicles, capacitors are used for energy recuperation systems.
9. **Medical Devices**: Capacitors are used in medical devices like defibrillators to deliver a burst of energy to restore a normal heartbeat.

Electrostatic potential (V)

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

$$V = -\int_{\infty}^{r} \vec{E}.\vec{dr}$$

https://ophysics.com/em4.html

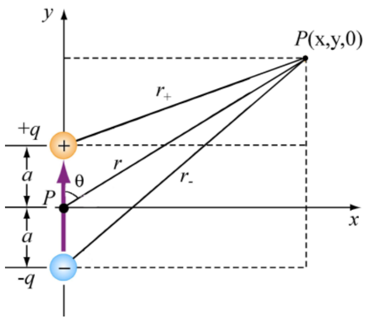
1. Electric potential due to point charge $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$
2. A system of charges $q_1, q_2, \ldots, q_n$ with position vectors $r_1, r_2, \ldots, r_n$ relative to some origin

The potential V at any point P due to the total charge configuration is the algebraic sum of the potentials due to the individual charges

$$V = V_1 + V_2 + V_3 + \text{-------------} + V_n$$

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1}{r_{1P}} + \frac{q_2}{r_{2P}} + \frac{q_3}{r_{3P}} + \cdots \ldots \ldots + \frac{q_n}{r_{nP}}\right)$$

3. Electric potential due to Electric dipole



(i) At any point

$$V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2} \quad \text{or} \quad V = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\hat{\imath}}{r^2}$$

(ii) At a point on the dipole axis (θ = 0, π)

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r} \quad \text{or} \quad V = -\frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

(iii) Potential in the equatorial plane ($\theta = \frac{\pi}{2}$)

$$V = 0$$

4. Electric potential uniformly charged spherical shell

(i) At a point outside the shell (r > R)

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

(ii) At a point on the surface of shell (r = R)

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

(iii) At a point inside the shell (r < R)

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

Electric Potential Difference (ΔV)

It is the work done against electric field in moving a unit positive charge from one point to other. That is

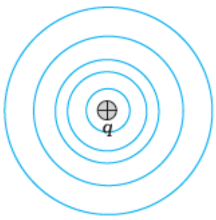
$$V_2 - V_1 = -\int_1^2 \vec{E}.\vec{dr}$$

If W_{12} is work done in moving a charge q from one point to another point then

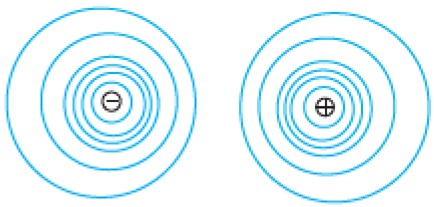
$$V_2 - V_1 = \frac{W_{12}}{q} \Rightarrow W_{12} = q(V_2 - V_1)$$

EQUIPOTENTIAL SURFACES

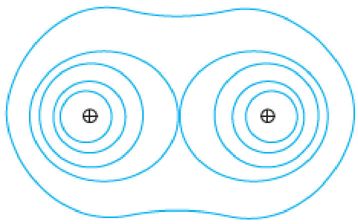
1. The electric potential is the same at all locations on the surface.
2. The electric field lines are always perpendicular to the equipotential surface.
3. Two equipotential surfaces cannot intersect.
4. No work is required to move a charge along an equipotential surface because the potential difference is zero along the surface.
5. No work is required to move a charge along an equipotential surface because the potential difference is zero along the surface.
6. Shape of equipotential surfaces



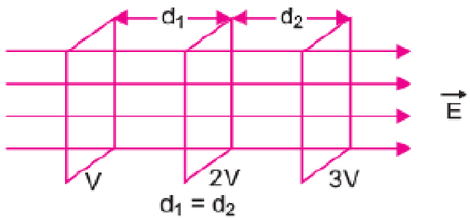
Point charge



a dipole



Two identical positive charges



Uniform electric field

Relation between field and potential

$$E = -\frac{dV}{dr}$$

(i) Electric field is in the direction in which the potential decreases steepest.

(ii) Its magnitude is given by the change in the magnitude of potential per unit displacement normal to the equipotential surface at the point.

Electric Potential Energy(U)

Potential energy of charge q at a point (in the presence of field due to any charge configuration) is the work done by the external force (equal and opposite to the electric force) in bringing the charge q from infinity to that point.

(i) Potential energy for a system of two charges q_1 and q_2 is

$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$$

(ii) Potential energy of a system of two charges in an external field

$$U = q_1\, V(r_1) + q_2\, V(r_2) + \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$$

(iii) Potential energy of a dipole in an external field

The amount of work done by the external torque rotating dipole from angle θ_0 to angle θ_1 at an infinitesimal angular speed and without angular acceleration will be given by

$W = pE(\cos\theta_0 - \cos\theta_1)$

This work is stored as the potential energy of the system. Take $\theta_0 = \frac{\pi}{2}$ and $\theta_1 = \theta$

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

Simulation link for topic:- Capacitor

https://phet.colorado.edu/en/simulations/capacitor-lab-basics

MULTIPLE CHOICE QUESTIONS

1. A uniform electric field pointing in positive x-direction exists in a region. Let A be the origin, B be the point on the x-axis at x = + 1 cm and C be the point on the y-axis at y = + 1 cm. Then, the potentials at the points A, B and C satisfy

(a) $V_A < V_B$ (b) $V_A > V_B$ (c) $V_A < V_C$ (d) $V_A > V_C$

2. Which statement is not correct for an equipotential surface?
(a) Electric field intensity is always perpendicular to the equipotential surface.
(b) Potential difference between any two points on it is zero.
(c) Equipotential surfaces are spherical in shape.
(d) No work is required to move a charge on an equipotential surface

3. An electron mass m and charge e travels from rest through a potential difference of V. What will be the final velocity of electron?

(a) eV (b) $\frac{2eV}{m}$ (c) $\sqrt{\frac{2eV}{m}}$ (d) $\sqrt{\frac{2mV}{e}}$

4. Four point charges –Q, -q, 2q and 2Q are placed, one at each corner of the square. The relation between Q and q for which the potential at the centre of the square zero, is

(a) Q = -q (b) $Q = \frac{-1}{q}$ (c) Q = q (d) $Q = \frac{1}{q}$

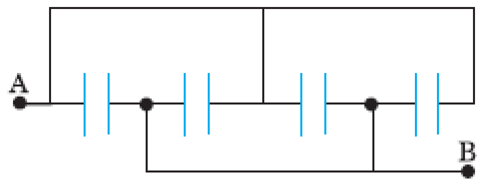
5. A hollow metal sphere of radius 10 cm is charged such that the potential on its surface is 80 V. The ratio of potential at a distance 5cm from the centre of the sphere to the potential at the surface of sphere is

(a) 1:2 (b) 2:1 (c) 1:1 (d) 1:4

6. There is one charged isolated air capacitor and *U* is the energy stored in it. Separation between the plates of the capacitor is increased to double of the initial value. Energy stored becomes

(a) U/2 (b) 2U (c) U/3 (d) 3U

7. Four condensers are joined as shown in the figure and the capacity of each condenser is 8 μF. The equivalent capacity between the points A and B will be:



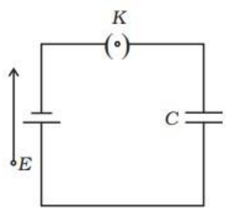
(*a*) 16 μF (*b*) 8 μF
(*c*) 32 μF (*d*) 2 μF

8. A parallel plate capacitor is connected to a battery as shown in Fig. Consider two situations:

A: Key K is kept closed and plates of capacitors are moved apart using insulating handle.

B: Key K is opened and plates of capacitors are moved apart using insulating handle.

Choose the correct option(s).



(a) In A : Q remains same but C changes.
(b) In B : V remains same but C changes.
(c) In A : V remains same and hence Q changes.
(d) In B : C remains same and hence V changes.

ANSWERS

1. (b) E = - $\frac{dV}{dr}$, Direction of electric field must be in the direction of the decreasing order of electric potential.
2. (c) Shape of equipotential surface depends on charge or distribution of charges
3. (c) eV = $\frac{1}{2}mv^2$ ➡ $v = \sqrt{\frac{2eV}{m}}$
4. (b) $\frac{1}{4\pi\varepsilon_0}\frac{-Q}{R} + \frac{1}{4\pi\varepsilon_0}\frac{-q}{R} + \frac{1}{4\pi\varepsilon_0}\frac{2Q}{R} + \frac{1}{4\pi\varepsilon_0}\frac{2q}{R} = 0$ ➡ Q = $\frac{-1}{q}$
5. (c) Value of potential inside and on the surface of a charged spherical shell is same
6.(b) As capacitor is isolated so charge on capacitor remains same

New capacitance $C' = \frac{C}{2}$ and $V' = 2V$

Hence, new energy $U' = 2U$

7.(c) All capacitors are connected in parallel so $C_{eq} = C_1 + C_2 + C_3 + C_4$ so C_{eq} = 32 μF
8.(c) As it is connected to battery so V remains same but as capacitance changes so charge changes

ASSERTION-REASON QUESTIONS

Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below:

(a) Both assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

(b) Both assertion (A) and Reason (R) are true and Reason (R) is NOT the correct explanation of Assertion (A).

(c) Assertion (A) is true and Reason (R) is false.

(d) Assertion (A) is false and Reason (R) is also false.

1. **Assertion (A):** Electric field is always normal to equipotential surfaces and along the direction of decreasing order of potential.
Reason (R): Negative gradient of electric potential is electric field.
2. **Assertion (A):** Electric field inside a hollow conducting sphere is zero.
Reason (R): Charge is present on the surface of conductor.
3. **Assertion (A):** Work done in moving a charge between any two points in a uniform electric field is independent of the path followed by the charge between these two points.
Reason (R): Electrostatic forces are non conservative.
4. **Assertion (A):** Electric potential and electric potential energy are two different quantities.
Reason (R): For a test charge Q and a point charge Q, the electric potential energy becomes equal to the potential.
5. **Assertion (A):** When the distance between the parallel plates of a parallel plate capacitor is halved and the dielectric constant of the dielectric used is made three times, then the capacitance becomes three times.
Reason (R): Capacitance does not depend upon the external battery connected.
6. **Assertion (A):** Circuit containing capacitors should be handled very carefully even when the power is off.
Reason (R): The capacitors may break down at any time.
7. **Assertion (A):** Capacity of a conductor is independent on the amount of charge on it.
Reason (R): Capacitance depends on the dielectric constant of surrounding medium, shape and size of the conductor.
8. **Assertion (A):** Two parallel metal plates having charge +Q and –Q are facing at a distance between them. The plates are now immersed in kerosene oil and the electric potential between the plates decreases.
Reason (R): Dielectric constant of kerosene oil is less than 1.

ANSWERS

1. Option (A) is correct. **Explanation:** E = - $\frac{dV}{dr}$
So, the electric field is always perpendicular to equipotential surface. Negative gradient of electric potential is electric field. So, direction of electric field must be in the direction of the decreasing order of electric potential.
2. Option (A) is correct. **Explanation:** Since no charge resides in the surface of a hollow sphere, the electric field also zero inside. So, assertion is true. For hollow conducting sphere, the charged reside on the surface only. So, reason is also true and it explains the assertion properly.
3. Option (C) is correct. **Explanation:** Work done in moving a charge between any two points in a uniform electric
field = charge × potential difference. So, it is independent of the path followed by the charge. Hence the assertion is true. Electrostatic forces are conservative type. Hence, the reason is false.
4. Option (C) is correct. **Explanation:** Electric potential and electric potential energy are two different quantities.
Hence the assertion is true. Electric potential is defined as the potential
energy per unit charge. Hence V = P.E./q
So, the reason is false.
5. Option (B) is correct. **Explanation:** Initial capacitance $C_1 = C = \frac{K\varepsilon_0 A}{d}$

$$C_2 = \frac{3K\varepsilon_0 A}{d/2}$$

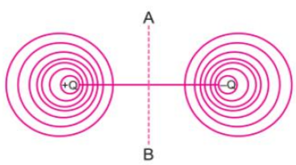
So $C_2 = 6C_1$**,** Hence the assertion is true
6. Option (C) is correct. **Explanation:** Even when power is off capacitor may have stored charge which may discharge through human body and thus one may get a shock.
So, assertion is true. Breakdown of capacitors requires high voltage.
So, reason is false.
7. Option (A) is correct. **Explanation:** $C = \frac{\varepsilon_0 A}{d}$
In the expression, there is no involvement of charge. So, capacitance is independent of charge. Hence the assertion is true.
It depends on permittivity of the surrounding medium and the area of the plate. So, reason is also true.Reason explains the assertion.
8. Option (C) is correct. **Explanation:** Electric field for parallel plate capacitor in vacuum

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

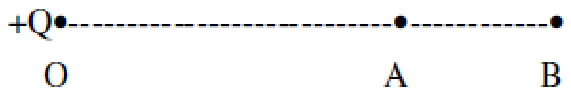
Electric field in dielectric $E' = \frac{\sigma}{K\varepsilon_0}$
Since the value of K for Kerosene oil is greater than 1, then E'< E. Hence the assertion is true. Dielectric constant of Kerosene oil is greater than 1. Hence the reason is false.

VERY SHORT ANSWER TYPE QUESTIONS (2 MARKS)

1. Draw an equipotential surface for a system consisting of two charges Q, –Q separated by a distance r in air. Locate the points where the potential due to the dipole is zero.
Ans. The equipotential surface for the system is as shown. Electric potential is zero at all points in the plane passing through the dipole equator AB.



2. A point charge +Q is placed at point O as shown in the figure. Is the potential difference $V_A – V_B$ positive, negative or zero?

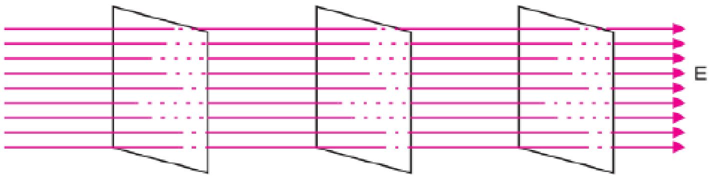


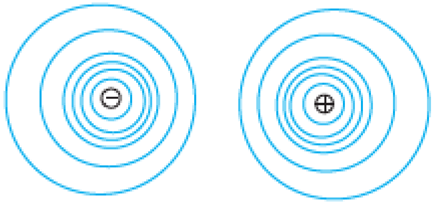
Ans. The potential due to a point charge decreases with increase of distance.

So, $V_A - V_B$ is positive.

3. Draw an equipotential surface in (i) a uniform electric field and (ii) a dipole

Ans. (i) (ii)





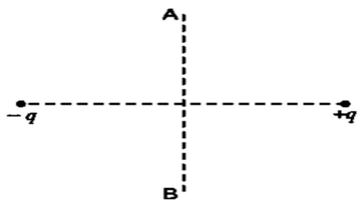
4. "For any charge configuration, equipotential surface through a point is normal to the electric field." Justify.

Ans. The work done in moving a charge from one point to another on an equipotential surface is zero. If electric field is not normal to the equipotential surface, it would have non-zero component along the surface. In that case work would be done in moving a charge on an equipotential surface.

5. A charge 'q' is moved from a point A above a dipole of dipole moment 'p' to a point B below the dipole in equatorial plane without acceleration. Find the work done in the process.

Ans. Work done in the process is zero. Because equatorial plane of a dipole is equipotential surface and work done in moving charge on equipotential surface is zero.

$W = q\ (V_B - V_A) = q \times 0 = 0$



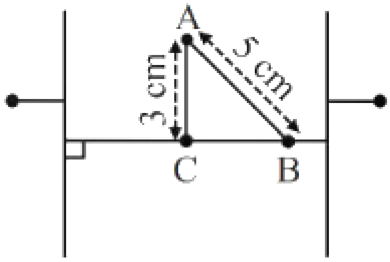
6. A charged particle (+q) moves in a uniform electric field ($\vec{E}$) in the direction opposite to $\vec{E}$. What will be the effect on its electrostatic potential energy during its motion?

Ans. When charge +q moves in opposite direction to electric field then work done is negative.

$\Delta U = -W$

so, change in potential energy is positive, the potential energy increases.

7. Two large plane parallel conducting plates are kept 8 cm apart as shown in figure. The potential difference between them is V. Find potential difference between the points A and B (shown in the figure) ?

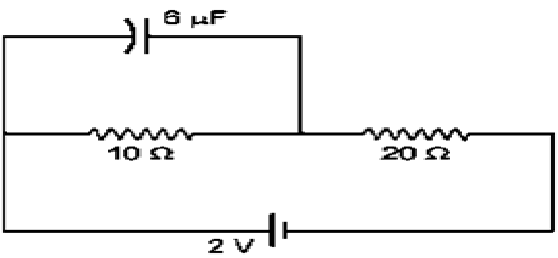


Ans. As $V = E\,d$

$V = E(8)$

Therefore $V_{AB} = E(4) = \left(\frac{V}{8}\right)4 = \frac{V}{2}$

8. Find the charge on the capacitor as shown in the circuit.



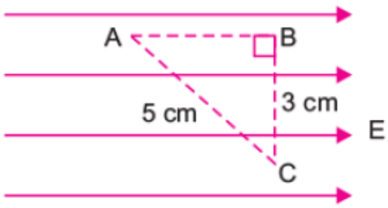
Ans. Total resistance, R = 10Ω + 20Ω = 30Ω, So the current, $I = \frac{V}{R} = \frac{2}{30} = \frac{1}{15}$ A

Potential difference, $V = IR = \frac{1}{15}$ X 10 = $\frac{2}{3}$ V, Therefore, charge Q = CV = 6 X $\frac{2}{3}$ = 4 μC

SHORT ANSWER TYPE QUESTIONS

1. Three points A, B and C lie in a uniform electric field (E) of 5×10^3 NC^{-1} as shown in the figure.

Find the potential difference between (i)A and B, and (ii) A and C.



Ans.(i) Potential difference between A and B = E × (AB) = $5 \times 10^3 \times (4 \times 10^{-2})$ = 200 volt

(ii) The line joining B to C is perpendicular to electric field, so potential of B = potential of C i.e., VB = VC

Distance AB =4 cm

Potential difference between A and C = E × (AB)

= $5 \times 10^3 \times (4 \times 10–2)$ = 200 volt

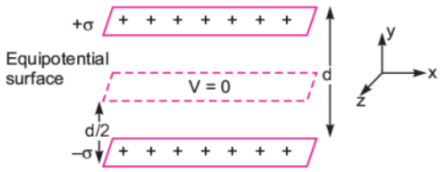
2. Two uniformly large parallel thin plates having charge densities +σ and – σ are kept in the X-Z plane at a distance 'd' apart. Sketch an equipotential surface due to electric field between the plates. If a particle of mass m and charge '–q' remains stationary between the plates, what is the magnitude and direction of this field?

Ans. **(i)** Weight mg acts vertically downward

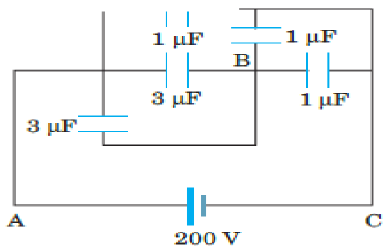
(ii) Electric force qE acts vertically upward.

so mg = qE

$E = \frac{mg}{q}$



3. Calculate the potential difference between points A and B as shown in figure



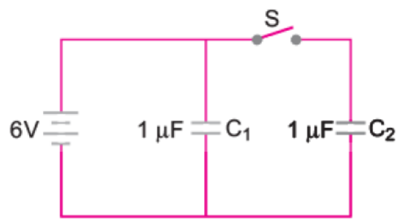
Ans. Equivalent capacitance = $\frac{5}{2}$ μF

Charge supplied by battery = $\frac{5}{2}$ X 200 = 500 μC

Potential difference between A and B is 80V

4. Figure shows two identical capacitors, C_1 and C_2, each of 1 mF capacitance connected to a battery of 6 V. Initially switch 'S' is closed. After sometimes 'S' is left open and dielectric slabs of dielectric constant K = 3 are inserted to fill completely the space between the plates of the two capacitors.

How will the (i) charge and (ii) potential difference between the plates of the capacitors be affected after the slabs are inserted?



Ans. When switch S is closed, p.d. across each capacitor is 6V

$V_1 = V_2$ = 6 V and $C_1 = C_2$ = 1 μC

∴ Charge on each capacitor

$q_1 = q_2$ (= CV) = (1 μF) × (6 V) = 6 μC

When switch S is opened, the p.d. across C1 remains 6 V, while the charge on capacitor C_2 remains 6 μC. After insertion of dielectric between the plates of each capacitor, the new capacitance of each capacitor becomes

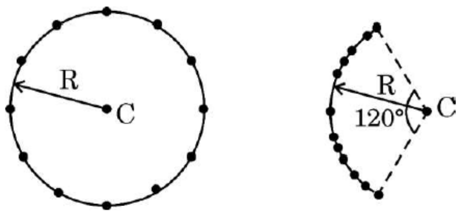
$C'_1 = C'_2 = 3 \times 1$ μF = 3 μF

Charge on capacitor C_1, $q'_1 = C'_1 V_1$ = (3 μF) × 6 V = 18 μC Charge on capacitor C_2 remains 6 μC

Potential difference across C_1 remains 6 V. Potential difference across C_2 becomes

$V_2' = \frac{6}{3} = 2$ V

5. (a) Twelve negative charges of same magnitude are equally spaced and fixed on the circumference of a circle of radius R as shown in Fig. (i). Relative to potential being zero at infinity, find the electric potential and electric field at the centre C of the circle.
(b) If the charges are unequally spaced and fixed on an arc of 120° of radius R as shown in Fig. (ii), find electric potential at the centre C.



(i) (ii)

Ans. (a) Potential due to single charge at C, $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$

Net potential at C is $V = \frac{-1}{4\pi\varepsilon_0}\frac{12q}{R}$

Due to symmetry of distribution of charge, electric fields are cancel each other, so E = 0
(b) Potential is scalar quantity so orientation is irrelevant
Hence potential at C is $V = \frac{-1}{4\pi\varepsilon_0}\frac{12q}{R}$

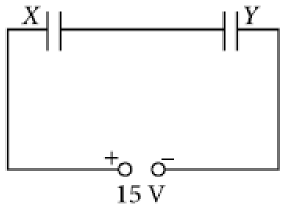
6. Three point charges +Q, –2Q and –3Q are placed at the vertices of an equilateral triangle ABC of side L. If these charges are displaced to the mid points A_1, B_1 and C_1 respectively, calculate the amount of work done in shifting the charges to the new locations.

Ans. $U_{initial} = \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{l}$

$U_{final} = \frac{1}{4\pi\varepsilon_0}\frac{2Q^2}{l}$

$W = U_{final} - U_{initial} = \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{l}$

7. Two parallel plate capacitors X and Y have the same area of plates and same separation between them. X has air between the plates while Y contains a dielectric medium $\varepsilon_r = 4$.
(i) Calculate the capacitance of each capacitor if equivalent capacitance of the combination is 4 µF.
(ii) Calculate the potential difference between the plates of X and Y.



Ans.(i) $\frac{C_Y}{C_X} = 4$ and $\frac{C_Y C_X}{C_X + C_y} = 4\mu F$

After solving $C_X = 5\ \mu F$ and $C_Y = 20\mu F$

(ii) in series charge on each capacitor is same so) $\frac{V_X}{V_Y} = 4$

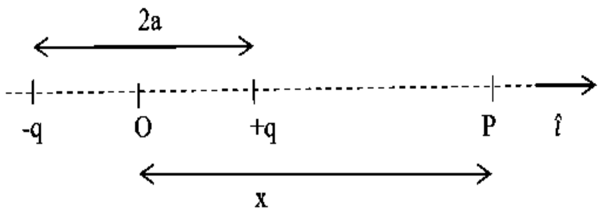
$V_X + V_Y = 15$
After solving $V_X = 12V$, $V_Y = 3V$

LONG ANSWER TYPE QUESTIONS

1. (i) An electric dipole (dipole moment $\vec{p} = p\hat{\imath}$), consisting of charges - q and q, separated by distance 2a, is placed along the x-axis, with its centre at the origin. Show that the potential V, due to this dipole, at a point x, (x >> a) is equal to $\frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\hat{\imath}}{x^2}$

(ii) Two isolated metallic spheres S_1 and S_2 of radii 1 cm and 3 cm respectively are charged such that both have the same charge density $\left(\frac{2}{\pi} X\ 10^{-9}\right)$C/m^2.. They are placed far away from each other and connected by a thin wire. Calculate the new charge on sphere S_1.

Ans.(i) Derive expression of potential at P, $V = \frac{1}{4\pi\varepsilon_0}\frac{p}{x^2 - a^2}$



As p is along x-axis so

$V = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\hat{\imath}}{x^2 - a^2}$

If x>>a

$V = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\hat{\imath}}{x^2}$

(ii) Charge on $S_1 = \sigma \times 4\pi r^2 = \left(\frac{2}{\pi} X\ 10^{-9}\right) \times 4\pi\ (1X\ 10^{-2})^2 = 8 \text{ X } 10^{-13}$ C

Charge on $S_2 = \sigma \times 4\pi r^2 = \left(\frac{2}{\pi} X\ 10^{-9}\right) \times 4\pi\ (3X\ 10^{-2})^2 = 72 \text{ X } 10^{-13}$ C

When connected by thin wire they acquire common potential V and charge remains conserved

$Q_1 + Q_2 = Q_1' + Q_2'$ and $\frac{Q_1'}{Q_2'} = \frac{r_2}{r_1}$

On solving $Q_1' = 2 \text{ X } 10^{-12}$ C

2. (i) Derive an expression for potential energy of an electric dipole p in an external uniform electric field E . When is the potential energy of the dipole (1) maximum, and (2) minimum?

(ii) Three point charges q, 2q and nq are placed at the vertices of an equilateral triangle. If the potential energy of the system is zero, find the value of n.

Ans. (i) Derivation of expression of potential energy

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

(1) Potential energy is maximum $\theta = 180^0$

(2) Potential energy is minimum $\theta = 0^0$

(ii) Consider an equilateral triangle of side a

Potential energy $U = \frac{kq_1q_2}{a} + \frac{kq_2q_3}{a} + \frac{kq_1q_3}{a}$

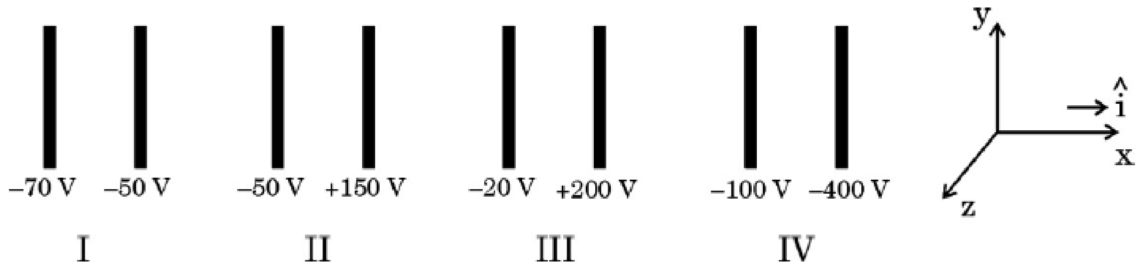
$U = \frac{k\ q\ .2q}{a} + \frac{k\ 2q\ .nq}{a} + \frac{k\ q\ .nq}{a}$

According to question U=0

So $\frac{k\ q\ .2q}{a} + \frac{k\ 2q\ .nq}{a} + \frac{k\ q\ .nq}{a} = 0$, After solving $n = -\frac{2}{3}$

CASE STUDY TYPE QUESTIONS

1. The figure shows four pairs of parallel identical conducting plates, separated by the same distance 2.0 cm and arranged perpendicular to x-axis. The electric potential of each plate is mentioned. The electric field between a pair of plates is uniform and normal to the plates.



(i) For which pair of the plates is the electric field E along $\hat{\imath}$?

(A) I (B) II (C) III (D) IV

(ii) An electron is released midway between the plates of pair IV. It will :

(A) move along $\hat{\imath}$ at constant speed (B) move along -$\hat{\imath}$ at constant speed

(C) accelerate along $\hat{\imath}$ (D) accelerate along -$\hat{\imath}$

(iii) Let E_1, E_2, E_3 and E_4 be the magnitudes of the electric field between the pairs of plates, I, II, III and IV respectively, then:

(A) $E_1 > E_2 > E_3 > E_4$ (B) $E_3 > E_4 > E_1 > E_2$

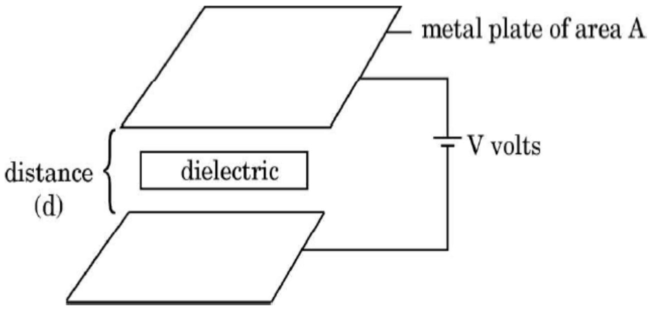
(C) $E_4 > E_3 > E_2 > E_1$ (D) $E_2 > E_3 > E_4 > E_1$

(iv) An electron is projected from the right plate of set I directly towards its left plate. It just comes to rest at the plate. The speed with which it was projected is about :

(Take (e/m) =1.76 X 10^{11} C/kg)

(A) 1.3 X 10^5 m/s (B) 2.6 X 10^6 m/s (C) 6.5 X 10^5 m/s (D) 5.2 X 10^7 m/s

2. A parallel plate capacitor is an arrangement of two identical metal plates kept parallel, a small distance apart. The capacitance of a capacitor depends on the size and separation of the two plates and also on the dielectric constant of the medium between the plates. Like resistors, capacitors can also be arranged in series or parallel or a combination of both. By virtue of electric field between the plates, charged capacitors store energy.



Q(a) The capacitance of a parallel plate capacitor increases from 10μF to 80μF on introducing a dielectric medium between the plates. Find the dielectric constant of the medium.

Q(b) n capacitors, each of capacitance C, are connected in series. Find the equivalent capacitance of the combination.

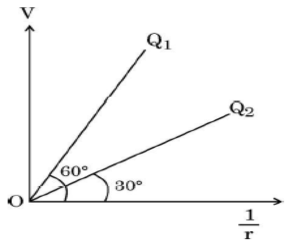
Q(c) A capacitor is charged to a potential (V) by connecting it to a battery. After some time, the battery is disconnected and a dielectric is introduced between the plates. How will the potential difference between the plates, and the energy stored in it be affected ? Justify your answer.

3. Electrostatics deals with the study of forces, fields and potentials arising from static charges. Force and electric field, due to a point charge is basically determined by Coulomb's law. For symmetric charge configurations, Gauss's law, which is also based on Coulomb's law, helps us to find the electric field. A charge/a system of charges like a dipole experience a force/torque in an electric field. Work is required to be done to provide a specific orientation to a dipole with respect to an electric field.

Answer the following questions based on the above:

Q(a) Consider a uniformly charged thin conducting shell of radius R. Plot a graph showing the variation of V with distance r from the centre, for points $0 < r < 3R$.

Q(b) The figure shows the variation of potential V with $\frac{1}{r}$ for two point charges Q_1 and Q_2, where V is the potential at a distance r due to a point charge. Find $\frac{Q_1}{Q_2}$.



Q(c) An electric dipole of dipole moment $\vec{p}$ is initially kept in a uniform electric field $\vec{E}$ such that $\vec{p}$ is perpendicular to $\vec{E}$. Find the amount of work done in rotating the dipole to a position at which $\vec{p}$ becomes antiparallel to $\vec{E}$.

ANSWERS

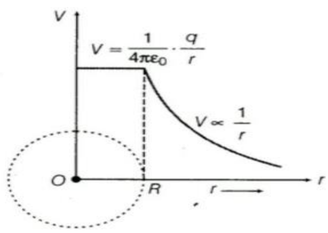
Ans.1. (i) (D) IV (ii) (D) accelerate along $-\hat{\imath}$ (iii) (C) $E_4 > E_3 > E_2 > E_1$

(iv) (B) 2.6×10^6 m/s

Ans.2 (a) K=8 (b) $C_s = \frac{C}{n}$

(c) Potential difference decreases by a factor 1/K, Energy reduces by a factor 1/K

Ans. 3 (a)



(b) $\frac{Q_1}{Q_2} = \frac{\tan 60}{\tan 30} = 3$

(c) Work done = + pE

CHAPTER-03 - CURRENT ELECTRICITY

SYLLABUS

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.

CONCEPT MAP

CURRENT ELECTRICITY

Current Density Conductance Conductivity

$J = \frac{di}{dA \cos\theta}$

Reciprocal of resistance is known as conductance.

$\sigma = \frac{1}{\rho}$

Electric Current

I = charge/time = $\frac{dq}{dt}$, if flow is uniform i = $\frac{q}{t}$

Ohm's Law Resistance & Resistivity

$i \propto V \Rightarrow V = iR$

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

$R_t = R_0(1+\alpha t)$

$\alpha = \frac{R_t - R_0}{R_0 \times t}$

Drift Velocity & Mobility of Charges

Drift velocity $V_d = \frac{-eE}{m}\tau$

$v_d = \frac{i}{neA} = \frac{J}{ne} = \frac{\sigma E}{ne} = \frac{E}{\rho ne}$

Current $I = neAV_d$

Current Density $J = \frac{i}{A} = nev_d$

$\Rightarrow I = \frac{nAe^2E}{m}\tau$

$\Rightarrow I = \frac{nAe^2V}{ml}\tau$

$I \propto V$

Resistance & Resistivity

$R = \rho\frac{l}{A} = \frac{m}{ne^2\tau}\cdot\frac{l}{A}$

From $R = \rho\frac{l}{A}$; $\rho = \frac{m}{ne^2\tau}$

Reciprocal of resistivity is called conductivity (σ) i.e. $\sigma = \frac{1}{\rho}$

Drift velocity per unit electric field is called mobility of electron

$\mu = \frac{V_d}{E} = \frac{-e}{m}\tau$

Kirchhoff's Law

Current law (*KCL*) is the algebraic sum of currents meeting at a junction is zero. *i.e.* $\sum i = 0$.

Voltage law (KVL) is the algebraic sum of the changes in potential in complete traversal of a closed loop is zero. *i.e.* $\sum V = 0$

Wheatstone Bridge

The bridge is said to be balanced when deflection in galvanometer is zero *i.e.* no current flows through the galvanometer. On mutually changing the position of cell and galvanometer this condition will not change.

Electric Cell

Emf of cell (E) : The potential difference across the terminals of a cell when it is not supplying any current.

Potential difference (V) : The voltage across the terminals of a cell when it is supplying current to external resistance.

Internal resistance (r) : In case of a cell the opposition of electrolyte to the flow of current through it.

In Series combination of cells- $E_{eq} = E_1 + E_2$ and $r_{eq} = r_1 + r_2$

In Parellel combination of cells- $E_{eq} = \frac{E_1r_2 + E_2r_1}{r_1 + r_2}$

and $r_{eq} = \frac{r_1r_2}{r_1 + r_2}$

In charging $V > E$.

In open circuit of a cell $V = E$

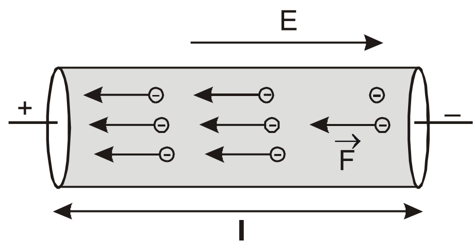
GIST OF THE CHAPTER

ELECTRIC CURRENT

- The electric current in measured by 'rate of flow of charge'.Or Charge flowing per second from any cross section of the conductor is called electric current,
- Current i = charge/time = $\frac{dq}{dt}$, if flow is uniform i = $\frac{Q}{t}$
- **Unit :** Ampere (A), Dimension : ($M^0L^0T^0A^1$)
- 1 ampere = 1 coulomb/second. i.e. if 1 coulomb of charge flows per second then 1 ampere of current is said to be flowing.

- 1 ampere of current means the flow of 6.25×10^{18} electrons per second through any cross section of conductor
- If n electrons pass through any cross section in every t seconds then $i = \frac{ne}{t}$ where $e = 1.6 \times 10^{-19}$ coulomb.
- The conventional direction of current is taken to be the direction of flow of positive charge, *i.e.* field
- Value of the current is same throughout the conductor, irrespective of the cross section of conductor at different points.
- Net charge in a current carrying conductor is zero at any instant of time.

Note : A current carrying conductor cannot said to be charged, because in conductor the current is caused by electron (free electron). The no. of electron (negative charge) and proton (positive charge) in a conductor is same. Hence the net charge in a current carrying conductor is zero.



- Electric field outside a current carrying conductor is zero, but it is non zero inside the conductor and is given by $e = -\frac{v}{l}$

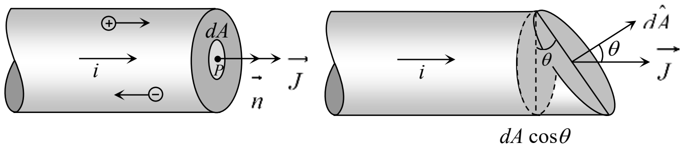
Note : The electric field inside charged conductor is zero, but it is non zero inside a current carrying conductor

Note : Current is a scalar quantity because it does not obey law of vector

CURRENT DENSITY

Current density at any point inside a conductor is defined as a vector having magnitude equal to current per unit area surrounding that point. Remember area is normal to the direction of charge flow (or current passes) through that point.

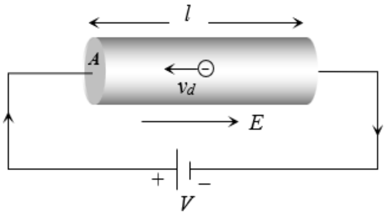
- Current density at point *P* is given by $\vec{J} = \frac{di}{dA}\vec{n}$



- If the cross-sectional area is not normal to the current, but makes an angle θ with the direction of current then $J = \frac{\text{di}}{\text{dAcos}\theta} \Rightarrow di = JdA\cos\theta = \vec{J}\,.\,\overrightarrow{dA} \Rightarrow i = \int \vec{J} \cdot \overrightarrow{dA}$
- If current density $\vec{J}$ is uniform for a normal cross-section **A** then J= i/A
- Current density **J** is a vector quantity. It's direction is same as that of **E**. It's S.I. unit is *amp/m*^{2} and dimension $[L^{-2}A]$.
- In case of uniform flow of charge through a cross-section normal to it as $i = \text{nqvA} \Rightarrow J = \frac{i}{A} = \text{nqv}$
- Current density relates with electric field as $\vec{J} = \sigma\vec{E} = \frac{\vec{E}}{\rho}$; where σ = conductivity and ρ = resistivity or specific resistance of substance.

Drift Velocity

Drift velocity is the average uniform velocity acquired by free electrons inside a metal by the application of an electric field which is responsible for current through it. Drift velocity is very small it is of the order of $10^{-4} m/s$ as compared to thermal speed ($\simeq 10^5 m/s$) of electrons at room temperature.

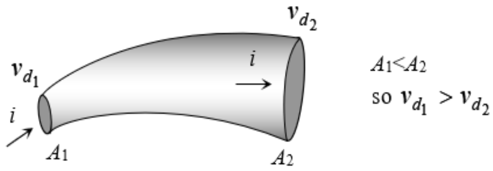


If suppose for a conductor *n* = Number of electron per unit volume of the conductor,

A = Area of cross-section, *V* = potential difference across the conductor, *E* = electric

field inside the conductor, *i* = current, *J* = current density, ρ = specific resistance, σ conductivity $\left(\sigma = \frac{1}{\rho}\right)$ then current relates with drift velocity as $i = \mathrm{neAv}_d$ we can also write $v_d = \frac{i}{\mathrm{neA}} = \frac{J}{\mathrm{ne}} = \frac{\sigma E}{\mathrm{ne}} = \frac{E}{\rho \mathrm{ne}} = \frac{V}{\rho l n e}$.

- The direction of drift velocity for electron in a metal is opposite to that of applied electric field (*i.e.* current density$\vec{J}$).$v_d \propto E$ *i.e.*, greater the elecic field, larger will be the drift velocity.
- When a steady current flows through a conductor of non-uniform cross-section drift velocity varies inversely with area of cross-section $\left(v_d \propto \frac{1}{A}\right)$



- If diameter (*d*) of a conductor is doubled, then drift velocity of electrons inside it will not change.

Relaxation time (τ) : The time interval between two successive collisions of electrons with the positive ions in the metallic lattice is defined as relaxation time $\tau = \frac{\text{mean free path}}{\text{r.m.s. velocity of electrons}} = \frac{\lambda}{v_{rms}}$. With rise in temperature v_{rms} increases consequently τ decreases.

Mobility : Drift velocity per unit electric field is called mobility of electron *i.e.*$\mu = \frac{v_d}{E}$. It's unit is $\frac{m^2}{volt-sec}$.

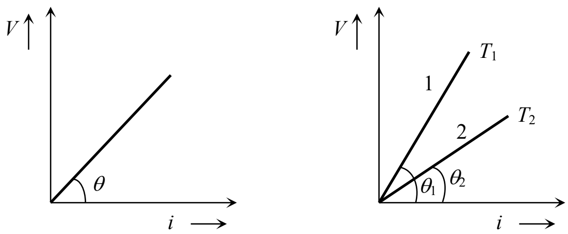
Ohm's Law

If the physical conditions of the conductor (length, temperature, mechanical strain etc.) remains some, then the current flowing through the conductor is directly proportional to the potential difference across it's two ends *i.e.*$i \propto V \Rightarrow V = iR$ where *R* is a proportionality constant, known as electric resistance.

(1) Ohm's law is not a universal law, the substances, which obey ohm's law are known as ohmic substance.

(2) Graph between *V* and *i* for a metallic conductor is a straight line as shown. At different temperatures *V-i* curves are different.

Ohm's law is true For metallic conductors at low temperature Because with rise in temperature resistance of conductor increase, so graph between V and i becomes non linear.



(A) Slope of the line = $\tan\theta = R$

(B) Here $\tan\theta_1 > \tan\theta_2$ So $R_1 > R_2$ *i.e.* $T_1 > T_2$

Resistance

- The property of substance by virtue of which it opposes the flow of current through it, is known as the resistance.
- **Formula of resistance :** For a conductor if *l* = length of a conductor *A* = Area of cross-section of conductor, *n* = No. of free electrons per unit volume in conductor, τ = relaxation time then resistance of conductor $R = \rho \frac{l}{A} = \frac{m}{\mathrm{ne}^2\tau} . \frac{l}{A}$; where ρ = resistivity of the material of conductor
- **Unit and dimension :** It's S.I. unit is *Volt/Amp*. or *Ohm* (Ω).It's dimension is $[ML^2T^{-3}A^{-2}]$
- **Dependence of resistance :** Resistance of a conductor depends upon the following factors.

(i) Length of the conductor :Resistance of a conductor is directly proportional to it's length *i.e.* $\boldsymbol{R \propto l}$ and inversely proportional to it's area of cross-section *i.e.* $R \propto \frac{1}{A}$

(ii) Temperature : For a conductor

If R_0 = resistance of conductor at 0^oC

R_t = resistance of conductor at t^oC

and α, β = temperature co-efficient of resistance

then $R_t = R_0(1 + \alpha t)$ for $t \leq 300^oC$ or $\alpha = \frac{R_t - R_0}{R_0 \times t}$

If R_1 and R_2 are the resistances at t_1^oC and t_2^oC respectively then $\frac{R_1}{R_2} = \frac{1+\alpha t_1}{1+\alpha t_2}$.

The value of α is different at different temperature. Temperature coefficient of resistance averaged over the temperature range t_1^oC to t_2^oC is given by $\alpha = \frac{R_2 - R_1}{R_1(t_2 - t_1)}$ which gives

$R_2 = R_1 [1 + \alpha (t_2 - t_1)]$.

Resistivity (ρ), Conductivity (σ) and Conductance (C)

Resistivity : From $R = \rho \frac{l}{A}$; If $l = 1m$, $A = 1\ m^2$ then $R = \rho$ *i.e.* resistivity is numerically equal to the resistance of a substance having unit area of cross-section and unit length.

- Unit and dimension : It's S.I. unit is *ohm×m* and dimension is $[ML^3T^{-3}A^{-2}]$
- (ii) It's formula : $\rho = \frac{m}{ne^2\tau}$
- (iii) Resistivity is the intrinsic property of the substance. It is independent of shape and size of the body (*i.e.* l and A).

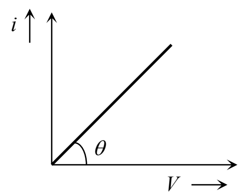
For different substances their resistivity is also different

$$\underset{(Maximum\ for\ fused\ quartz)}{\rho_{insulator}} > \rho_{alloy} > \rho_{semi-conductor} > \underset{(Minimum\ for\ silver)}{\rho_{conductor}}$$

- Resistivity depends on the temperature. For metals $\rho_t = \rho_0(1 + \alpha \Delta t)$ *i.e.* resistivity increases with temperature.
- Resistivity increases with impurity and mechanical stress.

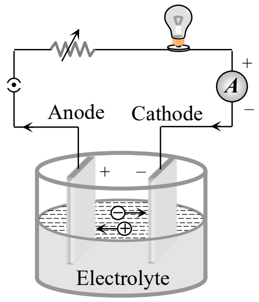
Conductivity : Reciprocal of resistivity is called conductivity (σ) *i.e.* $\sigma = \frac{1}{\rho}$ with unit *mho/m* and dimensions $[M^{-1}L^{-3}T^3A^2]$.

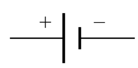
Conductance: Reciprocal of resistance is known as conductance. $C = \frac{1}{R}$ It's unit is $\frac{1}{\Omega}$ or Ω^{-1}.



Cell

The device which converts chemical energy into electrical energy is known as electric cell. Cell is a source of constant emf but not constant current.





Symbol of cell

(1) **Emf of cell (E) :** The potential difference across the terminals of a cell when it is not supplying any current is called it's emf.

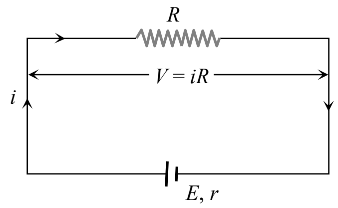
(2) **Potential difference (V) :** The voltage across the terminals of a cell when it is supplying current to external resistance is called potential difference or terminal voltage.

Potential difference is equal to the product of current and resistance of that given part *i.e.* $V = iR$.

(3) **Internal resistance (r) :** In case of a cell the opposition of electrolyte to the flow of current through it is called internal resistance of the cell. The internal resistance of a cell

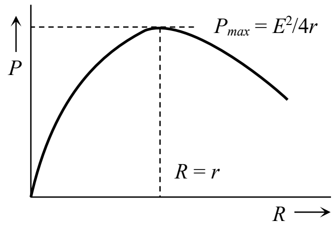
depends on the distance between electrodes ($r \propto d$), area of electrodes [$r \propto (1/A)$] and nature, concentration ($r \propto C$) and temperature of electrolyte [$r \propto$ (1/ temp.)].
A cell is said to be ideal, if it has zero internal resistance.

Cell in Various Positions

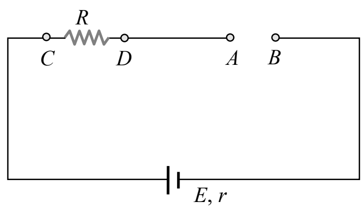


(1) **Closed circuit :** Cell supplies a constant current in the circuit.
(i) Current given by the cell $i = \frac{E}{R+r}$
(ii) Potential difference across the resistance $V = iR$
(iii) Potential drop inside the cell = ir
(iv) Equation of cell $E = V + ir$ ($E>V$
(v) Internal resistance of the cell $r = \left(\frac{E}{V} - 1\right) \cdot R$
(vi) Power dissipated in external resistance (load)

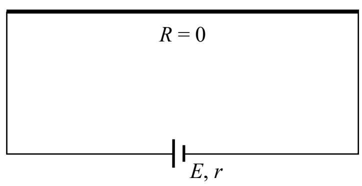
$$P = Vi = i^2R = \frac{V^2}{R} = \left(\frac{E}{R+r}\right)^2 .R$$



Power delivered will be maximum when$R = r$ so $P \frac{E^2}{4r}_{max}$.
This statement in generalised from is called "*maximum power transfer theorem*".
(vii) When the cell is being charged *i.e.* current is given to the cell then $E = V - ir$ and
$E<V$.



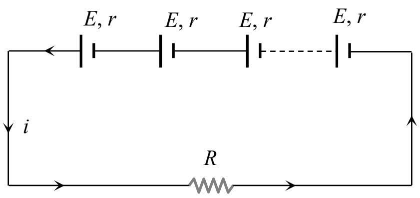
(2) **Open circuit :** When no current is taken from the cell it is said to be in open circuit
(i) Current through the circuit $i = 0$
(ii) Potential difference between A and B, $V_{AB} = E$
(iii) Potential difference between C and D, $V_{CD} = 0$



(3) **Short circuit :** If two terminals of cell are join together by a thick conducting wire
(i) Maximum current (called short circuit current) flows momentarily $i_{sc} = \frac{E}{r}$
(ii) Potential difference $V = 0$

Grouping of Cells

(1) **Series grouping :** In series grouping anode of one cell is connected to cathode of
other cell and so on. If n identical cells are connected in series



(i) Equivalent emf of the combination $E_{eq} = nE$
(ii) Equivalent internal resistance $r_{eq} = nr$
(iii) Main current = Current from each cell= $i = \frac{nE}{R+nr}$
(iv) Potential difference across external resistance $V = iR$
(v) Potential difference across each cell $V' = \frac{V}{n}$
(vi) Power dissipated in the external circuit = $\left(\frac{nE}{R+nr}\right)^2 .R$
(vii) Condition for maximum power $R = nr$ and$P \left(\frac{E^2}{4r}\right)_{max}$
(viii) This type of combination is used when $nr << R$.
(2) **Parallel grouping :** In parallel grouping all anodes are connected at one point and all cathode are connected together at other point. If n identical cells are connected in

parallel.

(i) Equivalent emf $E_{eq} = E$

(ii) Equivalent internal resistance $R_{eq} = r/n$

(iii) Main current $i = \frac{E}{R + r/n}$

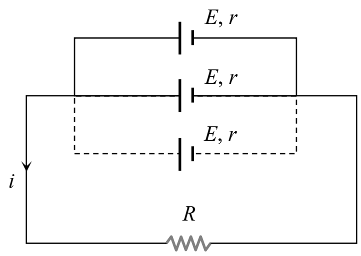
(iv) Potential difference across external resistance = p.d. across each cell = $V = iR$

(v) Current from each cell $i' = \frac{i}{n}$

(vi) Power dissipated in the circuit $P = \left(\frac{E}{R + r/n}\right)^2 . R$

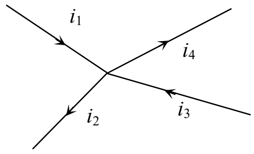
(vii) Condition for max. power is $R = r/n$ and$P \left(\frac{E^2}{4r}\right)_{max}$

(viii) This type of combination is used when $nr >> R$



Kirchoff's Laws

(1) **Kirchoff's first law :** This law is also known as junction rule or current law (*KCL*). According to it the algebraic sum of currents meeting at a junction is zero *i.e.*$\sum i = 0$. In a circuit, at any junction the sum of the currents entering the junction must equal the sum of the currents leaving the junction. $i_1 + i_3 = i_2 + i_4$



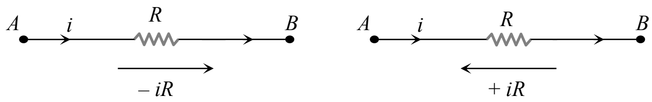
(ii) This law is simply a statement of "*conservation of charge*".

(2) **Kirchoff's second law :** This law is also known as loop rule or voltage law (KVL) and according to it "the algebraic sum of the changes in potential in complete traversal of a mesh (closed loop) is zero", *i.e.*$\sum V = 0$

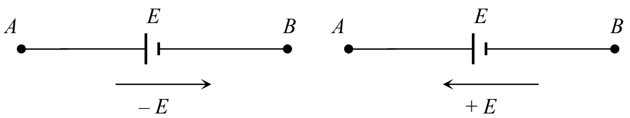
(i) This law represents "*conservation of energy*".

(3) **Sign convention for the application of Kirchoff's law :** For the application of Kirchoff's laws following sign convention are to be considered

(i) The change in potential in traversing a resistance in the direction of current is – *iR* while in the opposite direction +*iR*



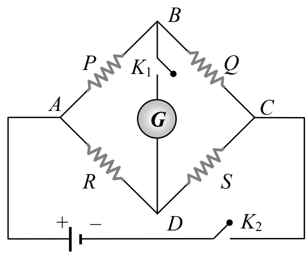
(ii) The change in potential in traversing an emf source from negative to positive terminal is +*E* while in the opposite direction – *E* irrespective of the direction of current in the circuit.



Wheatstone bridge : Wheatstone bridge is an arrangement of four resistance which can be used to measure one of them in terms of rest. Here arms *AB* and *BC* are called ratio arm and arms *AC* and *BD* are called conjugate arms

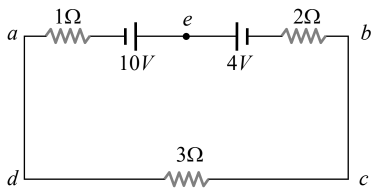
(i) **Balanced bridge :** The bridge is said to be balanced when deflection in galvanometer is zero *i.e.* no current flows through the galvanometer or in other words $V_B = V_D$. In the balanced condition $\frac{P}{Q} = \frac{R}{S}$, on mutually changing the position of cell and galvanometer this condition will not change.

(ii) **Unbalanced bridge :** If the bridge is not balanced current will flow from *D* to *B* if $V_D > V_B$ *i.e.*$(V_A - V_D) < (V_A - V_B)$ which gives *PS*>*RQ*.

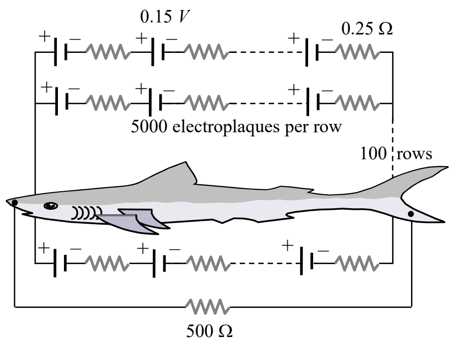


MULTIPLE CHOICE QUESTIONS

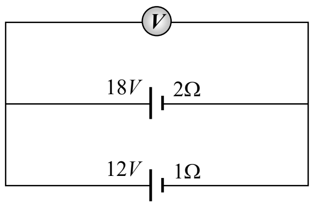
1. Every atom makes one free electron in copper. If 1.1 ampere current is flowing in the wire of copper having 1 mm diameter, then the drift velocity (approx.) will be (Density of copper $= 9 \times 10^3 kgm^{-3}$ and atomic weight = (63)
   (a) 0.3mm/sec (b) **0.1mm/sec** (c) 0.2mm/sec (d) $0.2 cm/sec$
2. The resistivity of iron is $1 \times 10^{-7} ohm - m$. The resistance of a iron wire of particular length and thickness is 1 ohm. If the length and the diameter of wire both are doubled, then the resistivity in $ohm - m$ will be
   (a) 1×10^{-7} (b) 2×10^{-7} (c) 4×10^{-7} (d) 8×10^{-7}
3. It is easier to start a car engine on a hot day than on a cold day. This is because the internal resistance of the car battery
   (a) Decreases with rise in temperature (b) Increases with rise in temperature
   (c) Decreases with a fall in temperature (d) Does not change with a change in temperature
4. The magnitude and direction of the current in the circuit shown will be
   (a) $\frac{7}{3}A$ from a to b through e
   (b) $\frac{7}{3}A$ from b to a through e
   (c) 1 A from b to a through e
   (d) 1 A from a to b through e



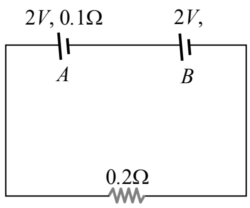
5. Two identical cells send the same current in 2 ohm resistance, whether connected in series or in parallel. The internal resistance of the cell should be
   (a) 0 (b) 0.5 ohm (c) 1.5 ohm (d) 2 ohm
6. Eels are able to generate current with biological cells called electro plaques. The electro plaques in an eel are arranged in 100 rows, each row stretching horizontally along the body of the fish containing 5000 electro plaques. The arrangement is suggestively shown below. Each electro plaques has an emf of 0.15 V and internal resistance of 0.25 Ω The water surrounding the eel completes a circuit between the head and its tail. If the water surrounding it has a resistance of 500 Ω, the current an eel can produce in water is about
   (a) 1.5 A (b) 3.0 A
   (c) 15 A (d) 30 A



7. Two batteries, one of emf 18 $volts$ and internal resistance 2Ω and the other of emf 12 $volt$ and internal resistance 1Ω, are connected as shown. The voltmeter V will record a reading of
   (a) 15 $volt$ (b) 30 $volt$ (c) 14 $volt$ (d) 18 $volt$



8. The internal resistances of two cells shown are 0.1Ω and 0.3Ω. If $R = 0.2\Omega$, the potential difference across the cell
   (a) B will be zero
   (b) A will be zero
   (c) A and B will be $2V$
   (d) A will be $> 2V$ and B will be $< 2V$



9. In Wheatstone's bridge $P = 9 ohm$, $Q = 11 ohm$, $R = 4 ohm$ and $S = 6 ohm$. How much resistance must be put in parallel to the resistance S to balance the bridge
   (a) 24 ohm (b) $\frac{44}{9} ohm$ (c) 26.4 ohm (d) 18.7 ohm

ANSWERS

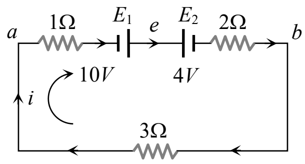
1. (b) Density of $Cu = 9 \times 10^3 kg/m^3$ (mass of 1 m^3 of Cu)

$\because$ 6.0×10^{23} atoms has a mass = 63×10^{-3} kg

$\therefore$ Number of electrons per m^3 are $= \frac{6.0\times10^{23}}{63\times10^{-3}} \times 9 \times 10^3 = 8.5 \times 10^{28}$

Now drift velocity $= v_d = \frac{i}{neA} = \frac{1.1}{8.5\times10^{28}\times1.6\times10^{-19}\times\pi\times(0.5\times10^{-3})^2} = 0.1 \times 10^{-3} m/sec$

2. (a) Resistivity of some material is its intrinsic property and is constant at particular temperature. Resistivity does not depend upon shape.
3. (b) Because as temperature increases, the resistivity increases and hence the relaxation time decreases for conductors $\left(\tau \propto \frac{1}{\rho}\right)$.
4. (d)



Applying Kirchoff's voltage law

$-1 \times i + 10 - 4 - 2 \times i - 3i = 0 \Rightarrow i = 1A$($a$to b via e)

$\therefore$ Current $= \frac{V}{R} = \frac{10-4}{6} = 1.0 ampere$

5. (d) In series , $i_1 = \frac{2E}{2+2r}$

In parallel, $I_2 = \frac{E}{2+\frac{r}{2}} = \frac{2E}{4+r}$, Since $i_1 = i_2 \Rightarrow \frac{2E}{4+r} = \frac{2E}{2+2r} \Rightarrow r = 2\Omega$

6.(a) Given problem is the case of mixed grouping of cells

So total current produced $i = \frac{nE}{R + \frac{nr}{m}}$

Here $m = 100,\ n = 5000,\ R = 500\,\Omega$

$E = 0.15\,V$ and $r = 0.25\,\Omega$

$$i = \frac{5000 \times 0.15}{500 + \frac{5000 \times 0.25}{100}} = \frac{750}{512.5} \approx 1.5\,A$$

7(c) Reading of voltmeter

Eeq $= \frac{E1r2+E2r1}{r1+r2}$

=(18*1+12*2)/(1+2) = 14 V

8(a) Applying Kirchhoff law, $(2 + 2) = (0.1 + 0.3 + 0.2)i \Rightarrow i = \frac{20}{3}A$

Hence potential difference across A

$= 2 - 0.1 \times \frac{20}{3} = \frac{4}{3}V$ (less than 2V)

Potential difference across $B = 2 - 0.3 \times \frac{20}{3} = 0$

9(c) $\frac{P}{Q} = \frac{R}{S'}$ (For balancing bridge)

$\Rightarrow S' = \frac{4\times11}{9} = \frac{44}{9} \Rightarrow \frac{1}{S'} = \frac{1}{r} + \frac{1}{6} \Rightarrow \frac{9}{44} - \frac{1}{6} = \frac{1}{r} \Rightarrow r = \frac{132}{5} = 26.4\Omega$

ASSERTION & REASON QUESTIONS

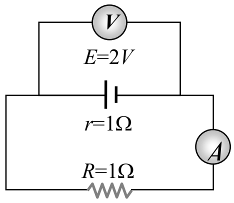
Read the assertion and reason carefully to mark the correct option out of the options given below :

(a)If both assertion and reason are true and the reason is the correct explanation of the assertion.

(b)If both assertion and reason are true but reason is not the correct explanation of the assertion.

(c) If assertion is true but reason is false.
(d) If the assertion and reason both are false.

1. **Assertion:** The resistivity of a semiconductor increases with temperature.
   Reason: The atoms of a semiconductor vibrate with larger amplitude at higher temperatures thereby increasing its resistivity.
2. **Assertion:** In a simple battery circuit the point of lowest potential is positive terminal of the battery
   Reason: The current flows towards the point of the higher potential as it flows in such a circuit from the negative to the positive terminal.
3. **Assertion:** The temperature coefficient of resistance is positive for metals and negative for *p*-type semiconductor.
   Reason: The effective charge carriers in metals are negatively charged whereas in *p*-type semiconductor they are positively charged.
4. **Assertion:** In the following circuit emf is $2V$ and internal resistance of the cell is 1 Ω and $R = 1\Omega$, then reading of the voltmeter is $1V$.
   Reason: $V = E - ir$ where $E = 2V$, $i = \frac{2}{2} = 1A$ and $R = 1\ \Omega$



5. **Assertion:** There is no current in the metals in the absence of electric field.
   Reason: Motion of free electron are randomly.
6. **Assertion:** Electric appliances with metallic body have three connections, whereas an electric bulb has a two pin connection.
   Reason: Three pin connections reduce heating of connecting wires.
7. **Assertion:** The drift velocity of electrons in a metallic wire will decrease, if the temperature of the wire is increased.
   Reason: On increasing temperature, conductivity of metallic wire decreases.
8. **Assertion:** The electric bulbs glows immediately when switch is on.
   Reason: The drift velocity of electrons in a metallic wire is very high.

ANSWERS

1. (d) Resistivity of a semiconductor decreases with the temperature. The atoms of a semiconductor vibrate with larger amplitudes at higher temperatures thereby increasing it's conductivity not resistivity.
2. (d) It is quite clear that in a battery circuit, the point of lowest potential is the negative terminal of the battery and the current flows from higher potential to lower potential.
3. (b) The temperature co-efficient of resistance for metal is positive and that for semiconductor is negative. In metals free electrons (negative charge) are charge carriers while in *P*-type semiconductors, holes (positive charge) are majority charge carriers.
4. (a) Here, $E = 2V, 1 = \frac{2}{2} = 1A$ and $r = 1\Omega$
   Therefore, $V = E - ir = 2 - 1 \times 1 = 1V$
5. (a) It is clear that electrons move in all directions haphazardly in metals. When an electric field is applied, each free electron acquire a drift velocity. There is a net flow of charge, which constitute current. In the absence of electric field this is impossible and hence, there is no current.
6. (c) The metallic body of the electrical appliances is connected to the third pin which is connected to the earth. This is a safety precaution and avoids eventual electric shock. By doing this the extra charge flowing through the metallic body is passed to earth and avoid shocks. There is nothing such as reducing of the heating of connecting wires by three pin connections.
7. (b) On increasing temperature of wire the kinetic energy of free electrons increase and so they collide more rapidly with each other and hence their drift velocity decreases. Also when temperature increases, resistivity increase and resistivity is inversely proportional to conductivity of material.

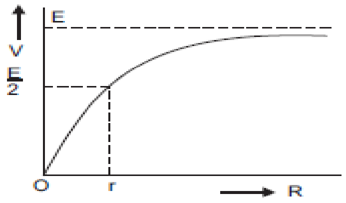
8. (c) In a conductor there are large number of free electrons. When we close the circuit, the electric field is established instantly with the speed of electromagnetic wave which cause electron drift at every portion of the circuit. Due to which the current is set up in the entire circuit instantly. The current which is set up does not wait for the electrons flow from one end of the conductor to the another end. It is due to this reason, the electric bulb glows immediately when switch is on.

VERY SHORT ANSWER TYPE QUESTIONS

1. A cell of emf (E) and internal resistance (r) is connected across a variable external resistance (R). Plot graphs to show variation of (i) E with R, (ii) Terminal p.d. of the cell (V) with R.

Sol. (i) The emf E of a cell is independent of external resistance (R).

(ii) The terminal p.d. $V = IR = \frac{E}{r+R}R = \frac{E}{1+\frac{r}{R}}$



On increasing R, V increases.

When R = 0, V→ 0. When R = r, V =$\frac{E}{2}$

When R → ∞, V = E.

2. A p.d. of V volts is applied to a conductor of length L and diameter D. How will the drift velocity of e's and the resistance of the conductor change when (i) V is doubled (ii) L is halved and (iii) D is halved , where is each case , the other two factors remain same . Give reason in each case.

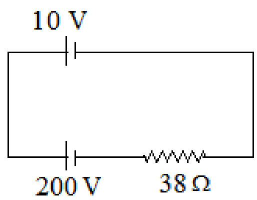
Sol. $V_d = \frac{eE}{m}\tau = \frac{eV}{ml}\tau$ and $R = \rho\frac{l}{A} = \rho\frac{l}{\pi D^2}$

(i) When V is doubled, V_d becomes double and R remains unchanged.

(ii) When l is halved, V_d becomes double and R becomes halved

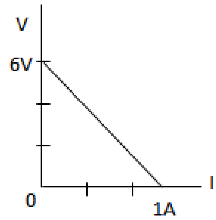
(iii) When D is halved, V_d remains unchanged and R becomes 4R.

3. A 10 V battery of negligible internal resistance is connected across a 200 V battery and a resistance of 38 Ω. Find the value of the current in circuit.



Sol. $I = \frac{E}{r+R} = \frac{200-10}{0+38} = 5A$

4. The plot of the variation of potential difference across a combination of three identical cells in series, versus current is as shown below. What is the emf of each cell?



Sol. Let E be emf of each cell and r be the total internal resistance of circuit. The equation of terminal potential difference $V = 3E - Ir$............(1)

At V = 6V, I = 0. Therefore from eq (1), $6 = 3E - 0 \Rightarrow E = 2V$

5.Write any two factors on which internal resistance of a cell depends.

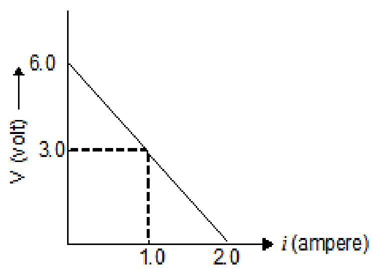
Sol. The internal resistance of a cell depends on

(i) distance (l) between electrodes.

(ii) area (A) of immersed part of electrode, and

(iii) nature and concentration of electrolyte.

6. The following graph shows the variation of terminal potential difference V, across a combination of three cells in series to a resistor, versus the current, I.



(i) Calculate the emf of each cell and internal resistance

(ii) For what current I will the power dissipation of the circuit be maximum?

Sol. (i) Let E be emf of each cell and r be the total internal resistance of circuit. The equation of terminal potential difference $V = 3E - Ir$...........(1)

At V = 6V, I = 0. Therefore from eq (1), $6 = 3E - 0 \Rightarrow E = 2V$

(ii) At V = 0V, I = 2A. Therefore from eq (1), $0 = 6 - 2r \Rightarrow r = 3\Omega$

(iii) For maximum power dissipation, external resistance (R) = Internal resistance (r)

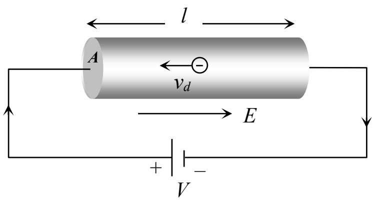
Current, I = $\frac{3E}{r+R} = \frac{6}{3+3} = 1A$

SHORT ANSWER TYPE QUESTIONS

1. Define the term drift velocity and relaxation time. On the basis of electron drift derive an expression for drift velocity of free electrons in term of relaxation time.

Sol. **Drift velocity** - Drift velocity is the average uniform velocity acquired by free electrons inside a metal by the application of an electric field which is responsible for current through it.

Relaxation time (τ) : The time interval between two successive collisions of electrons with the positive ions in the metallic lattice is defined as relaxation time.



In a metallic conductor, the free electrons are in continuous random motion due to thermal energy. The net flow of electrons in any direction is zero. Therefore the average velocity of electrons is zero. $\vec{u} = 0$

In the presence of external electric field$\vec{E}$ the free electron experiences a force opposite to the direction of applied field.

The electric force on electron $\vec{F} = -e\vec{E}$

The acceleration produced in electron $\vec{a} = \frac{\vec{F}}{m} = -\frac{e\vec{E}}{m}$

Since electrons are colliding frequently with each other and atoms of metal, therefore they are accelerated only for a short time interval between two successive collisions (relaxation time τ).

The average velocity of electrons after relaxation time τ,

$\vec{v} = \vec{u} + \vec{a}\tau \Rightarrow \vec{v} == 0 - \frac{e\vec{E}}{m}\tau \Rightarrow \vec{v} == -\frac{e\vec{E}}{m}\tau$

This velocity is called drift velocity. $\therefore \vec{v}_d == -\frac{e\vec{E}}{m}\tau$

2. Define the term 'mobility' of charge carriers in a current carrying conductor. Obtain the relation for mobility in term of relaxation time.

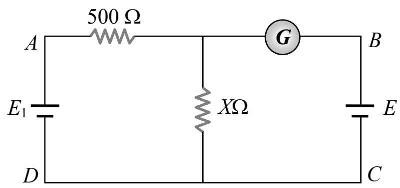
Sol. **Mobility :** Drift velocity per unit electric field is called mobility of electron *i.e.* $\mu = \frac{v_d}{E}$.

It's unit is $\frac{m^2}{volt-sec}$

$Vd = \frac{-eE}{m}\tau$

$\mu = \frac{Vd}{E} = \frac{-e}{m}\tau$, i.e. $|\mu| = \frac{e}{m}\tau$

3. In the adjoining circuit, the battery E_1 has an $e.m.f.$ of $12volt$ and zero internal resistance while the battery E has an $e.m.f.$ of $2volt$. If the galvanometer G reads zero, then the value of the resistance X in ohm is



Sol. For no current through galvanometer, we have

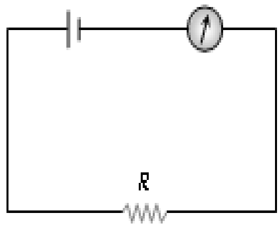
$$\left(\frac{E_1}{500+X}\right)X = E \Rightarrow \left(\frac{12}{500+X}\right)X = 2 \Rightarrow X = 100\ \Omega$$

CASE STUDY BASED QUESTIONS

Read the following paragraphs and answer the questions that follow.

Whenever an electric current is passed through a conductor, it becomes hot after some time. The

. Phenomenon of the production of heat in a resistor by the flow of an electric current through it is called heating effect of current or Joule heating. Thus, the electrical energy supplied by the source of emf is converted into heat. In purely resistive circuit the energy expended by the source entirely appears as heat. But if the circuit has an active element like a motor, then a part of the energy supplied by the source goes to do useful work and the rest appears as heat. Joule's law of heating form the basis of various electrical appliances such as electric bulb, electric furnace, electric press etc



I. Alloys used for making standard resistance coils as alloys
   (a) have more conductivity
   (b) less conductivity
   (c) less temperature coefficient of resistivity
   (d) more temperature coefficient of resistivity

II. Nichrome and copper wires of same length and same radius are connected in series. Current I is passed through them. Wire which gets heated up more is
   (a) Nichrome (b) copper
   (c) both gets heated up to same values (d) can't say

III. A 25 W and 100 W are joined in series and connected to the mains. The bulb which will glow brighter is
   (a) 25W as it has high resistance (b) 100 W as it has high resistance
   (c) 25W as it has low resistance (d) 100 W as it has low resistanc

IV. The heat emitted by an iron of 100 W in 1 minute is
   (a) 600J (b) 6000J (c) 60J (d)60000J

2. When electric field is applied across a conductor then the electrons move in the direction opposite to the electric field due to electric force on them. The average velocity with which free electrons get drifted in the direction opposite to the applied electric field inside a conductor is called drift velocity. This motion of the electrons in the direction opposite to the electric field is superimposed on their random motion. Drift velocity depends on electric field applied, the nature of material and temperature. On increasing the temperature, relaxation time decreases. Hence decrease in relaxation time, due to increase in temperature, will reduce the drift speed.

I. When a potential difference V be applied across a cylindrical conductor of length L and radius R, is doubled then the drift velocity of electrons gets:
   (a) doubled (b) four times (c) remain same (d) halved

II. Two wires made of same material but of different diameters are connected in series in a circuit. The current flows in the combination of wires. When the current flows from the wire with larger diameter to the one with smaller diameter then drift velocity of electrons:
   (a) will decrease (b) will increase
   (c) remains same (d) first will increase and after some time decrease

III. Two wires each of radius of cross section r but of different materials are connected together end to end (in series). If the densities of charge carriers in the two wires are in the ratio 1:4, the drift velocity of electrons in the two wires will be in the ratio:
   (a) 1 : 2 (b) 2 : 1 (c) 4 :1 (d) 1 : 4

IV. A current I flows through a uniform wire of diameter d when the electron drift velocity is v.The same current will flow through a wire of diameter d/2 made of the same material if the drift velocity of the electrons is
   (a)v/4 (b) v/2 (c) 2v (d) 4v

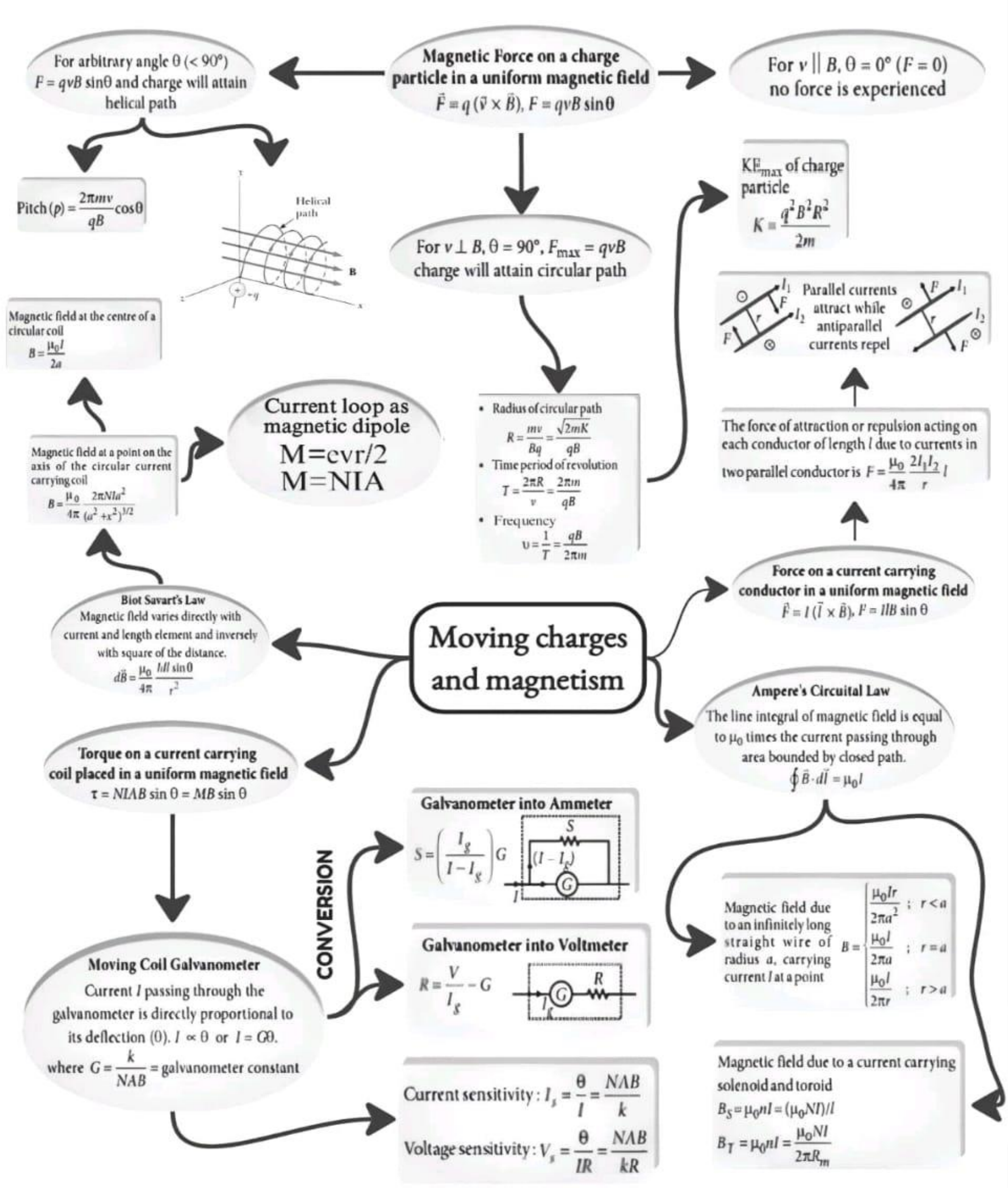
ANSWERS-

1 (i) c (ii) a (iii) a (iv) b
2 (i) a (ii) b (iii) c (iv) d

CHAPTER 4: Magnetic Effects of Current and Magnetism

Syllabus- 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.

MIND MAP



GIST OF THE CHAPTER

Magnetic field- It is a region of space around a magnet or a current carrying conductor in which it can exert force on other magnetic materials, moving charges, magnets and current carrying conductor.
A moving charge produces both electric and magnetic field while a stationary electron produces an electric field only.

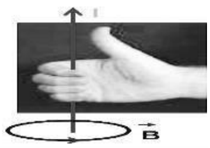
SI Unit of Magnetic field-

The SI unit of magnetic field is Wm^{-2} or T (tesla).
If 1A current is flowing through a straight conductor and it is kept at right angle to a magnetic field such that force per unit length on it is $1Nm^{-1}$ the strength of magnetic field is called one tesla,

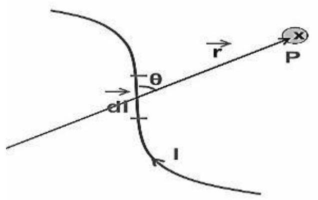
1 tesla (T) = 1 weber meter^{-2} (Wbm^{-2}) = 1 newton ampere^{-1} meter^{-1} (NA^{-1} m^{-1})
CGS units of magnetic field is called gauss or oersted. 1 gauss = 10^{-4} tesla.
Right hand thumb rule- Hold a conductor is Right Hand in such a way that thumb indicates the direction of current then the curled finger encircling the conductor will give the direction of magnetic field lines around it.

Biot- Savart law- It states that the magnetic field strength d**B** produced due to a current element (of current I and length dl) at a point having position vector r relative to current element is-

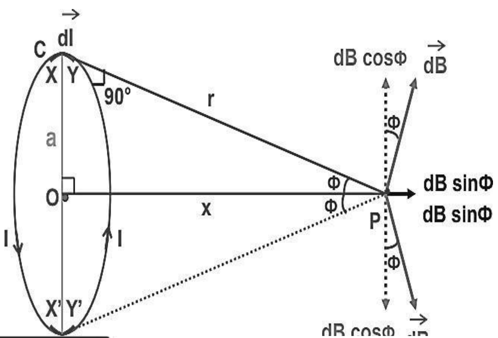
$$dB = \frac{\mu_0}{4\pi}\frac{(i\vec{dl}\times\vec{r})}{r^3} \quad or \quad dB = \frac{\mu_0}{4\pi}\frac{idl\,sin\theta}{r^2}$$



where μ_0 is the permeability of free space,
θ is the angle between current element and position vector **r** as shown in the figure.
The direction of magnetic field **B** is perpendicular To the plane containing **Idl** and **r**
The value of $\mu_0 = 4\pi \times 10^{-7}$ Wb/A-m.



Magnetic field due to a current carrying circular loop –
The magnetic field due to current carrying circular loop having radius 'a',carrying current 'I' at a distance 'x' from the centre of coil is –



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

(μ_0 , I, a, sinΦ are constants, ∫dl = 2πa and r & sinΦ are replaced with measurable and constant values.)

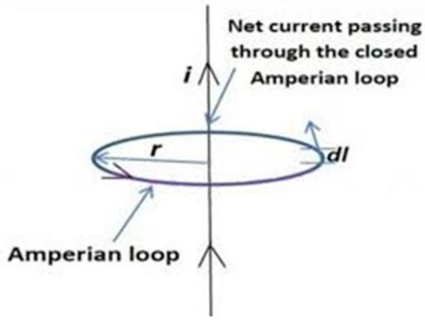
In case of coil having N turn, B(coil) = N x B(loop) $\therefore \boxed{B = \frac{\mu_0 I}{2a}}$

The magnetic field due to current carrying circular coil is along the axis. At the center, x=0

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

Ampere's Circuital law - It states that line integral of magnetic field around any closed loop (called Amperean loop) is equal to μ_0-times the current (I) threading through that loop.

$$\oint \vec{B}.\vec{dl} = \mu_0 I_{enclosed}$$



Magnetic field due to infinitely long straight wire using Ampere's law- Accordingto Ampere's circuital law.

$$\oint \vec{B}.\vec{dl} = \mu_0 I_{enclosed}$$

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

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

Straight solenoid- At the axis of a long solenoid, carrying current I , $B=\mu_0\, nI$, where n = N/L = number of turns per unit length.

Force on a current-carrying conductor in a uniform magnetic field →B

Magnitude of force is F = I L Bsinθ.

Direction of force is normal to and B & I ,given by Fleming's Left Hand Rule. If θ=0 (i.e. I or L is parallel to →B), then the magnetic force is zero.

Force on a moving charge in uniform magnetic field-The force on a charged particle moving with velocity 'v' in a uniform magnetic field is given by $\vec{F} = q(\vec{v} \times \vec{B})$ or F = qvb sinθ

θ is the angle between velocity(**v**) and magnetic field(**B**). Force (**F**) is perpendicular to both **v** and **B**. (i) If **v** and **B** are parallel **F**=0

(ii) When v is perpendicular to B, i.e. $\theta = 90^0$, F = qvB i.e F is maximum

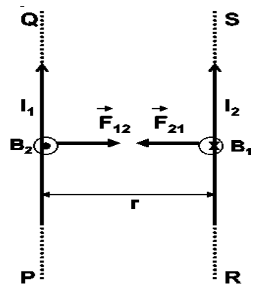
Lorentz force -The total force on a charged particle moving in co-existing electric field → and magnetic field → is given by $\vec{F} = q\,[\vec{E} + (\vec{v} \times \vec{B})]$

This is called the Lorentz force equation.

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

Fleming's Left Hand Rule- Stretch out the fingers in 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 ofcurrent then thumb gives the direction of the force acting on the conductor.

Force between two long straight parallel current carrying conductors-

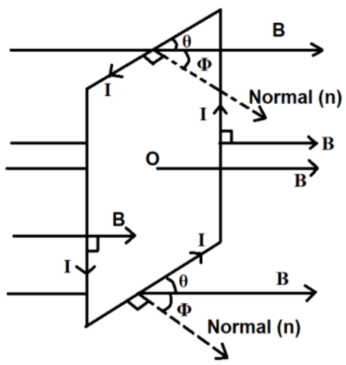


Two parallel current carrying conductors attract while they repel if current in them is anti-parallel. The magnetic forceper unit length on either current carrying conductor at separation a is given by

$$\frac{F}{l} = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r}\ N/m$$

Definition of ampere: - *1 ampere is the current which when flowing in each ofthe two parallel wires in vacuum separated by 1 m from each other exert a forceof 2 X 10^{-7}N/m on each other.*

Torque experienced by a current loop in uniform magnetic field-



A coil of N turns and area A is carrying current I is kept in a magnetic field as shown in figure as shown in figure. Force on it will be zero and torque on it will be

$$\tau = NIBA\cos\theta$$

θ = angle between coil and magnetic field

If Φ = angle between Normal ($\hat{n}$) to coil and magnetic field (**B**)

, Φ + θ = 90° so i.e. θ = 90° - Φ

So $\tau = N I A B \cos(90° - \Phi) = N I A B \sin\Phi$

$\underline{\tau = N I A B \sin\Phi}$

As $\tau = \boldsymbol{M} B \sin\Phi$ so $\underline{\boldsymbol{M = NIA}}$

In vector form $\vec{\tau} = NI(\vec{A} \times \vec{B})$

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

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

Potential energy of a current loop in a magnetic field- When a current loopof magnetic moment **M** is placed in a magnetic field (**B**), then potential energy of magnetic dipole is

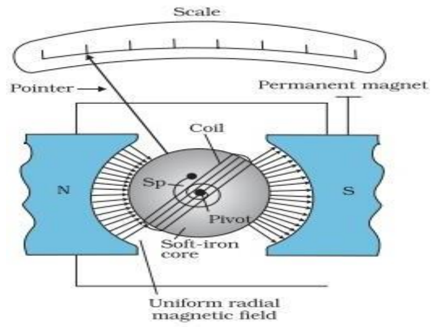
$$U = -MB\cos\theta = -\vec{M}\cdot\vec{B}$$

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

When θ = 180^0, U = +MB (maximum or unstable equilibrium position)

When θ = 90^0, potential energy is zero

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



$$\tau = NIBA \sin\Phi$$

for a radial magnetic field $\sin\Phi=1$ so $\tau = NIBA$

where **N** is the number of turns, **A** is the area of coil. If *C* is torsional rigidity of material of suspension wire. For deflection Φ, restoring torque $\tau = C\,\theta$. For equilibrium

$$NIAB = C\,\Phi \quad \text{or} \quad I = C\,\Phi/(NBA)$$

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

Use of radial magnetic field- when radial magnetic field is used the angle between the normal to the plane of loop (**A)** and magnetic field (**B**) $\Phi = 90^0$ for any orientation of loop, in a radial magnetic field the angular deflection of coil is proportional to the current flowing through it. Hence a linear scale can be used to determine the deflection of coil i.e. measurement of current.

Uses of galvanometer: (i) Used to detect electric current and direction of its flow in given branch of circuit. (ii) Usedto convert the ammeter by putting a low resistor in parellel. (iii) Used to convert voltmeterby putting a high resistor in series. (iv) Used as ohmmeter by making special arrangement

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

$$\Phi/I = NBA/C$$

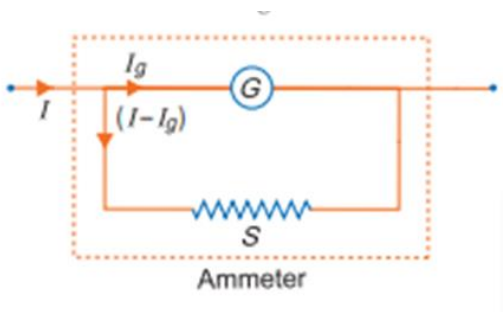
Voltage sensitivity: It is defined as the deflection of coil per unit potential

$$\Phi/V = NBA/RC$$

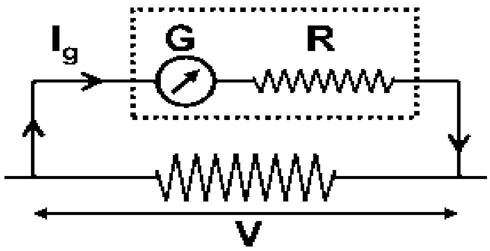
Conversion of Galvanometer into Ammeter: - A galvanometer can be converted into an ammeter by using a suitably small resistance in parallel with the galvanometer coil. The small resistance connected in parallel is called a shunt.If *G* is resistance of galvanometer, *Ig* is current in galvanometer for full scale deflection, then for conversion of galvanometer into ammeter of range *I* ampere,the shunt required can be found as

$I_g G = (I - I_g)S$ (As 'S' and 'G' are parallel combination)

So $\boldsymbol{S = \frac{I_g G}{(I - I_g)}}$



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



$V = I_g(R + G)$ So $\boldsymbol{R = \frac{V}{I_g} - G}$

Magnetic moment due to a revolving charge or electron-

A current loop or a revolving charge can be considered as a magnet. The magnetic moment of such a loop is M= qvr/2.

The face from which current flow appears **anticlockwise** is the **north pole** of equivalent magnet with magnetic moment **M**. I.e magnetic moment is outward

If we have a coil having N turns carrying current I having A as area of cross-section the magnetic moment is given by *M= NIA*

For an electron moving in Hydrogen atom

M=evr/2

As per Bohr's theory of Hydrogen atom L= mvr = nh/2π n= 0,1,2,3,4………. Where n is principal quantum number

M= -e**L**/2m

MULTIPLE CHOICE QUESTIONS

1 A proton and an alpha particle with same kinetic energy enters normally into a uniform magnetic field (**B**), the ratio of their radii of curvature of their path respectively will be

(a) More than 1 (b) 1 (c)Lesser than 1 (d) Dependent on the |**B**|

2 If a galvanometer of resistance R_g is connected with a shunt of resistance 'S' such that

R_g=n.S the ratio of power consumed by R_g and S respectively will be

(a) n^2 (b) n (c) 1/n (d) $1/n^2$

3 A galvanometer of can measure current up to 200µA. if a resistor of 10Ω is connected across it the range of it enhances to 1mA.If a resistor of 20Ω is connected in place of 10Ω the range will be

(a) 2mA (b) 0.4mA (c) 0.5mA (d) 0.6mA

4 A charge enters into a uniform magnetic field with a K.E. 'E' and leaves it after some time. The K.E. of the charge while leaving the field will be

(a) Lesser than E (b) More than E (c) Equal to E (d) Lesser than or equal

5 An electric field is applied along positive Y-axis and a magnetic field along negative Z-axis. An electron moving through this region along positive X-axis will

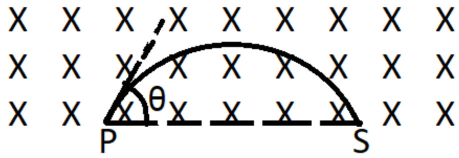
(a) Move undeflected (b) Deflect towards B (c) Deflect along E (d) Deflect against E

6 A positive charge moves parallel to flow of current in a long straight wire the charge will be

(a) Repelled by the wire (b) Attracted by the wire

(c) Unaffected by the wire (d) Oscillating

7 A particle of mass 'm' and charge 'q' enters at 'P' Into a uniform magnetic field 'B' and leaves it at 'S' as shown time spent by the charge inside the field will be



(a) $2m\theta/qB$
(b) $2m/qB$
(c) $2m/\theta qB$
(d) $m\theta/qB$

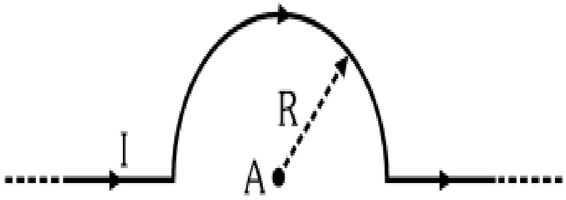
8 In a moving coil galvanometer the current sensitivity is given by

(a) NBA/C (b) C/NBA (c) NBA/CR (d) NBR/C

9 The magnetic field at a point due to a long straight wire carrying current I is B. A circular loop carries same current. For same magnetic field at its center the radius of the circular loop shall be

(a) 2a (b) a (c) a/2 (d) much more than 'a'

10 In the shown figure magnetic field at point A will be



(a) $\frac{\mu_0 I}{4\pi}$ (b) $\frac{\mu_0 I}{4R}$ (c) $\frac{\mu_0 I}{4\pi R}$ (d) Zero

SOLUTIONS-

1-b $(\sqrt{m})/q$ is same for both and $r= (\sqrt{2mE})/qB$
2-c $P \alpha R^{-1}$ as 'V' is constant
3-d $S_1 = I_gR_g/ (I_1- I_g)$ so $S_1/S_2 = (I_2- I_g)/ (I_1- I_g)$
4-c F perpendicular to v so no work is done and work done = change in KE =0 and
5-d **F** = q(**vXB**) and flemming's left hand rule
6-b Right hand palm rule and flemming's left hand rule
7-a $T= 2\pi m/qB$ arc makes an angle 2θ at center so replace 2π by 2θ
8-a equilibrium of deflection needle in galvanometer requires
$C\theta = NIBA$ so $\theta/I = NBA/C$
9-b compare result for B due to circular loop and long straight wire
10-b $B = B_0 /2$ and $B_0 = \mu_0 I/2r$ for full circle

ASSERTION –REASON QUESTIONS

1 ASSERTION- The magnetic field at a point due to long straight current carrying wire is inversely proportional to the of distance

REASON- Magnetic field at a point due to a current element is inversely proportional to the distance

2 ASSERTION- When a charge moves in a uniform magnetic field its kinetic energy doesn't change.

REASON-Lorentz force on the charge is normal to velocity at every point.

3 ASSERTION-A current carrying coil in a uniform magnetic field feels maximum torque when it is kept in the field parallel to its plane

REASON-Torque on a current carrying coil in magnetic field does not depend on the shape of the coil.

4 ASSERTION-The current sensitivity(Is) of a moving coil galvanometer is proportional to its voltage sensitivity(Vs).

REASON- Both are inversely proportional to resistance of the coil

5 ASSERTION- The magnetic field falls as inverse square with distance as me move from the axis to the surface of a long Current carrying bar.

REASON-The current density causing the magnetic field is falling as we move from axis to surface

6 ASSERTION- The magnetic moment of electron in outer orbit of Hydrogen atom is higher

REASON- The kinetic energy of electrons in outer orbit Hydrogen atom is lower

7 ASSERTION- The resistance of a milli-ammeter is higher than the resistance of an ammeter

REASON- The current sensitivity of an ideal ammeter shall be zero

8 ASSERTION-The pole pieces of a moving coil galvanometer are cylindrical.

REASON- The magnetic field in a moving coil galvanometer shall be radial in nature

9 ASSERTION-A charge fired at oblique incidence in magnetic field moves along a helical path such that axis of helix and magnetic field are at right angle.

REASON-The radius and pitch of helix is independent of angle of projection with

respect to the magnetic field

10 ASSERTION- A current carrying wire in magnetic field experiences a force

REASON- A charge moving in magnetic field experience a Loretz force

SOLUTIONS

1-b 2-a 3-b 4-d 5-c 6-b 7-c 8-a 9-d 10-a

SHORT ANSWER (2 MARKS)

1 An insulated circular loop carrying current is placed on a table and a light straight long wire carrying current is kept on it parallel to the diameter. Can the wire be pushed up by loop? Explain

2 Can a magnetic monopole exist in nature? Give reason

3 Write the Expression for magnetic field in a long solenoid. Draw the magnetic field for a solenoid having finite length. What is the ratio of magnetic field near the end and well inside it.

4 An arc of a circle of radius 10cm subtends angle 60^0 at its center. Find the magnetic field at the center if current in arc is 30A

5 A positive charge 'q' moves along X- axis with a speed 'v'. if largest Lorentz's force 'F' on it due to uniform magnetic field 'B' is along –Z axis. Find the magnitude and direction of magnetic field.

6 The velocity of a charge fired into a magnetic field normally is doubled. How would this effect the frequency of motion and curvature of path followed by the charge in magnetic field? Explain

7 A charge is moving in magnetic field in a circular orbit. Give the expression for its KE in terms of applied external magnetic field.How would the Kinetic energy be affected if it is made to move in a magnetic field of double the strength ? Explain.

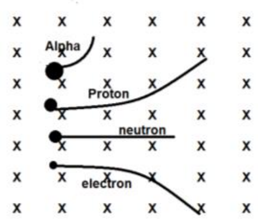
8 A long solenoid has a magnetic field of 0.25T inside it. If a bar of magnetic susceptibility 5 is inserted into it what will be the magnetic flux density inside it?

9 The torsional constant of the hair spring in MCG is increased what will be the affect on voltage sensitivity of it due to this? Give reason.

10 A proton, neutron electron and alpha particle enters normally into a magnetic field of uniform nature with same momentum directed into the plane of paper. Draw suitable diagram to indicate their paths.

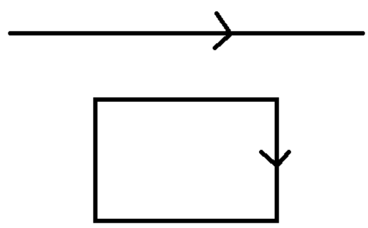
SOLUTION

1-No Lorentz force is parallel to wire for all cases
2- No , A loop having clockwise current from one side will appear anticlockwise from other face of it
3- $B = \mu_0 nI$ and near ends it is halved , usual figure from NCERT
4- $B = \mu_0 I\theta/4\pi r$ where θ in radians only, 3.14×10^{-5} T
5- -y axis and $B = F/qB$ (use Lorentz force in vector form)
6- No change 'f' doesn't depend on speed
7- $KE = (qBr)^2/2m$, No change because change of B affects r in inverse ratio
8- $\mu_r = 1 + X_m = 6$ so $B = 0.25 \times 6 = 1.5T$
9- $V.S. = \theta/V = NBA/CR$ C rises V.S. decreases
Conceptually stiff hair spring will not allow the needle to move if voltage is low i.e Voltage sensitivity has decreased.
10- $r = p/qB$, neutron goes

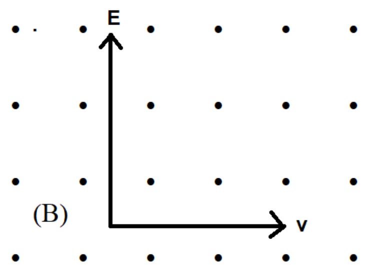


SHORT ANSWER (3 MARKS)

1- A square loop of side 'a' is kept near a long charged wire in a plane such that a side of it is parallel to the wire (kept in same plane) at a distance 'a' from it. Find the force on the wire due to the loop. If Current in wire is I_1 and in loop is I_2 in clockwise direction



2- In a region of crossed electric (**E**) and magnetic(**B**) fields many particles of same mass but charge (positive, negative or neutral) are fired into a direction normal to both **E** and **B** with their velocity in the range 5m/s to 500m/s as shown in the figure

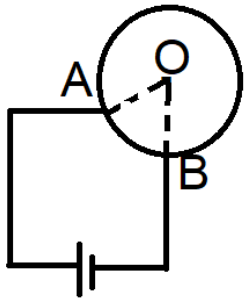


. if E is 80v/m and B is 0.4T which of these can pass through the region without any deflection?

Draw figure to show path of positive and negative charged particles moving with 40m/s and 400m/s respectively

3 Two electrons are moving along parallel lines separated by 'r' with (i) same speed (v) . In which case force on an electron due to other will be more (a)in its own frame of reference (b) with respect to the ground. Give reason

4 Show that the magnetic field at the center is zero irrespective of the resistance of circular loop and irrespective of the angle made by arc AB at 'O'

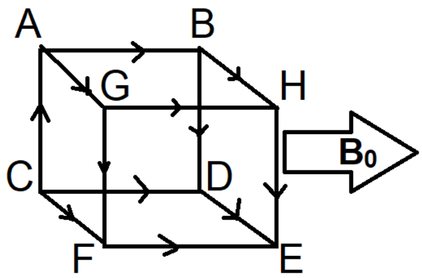


5 Use ampere's circuital law to find magnetic field due to along straight wire. Can we use it if wire is finite? Give reason

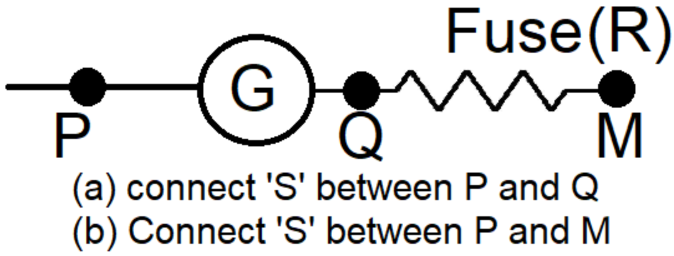
6 What is a radial magnetic field? Why do we need it in moving coil galvanometer?

Changing current sensitivity of a moving coil galvanometer may or may not affect its voltage sensitivity. Explain

7 A cube ABCDEFGH is kept in a uniform magnetic field B_0 shown. Determine the direction of force on each side. Which side(s) will experience minimum force?



8 The resistance of galvanometer is Rg and its full scale deflection current is Ig. For safety purpose a fuse of resistance 'R' is joined with it.To convert it to an ammeter of suitable range which is the correct way (a) or (b)? If he/she connects 'S' the wrong way what will be the new range of the device.



SOLUTIONS 3 MARKS

1. $\frac{F}{a} = \frac{\mu_0 2 I_1 I_2}{4\pi}\left[\frac{1}{a} - \frac{1}{2a}\right]$

Or $\frac{F}{a} = \frac{\mu_0 2 I_1 I_2}{4\pi}\left[\frac{a}{2a}\right]$

Or $F = \frac{\mu_0 I_1 I_2 a}{4\pi}$ attractive

2. for no deflection qE = qvB

v = E/B = 200 m/s these will go undeflected

For v< 200m/s qE > qvB

positive particle deflects along E field and negative particles deflect against electric field.

For v> 200m/s qE < qvB positive particle deflects against **E** field and negative particles deflect along **E** field.

3. In Earth Frame of reference electron experiences electric and magnetic force both. These forces will be in opposite direction and for electron's frame of reference (F O R) there is only one force electric force .

Hence in earth F.O.R. lesser force.

4. Let current splits and I_1 goes in smaller arc and $I-I_1$ in bigger arc such that

$V_{small\ arc} = V_{big\ arc}$

$I_1R_1 = I_2 R_2$

$\frac{I_1 \rho l_1}{A} = \frac{I_2 \rho l_2}{A}$

$I_1 l_1 = I_2 l_2$

Now $B_1 = \frac{\mu_0}{4\pi}\frac{I_1}{r}\theta$

$B_2 = \frac{\mu_0}{4\pi}\frac{I_2}{r}(2\pi - \theta)$

Here $\theta = \frac{l_1}{r}$ $and\ 2\pi - \theta = \frac{l_2}{r}$

Using in B_1 and B_2, we get

$I_1 l_1 = I_2 l_2$

Therefore $B_1 = B_2$

i.e. $B_1 - B_2 = 0$

5. $\oint B.dl = \mu_0 I$

B $2\pi r = \mu_0 I$

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

No, as the symmetry condition is violated for any general point near the wire of finite length violated.

6. B parallel to plane of the coil is called radial magnetic field.

So that torque α current

Vs = NBA/CR

Is = NBA/C

(i) If N rises both rises.
(ii) IF R rises V.S. falls but C.S. does not change.
So it depends on how change is brought about.

7. $F_{AB} = F_{GH} = F_{FE} = F_{CD} = 0 \quad (\theta = 0^\circ)$

$F_{AC} = F_{GH} = F_{HE} = F_{BD} = +\mathbf{k}$

$F_{AB} = F_{AB} = F_{AB} = F_{AB} = +\mathbf{j}$

8. correct way is to join 'S' between PQ

$S = \frac{I_g R_g}{I - I_g}$ or $I = I_g\left(\frac{R_G}{S} + 1\right)$

Range becomes I when joined 'S' across 'PQ'

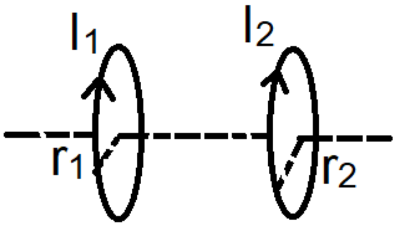
When S is connected the wrong way i.e. between PM

If $S = \frac{I_g(R_g + R)}{I' - I_g}$

$I' = I_g\left[\frac{1 + R + R_g}{S}\right]$

LONG ANSWER (5 MARKS)

State Biot-Savart's law. Express it in vector form. Find the magnetic field at the mid-point if gap between the coils is 2a having N turns each.(see figure) Draw graph to show variation of B with distance between the coils.



2 Draw the diagram of a moving coil galvanometer. Give its principle.

A student needs to perform an experiment on OHM's law but he was given two galvanometers and variable resistors of all possible values along with a multimeter.

How would he be able to perform his task? Give the formula he should use to find the value of variable resistors to be used and draw relevant circuits to show the modifications to be undertaken by him

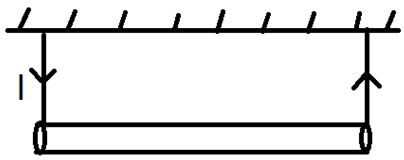
Two ammeters X and Y has resistance of 50 ohm and 80ohm if same current is sent in them which of two will show a greater deflection? Explain

3 Show that a current carrying coil in magnetic field experiences a torque. Hence find the expression for magnetic moment of the coil? Does the torque on the coil depend on the shape of the coil?

4 Derive the formula for Force per unit length between two long straight parallel wires. Define one ampere using your result.

A rectangular coil of size 40cm x 50 cm having 500 turns is carrying current of 5A. it is kept in a uniform magnetic of 0.2T field making an angle of 60^0 from the plane of coil. Find the force and torque on the coil.

5 Figure shows a metal bar of length ‘L’ and mass ‘m’ in equilibrium in the plane of paper when a uniform magnetic field ‘B’ acting outward from the plane of paper. Find the magnitude of tension in each wire.



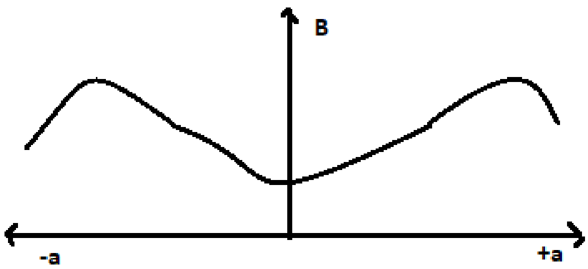
(a) What will be the tension in each wire if magnetic field is turned inward?
(b) The uniform magnetic field is made to rotate about an axis in the plane of paper perpendicular to the bar with a constant angular velocity ω. Draw a graph to show the rate of change of tension

ANSWERS TO LONG ANSWER TYPES QUESTIONS:

1. **B = B_1 + B_2**

where $B_1 = \frac{\mu_0}{4\pi}\frac{2\pi N I_1 r_1^2}{(r_1^2 + a^2)^{\frac{3}{2}}}$ similarly B_2 can be written

so total B = B_1 - B_2 as they act opposite to each other

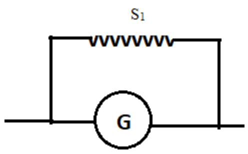


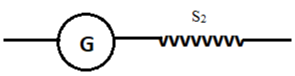
2. He will calculate Shunt / resistor Required

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

Low ‘S’ in parallel to make ammeter

High ‘S’ in series to make voltmeter S = (V/Ig) -R





$S_1 << S_2$

50Ω will show higher deflection as it is closer to ideal behavior of an ammeter.

$I = \frac{E}{R_c + R_g}$; Where Rc = Circuit Resistance

3. $\tau = NIAB\, sin\theta$ or $mBsin\theta = NIBAsin\theta$

Or m = NIA, No

4. $\frac{F}{L} = \frac{\mu_0}{4\pi}\frac{2 I_1 I_2}{r}$

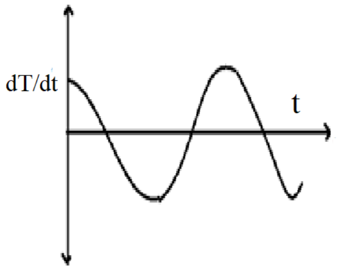
Definition of 1A: If $I_1 = I_2 = 1$ A, r = 1m then F/L = $\frac{\mu_0}{2\pi} = 2 \times 10^{-7} N/m$

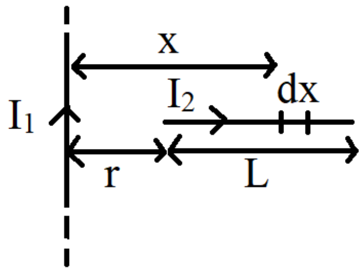
$\tau = NIAB \sin\theta = 50\ Nm$

5. $2T = mg + IBL \sin\theta$ (when B is outwards) ---------------eq (i)

(a) if B is acting inwards $2T = mg - IBL \sin\theta$

(b) by eq (i) $\frac{dT}{dt} = 0 + IBL\cos\theta \frac{d\theta}{dt} = IBL\omega \cos\omega t$





SOURCE BASED QUESTIONS (4 - MARKS)

Q1 Two particles of same mass having charges q_1 and q_2 ($q_1 > q_2$) are fired into in a magnetic field with velocity v_1 and v_2 at angle θ and α respectively ($90^0 > \alpha > \theta$). The charges will experience a force due to magnetic field and that decides the path charge will follow.

(i) The locus of charges in magnetic field will be a path that is

(a)Helical (b) linear (c) circular (d) parabolic

(ii) In a case where path is helical the pitch will be same for both provided

(a) $v_1 = v_2$
(b) $v_1 \sin\alpha = v_2 \sin\alpha$
(c) $v_1 \cos\theta = v_2 \sin\alpha$
(d) $v_1 \cos\theta = v_2 \cos\alpha$

(iii) The radius of curvature of the path followed by the charges will be same if

(a) $v_1 / v_2 = \cos\alpha / \cos\theta$
(b) $v_1 / v_2 = \sin\alpha / \sin\theta$
(c) $v_1 / v_2 = \cos\theta / \cos\alpha$
(d) $v_1 / v_2 = \sin\theta / \sin\alpha$

(iv) If the magnetic field is varying with time which of the following is correct

(a)The K.E of both the particles will not change with time

(b) The K.E of both the particles may vary with time

(c) The angular frequency of both the particles will have a ratio sinθ/sinα

(d) The magnetic Lorentz force will be normal to velocity all the time

OR

The locus of path will be will have an axis of symmetry (a)If and only if $\theta + \alpha = 180^0$

(b) If and only if $\theta + \alpha = 90^0$

(c) Along the direction of magnetic field

(d)Normal to the direction of magnetic field

Q2 A moving coil galvanometer (MCG) is a parent device that can work as an ammeter or voltmeter after suitable external modification. In practical cases a galvanometer can measure current only upto few hundred μA and voltage upto few mV so they are not much useful for measurements. R_1 and R_2 ($R_1 < R_2$) are two resistors that are available for modifying a galvanometer into an ammeter or voltmeter.

(i) When a galvanometer is converted to a voltmeter its voltage sensitivity is

(a)Decreased (b)Doesn't change

(c) Increased (d) May increase or decrease as per the value of R_2

OR

To convert MCG to a voltmeter of suitable range we must use

(a) R_1 in series (b) R_2 in series (c) R_1 in parallel (d) R_2 in parallel

(ii)A voltmeter with higher resistance but same range will show

(a)Greater deflection and lower voltage sensitivity (b)Lesser deflection and higher voltage sensitivity

(c) Greater deflection and higher voltage sensitivity (d) Lesser deflection and lesser voltage sensitivity

(iii)A student argues even if we modify an MCG into an ammeter of range 0 to I it never knows about the modification done. The current I (I >Ig) isn't passing through the galvanometer. Galvanometer is still permitting Ig current and the extra current (I-Ig) is not passing through the galvanometer in reality so the deflection is not a true measurement of current sent into the system. The best logic that can resolve the issue is - Student's argument is

(a) incorrect as current sensitivity is constant
(b) incorrect as network has a lower resistance than before
(c) correct and the device is merely calibrated after modification
(d) Correct as voltage sensitivity of it increases proportionally.

(iv) A galvanometer is converted to an ammeter of range I_1 using S_1 and I_2 using S_2. If $S_1 = xR_g$ and $S_2 = yR_g$ the ratio of I_1 and $_2$ will be

(a) x/y (b) y/x (c) y(1+x))/[x(1+y)] (d) y(1-x)/[(x(1-y)]

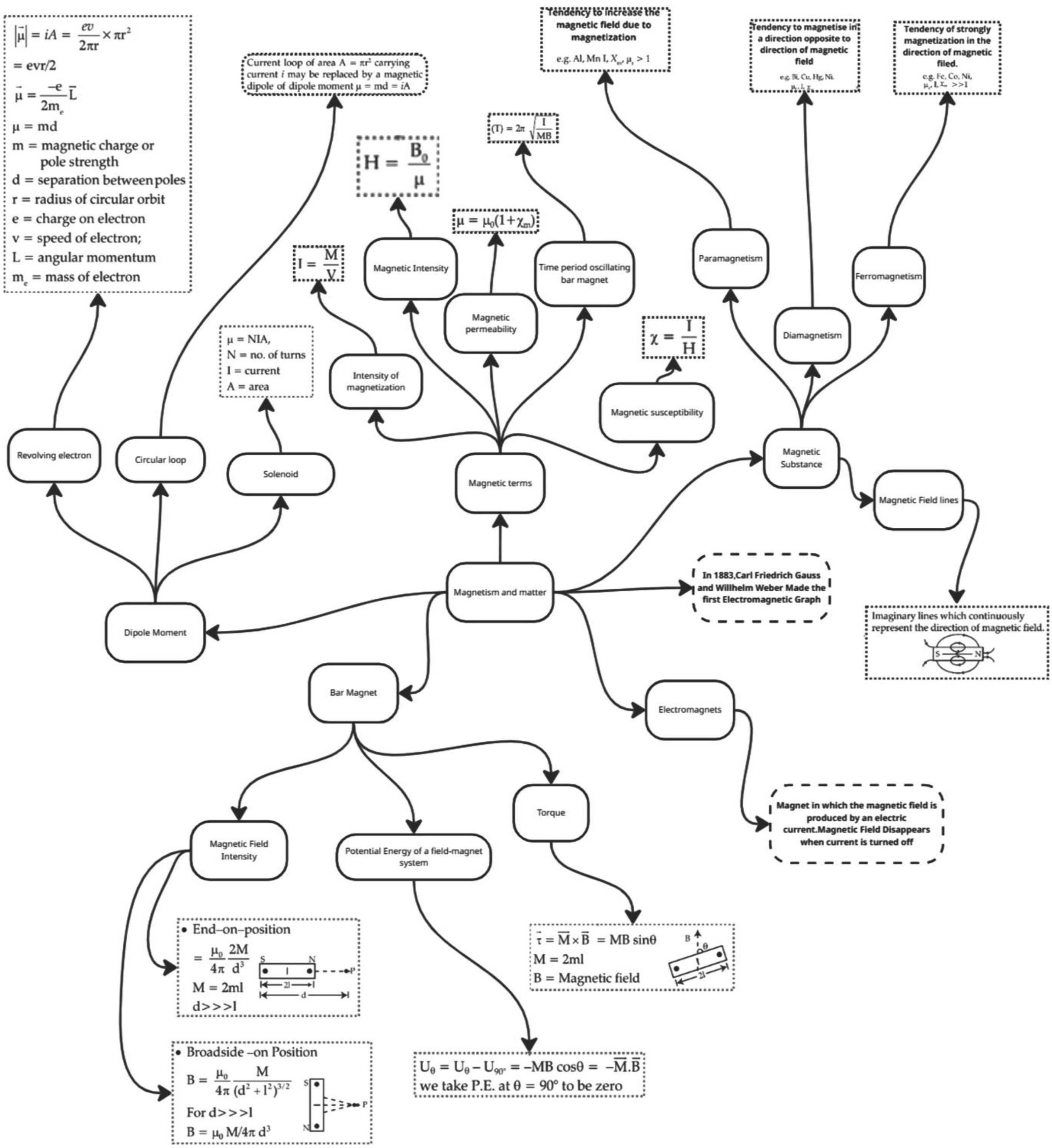
SOLUTIONS-

Case Study:

1. (i) (a) (ii) (c) (iii) (d) (iv) (b) or (c)
2. (i) (c) (ii) (c) (iii) (b) or (c) (iv) (a)

CHAPTER 5: MAGNETISM AND MATTER

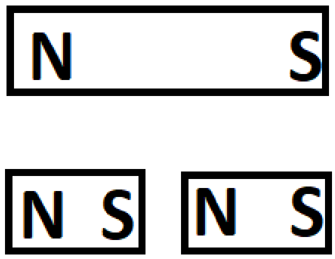
Magnetism- Magnetism is the study of with the properties magnets and magnetic materials along with their behavior and properties. The Earth itself acts like a giant magnet.With the development of atomic sciences we have come to know that magnetic effects are due to moving charges or electrons.It was discovered that some materials in nature has a natural ability to attract iron towards it. These materials are called natural magnets. These were used mainly for navigation in earlier times.



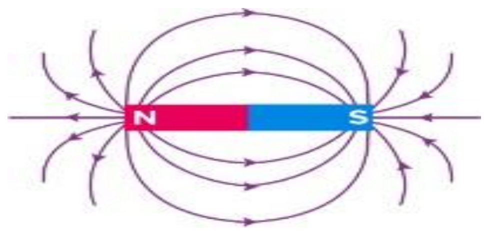
GIST OF THE CHAPTER

Magnetism- Magnetism is the study of the properties of magnets and magnetic materials along with their behavior and properties. The Earth itself acts like a giant magnet. With the development of atomic sciences we have come to know that magnetic effects are due to moving charges or electrons. It was discovered that some materials in nature has a natural ability to attract iron towards it. These materials are called natural magnets. These were used mainly for navigation in earlier times.

Bar magnet- Natural magnets can be mould into various shapes like bars, cylinder, horse-shoe etc.for different purposes. Bar is just one such shape. Such magnets are called bar magnets. So we can say that a bar magnet is a rectangular piece of an object, made of ferromagnetic substances, that shows permanent magnetic properties. It has two poles - North and South. These poles are always in pairs even if we keep splitting the magnet into smaller and smaller parts



Magnetic field- The region of space around a magnet in which it can influence other magnets is called its magnetic field. Magnetic field is represented by closed continuous curves called magnetic field lines.



A tangent at any point on magnetic field line gives the direction of magnetic field at that point. These curves are called magnetic field lines.

Magnetic field lines of a bar magnet appear to emanate from North pole and enter into its south pole but forms complete loop (considering them inside the magnet too).Inside the magnet their direction is from S pole to N- pole while outside its N-pole to S-pole

The properties of magnetic lines of force are as follows:

Magnetic field lines emerge from the north pole and merge at the south pole.

As the distance between the poles increases, the density of magnetic lines decreases.

The direction of field lines inside the magnet is from the South Pole to the NorthPole. Magnetic lines do not intersect with each other. The strength of the magnetic lines is the same throughout and is proportionalto how close are the lines.

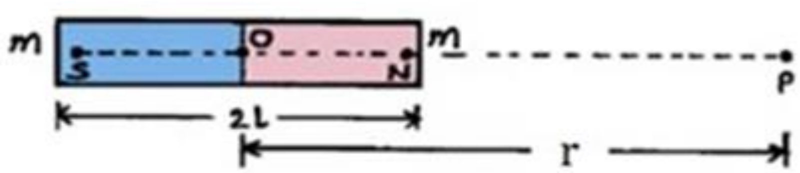
Magnetic dipole- A magnetic system like a bar magnet is essentially a magnetic dipole as its poles are not separable.

Magnetic dipole moment- It is a vector quantity having magnitude m x l where m is pole strength of each pole of magnet and l is effective length of the magnet. It is directed from South pole towards North pole of magnet

$|\mathbf{M}| = m \times l$, SI unit of **M** and m are Am^{-2} and Am^{-1} respectively

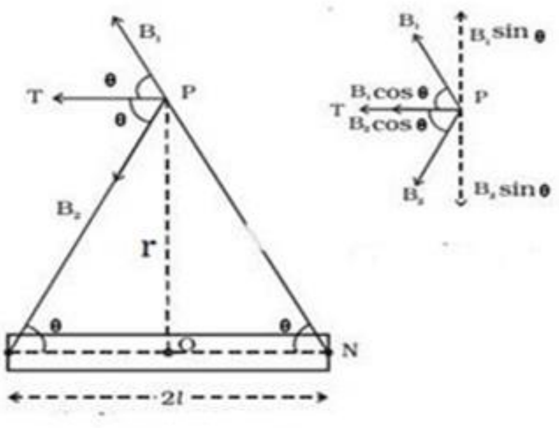
Key Points:

- **B** it is magnetic induction or magnetic flux density
- **H** = magnetizing force or intensity of magnetizing field
- **B** = μH for a material medium for vacuum $B_0 = \mu_0 H$
- **B/ B_0** $= \mu/ \mu_0 = \mu_r$ is called relative magnetic permeability
- 'I' is called intensity of magnetization it is equal to magnetic moment developed per unit volume in the sample. **I** = **M**/V SI unit of I is A/m
- Magnetic susceptibility (χ_m) – Ratio of intensity of magnetization (I) and intensity of magnetizing field (H) is called magnetic susceptibility. It has no units
- $\mu = \mu_0 (1+ \chi_m)$
- Magnetic field lines emerge from the North pole and enter the South pole. But they completes their loop inside the magnet.
- Magnetic dipole moment (**M**): M = m × 2l (direction is from S pole to N pole)
- Magnetic field on axial line:



B = $(\mu_0 / 4\pi) \times (2\mathbf{M} / r^3)$

B and **M** are parallel

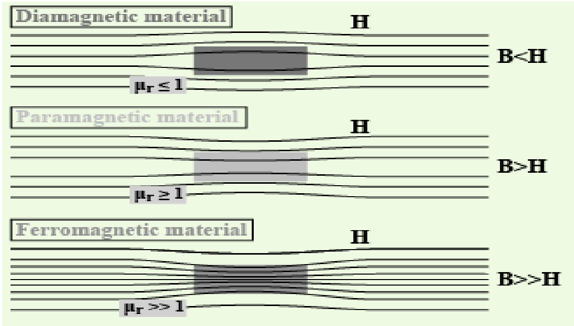


- Magnetic field on equatorial line:
  B = $(\mu_0 / 4\pi) \times (\mathbf{M} / r^3)$
  B and **M** are anti-parallel

Torque on a Magnetic Dipole: $\boldsymbol{\tau} = \mathbf{M} \times \mathbf{B}$ such that $\tau = MB \sin\theta$

- Potential Energy: U = -**M** . **B** or U = -MBcosθ
- Work done to rotate a magnet in magnetic field
  $W = -MB (\cos\theta_2 - \cos\theta_1)$
- Gauss Law of Magnetism essentially states that the magnetic flux through a closed surface/loopis zero. i.e. $\oint \vec{B}.\vec{ds} = 0$ It means magnetic monopoles do not exist in nature
- A bar magnet of magnetic moment **M** is equivalent to a coil of magnetic moment **NIA**
- Magnetic moment of charge moving in a circle is M= qvr/2

Magnetic Properties of Materials



Substances can be divided into three groups based on their magnetic properties i.e. diamagnetic, paramagnetic, and ferromagnetic. They can be classified based on their magnetic susceptibility.

Diamagnetic Materials

The materials that develop temporary magnetization such that the magnetic moment is in the opposite direction to that of the magnetic field in which they are placed are known as Diamagneticmaterials. In simple words, they are repelled by magnets.

Their magnetic susceptibility is small and negative. They have no unpaired electrons in them so magnetic moment of each atom in them is zero individually. Examples of diamagnetic materials are Bismuth, Copper, Zinc, Lead, etc

Paramagnetic Materials

The materials that develop temporary magnetization such that the magnetic moment is in the same direction as that ofthe magnetic field in which they are placed are known as

Paramagnetic materials. They are slightly attracted by magnets. They have positive but very low susceptibility.They have unpaired electrons in them so each atom has magnetic moment of its own. In an external magnetic field torque acts on tiny atomic magnetic dipoles and align them along applied field. They can be called as poor ferromagnets.

Examples of Paramagnetic materials are Aluminium, Sodium, Calcium, etc

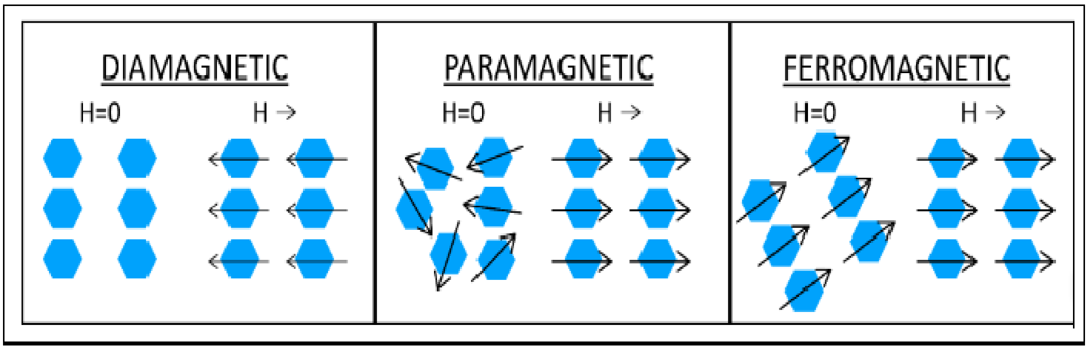
Ferromagnetic Materials

The materials that develop temporary but strong magnetization such that the magnetic moment is in the same direction to that of the magnetic field in which they are placed are known as *ferromagnetic materials*. They are strongly attracted by magnets.

They have positive and high susceptibility. They have unpaired electrons in them. The atoms interact with neighbouring atoms to form ‘domains’ in them.In a domain all atoms align their magnetic moment in same direction. So a domain has large magnetic moment compared to an atom.in external field these domains get aligned parallel to the field so they get strongly magnetized.

Examples of Ferromagnetic materials are Iron, Nickel, Cobalt, Haematite, etc

	Property	Dia	Para	Ferro
1.	Effect of magnet	They are feebly repelled by magnets.	They are feebly attracted by magnets.	They are strongly attracted by magnets.
2.	Relative magnetic permeability (μ_r).	$0 \le \mu_r < 1$	$1 < \mu_r$	$\mu_r >> 1$
3.	Susceptibility value (χ)	χ is small and negative $-1 \le \chi \le 0$	χ is small and positive. $0 < \chi$	χ is large and positive. $\chi >> 1$



Effect of temperature on magnetic properties

According to Curie's Law, the magnetization in a paramagnetic material is directlyproportional to the applied magnetic field. If the object is heated, the magnetization isviewed to be inversely proportional to the temperature

$$\chi = \frac{I}{H} = \frac{C}{T}$$

I = magnetic moment per unit volume

H= intensity of magnetizing field = B/μ_0

The Curie temperature (T_C) of a ferro-magnetic material is the temperature above which it behaves like a para-magnetic material.

$$\chi = \frac{I}{H} = \frac{C}{(T - T_c}$$

MULTIPLE CHOICE QUESTIONS

1 A ball of a diamagnetic material is heated. The magnetic susceptibility of its material will

(a) increase (b) Decrease (c)Not change
(d) Increases than attains a saturation value

2 A diamagnetic bar is suspended freely between parallel magnetic poles. It will tend to align its length

(a) Perpendicular to the poles (c) Parallel to the poles
(b) At 45^0 to the poles (d) In any random direction

3 The magnetic nature of atomic hydrogen is

(a) Diamagnetic (b) Paramagnetic (c) Ferromagnetic (d) Non - magnetic

4 In a bar magnet the distance between its magnetic poles is n times the length of bar magnet where 'n' is nearly

(a) 1 (b) 0.64 (c) 0.74 (d)0.84

5 Magnetic susceptibility and relative permeability of a material are

(a) directly proportional (c) differs by unity
(b) inversely proportional (d) equal

6 Natural bar magnets are not very useful for practical purposes because their

(a) size is small (b) mass is large

(c) magnetic moment is low (d) magnetic moment is high

7 Superconductors are perfect dia-magnets. A superconductor is kept in an external magnetizing field having intensity 'H' the intensity of magnetization (I) due to its own magnetization will be

(a) Zero (b) –H (c) H (d) -1

8 If **B** denotes magnetic flux density and **H** denotes intensity of magnetizing field which of the following is correct

(a) $B = \mu H$ (b) $B = H/\mu$ (c) $H.B = \mu$ (d) μBH = constant

9 If a bar of volume 'V' is kept in a magnetic field it gets magnetized. If its intensity of magnetization is 'I' and its magnetic moment developed in it is 'M'

(a) I= M (b) I α 1/M (c) I = M/V (d) M= I/V

10 The force between two poles of small sized magnets 'X' and 'Y' is F if their separation is increased to double the force between them will be

(a) F/2 (b) F/4 (c) F/8 (d) F/16

SOLUTIONS-

1- c diamagnetism is independent of temperature
2- c $U = -MB\cos\theta$ is minimum in that orientation
3- b Paramagnetic, it has unpaired electrons
4- d
5- c $\mu_r = 1 + \chi_m$
6- c
7- b $\chi_m = -1$, $I/H = -1$ so $I = -H$
8- a
9- c
10- b F is inversely proportional to r^2

ASSERTION REASON QUESTIONS

1 ASSERTION- Each atom of a paramagnetic material has a non-zero magnetic moment of its own.

REASON- Paramagnetism is shown by materials having unpaired electrons in them

2 ASSERTION- The magnetic moment of electron in outer orbit of Hydrogen atom is higher

REASON- The kinetic energy of electrons in outer orbit Hydrogen atom is higher

3 ASSERTION- A diamagnetic bar in magnetic field aligns itself along the field.

REASON- Susceptibility of a diamagnet is slightly more than zero

4 ASSERTION- A bar magnet is equivalent to a solenoid as both generate magnetic field

REASON- Magnetic field at the center of bar magnet is weaker as compared to its poles

5 ASSERTION- Two poles of a magnet can never be separated
REASON – Magnetic field lines always form closed loops.

6 ASSERTION- A magnetic dipole tries to align itself at right angle to the applied external magnetic field.
REASON – When a magnet is perpendicular to a magnetic field its potential energy is maximum

7 ASSERTION – The magnetic permeability of a material doesn't depend on its temperature.
REASON – The magnetic induction (**B**) doesn't depend on temperature.

8 ASSERTION – The magnetic moment of a magnet is equal to the product of magnetic pole strength and least distance between the poles of the magnet.
REASON – Magnetic moment is a vector quantity.

9 ASSERTION – A ferromagnetic material has high magnetic susceptibility.
REASON- Ferromagnetic materials have domains and each domain has high magnetic moment

10 ASSERTION – Two identical charges moving in circular orbits of different radii can have same magnetic moment
REASON- The magnetic moment of a circulating charge is ZERO.

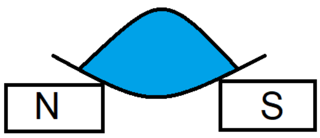
ANSWERS

1- a 2- c 3- d 4-d 5-a 6- d 7-d 8-b 9-a 10-c

2 MARKS QUESTIONS

1 Can a magnetic monopole exist in nature? Give reason

2 A paramagnetic sample is placed on a watch glass as shown below. Draw diagram to show how the distribution of sample is affected in due course of time. In which case it attains new arrangement quicker (i) a hotter sample (ii) a colder sample



3 A long solenoid has a magnetic field of 0.25T inside it. If a bar of magnetic susceptibility 5 is inserted into it what will be the magnetic flux density inside it?

4 A Diamagnetic bar and a paramagnetic bar are kept in a long solenoid for magnetizing them. Draw diagram to show magnetic field lines with samples placed inside clearly mention the magnetic poles induced in the two bars.

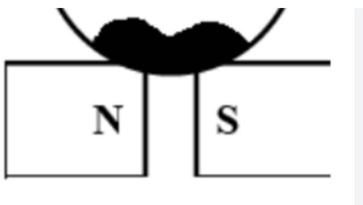
5 Why the susceptibility of a diamagnetic material doesn't depend on the temperature?

6 The susceptibility of a ferromagnet is reduced by 10% when its temperature is raised above 1200K by 50^0C. Find the temperature below which it will be paramagnetic in nature

SOLUTIONS-

1- No, A circulating charge causes magnetic character. From one face it appears to move clockwise while from other face it appears to move anticlockwise. So the two faces are two poles. It same thing viewed from two sides.

2- Refere gist given above. The hump will split into two mounts of smaller size as paramagnetic salt is weakly



attracted by magnetic poles.

The new arrangement will be quicker in colder sample as hotter sample is less susceptibile to magnetic field so it will respond slower

3- $\mu = \mu_0 (1+ \chi_m)$ so $\mu = 6\mu_0$
$B = \mu H = 6\mu_0 H = 6 B_0$

$B = 6 \times 0.25 = 1.5T$

4- refer Gist of chapter
5- In a diamagnetic material all electrons are paired so the magnetic moment of an electron is nullified in pair. Even if we change temperature the magnetic moments get nullified so diamagnetism is independent of temperature.
6- Using formula $\chi_m = C/ (T- T_c)$
$1/0.9 = (1250- T_c) / (1200- T_c)$

$T_c = 750K$

3 MARKS QUESTIONS

1 A bar magnet is bent to make a semi circle. Find the ratio of its initial and final magnetic moment.

What will be the magnetic moment of the system if it is broken into three equal parts and make a proper triangle such that at two vertices like poles are held together?

2 The relative permeability of a material is $1.03\mu_0$. Find its susceptibility and identify the magnetic nature of the material. What will be the effect on it's susceptibility if its temperature on heating it.

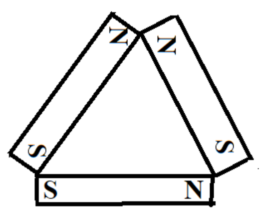
3 For a magnetic material the relative permeability is $1.05\mu 0$. find its susceptibility. Draw a diagram showing the magnetic field lines when such a sample is kept in magnetic field.

4 A square coil of side 20cm and 2000 turns is carrying a current of 10A.Calculate the magnetic field at a point on its axis 8m away from its center.

5 Two identical small bar magnets each of magnetic moment 'M' are placed along X-axis and Y-axis such that their mid point is at origin. (a)Determine the expression for magnetic field at a point 'r' distance away on Z-axis, (b)Find the direction of resultant magnetic field at that point

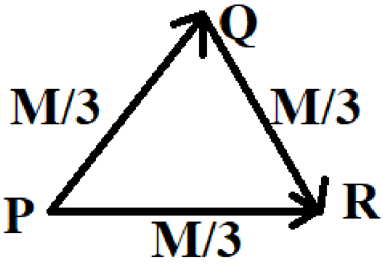
6 A paramagnetic sample shows a saturation magnetization of 12% at 10K in an external magnetic field of 0.5T. what will be the saturation magnetization in a magnetic field of 0.8T at 12K?

7 Three identical bars of magnetic moment M each are arranged as shown to make an equilateral triangle. Find the magnetic moment of the system.



SOLUTIONS-

1- Let M = mx l
   But A.T,Q, $l = \pi r$, so M' = mx 2r ,thus M/M' = m l/2mr , hence M/M' = $\pi/2$



$\overrightarrow{PQ} + \overrightarrow{QR} = \overrightarrow{PR}$ angle between $\overrightarrow{PQ}$& $\overrightarrow{QR}$ is 120^0

so $|\overrightarrow{PR}| = \frac{M}{3}$ hence M_{total} = 2M/3 along $\overrightarrow{PR}$

2- $\mu = \mu_0(1+\chi)$
   $1.03\ \mu_0 = \mu_0(1+\chi)$

   $\chi = 0.03$, it is paramagnetic.

   Susceptibility decreases with temperature inversely as per curie's law

3- do yourself
4- M = NIA
   M = 2000x 0.2 x 0.2 x 10 = 80 Am^2.

   B = $(\mu_0 / 4\pi) \times (2$**M**$/ r^3)$

   B = 10^{-7} $(160/8^3)$ = 3.125 x 10^{-8} T along the axis of coil

5- Do yourself
6- Do yourself 16%
7- Do as in Q1 2M towards right

SOURCE BASED QUESTIONS

Q1 In a paramagnetic sample each atom has unpaired electrons so each atom in them has a permanent magnetic moment of its own. Under ordinary conditions the random orientations of these tiny atomic magnets sum up to zero. When the sample is placed in an external magnetic field the tiny magnets get oriented along it due to which sample gets magnetized. If we raise the temperature the thermal agitation disturbs the alignment so system starts losing its magnetic character.

(i) The magnetic moment of each atom is non-zero for

(a) Diamagnets only

(b) Paramagnets and diamagnets both

(c) Paramagnets and ferromagnets both

(d) Ferromagnets and diamagnets both

(ii) When a paramagnet is placed in an external magnetic field B

(a) All the atomic magnets get aligned along B
(b) All the atomic magnets get aligned opposite to B

(c) Few atomic magnets get aligned along B
(d) Most of the atomic magnets get aligned along B

(iii) Two Aluminum bars P and Q have same volume but area of cross-section of P is more than Q they are kept inside a long solenoid. Their saturation magnetic moments are M_P and M_Q respectively and the respective pole strengths are m_P and m_Q respectively then

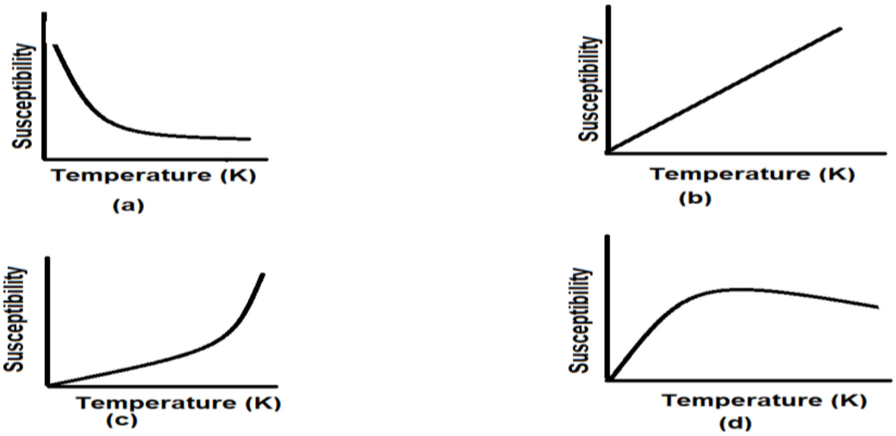
(a) $M_P > M_Q$ and $m_P < m_Q$
(b) $M_P = M_Q$ and $m_P > m_Q$
(c) $M_P < M_Q$ and $m_P = m_Q$
(d) $M_P < M_Q$ and $m_P > m_Q$

OR

If a paramagnetic bar is kept in an external magnetic field its

(a) Magnetic moment does not change with magnetizing force (H)
(b) Intensity of magnetization does not change with magnetizing force (H)
(c) Its pole strength rises with magnetizing force (H)
(d) its susceptibility rises with magnetizing force (H)

(iv) The variation of magnetic susceptibility of a paramagnet with temperature is correctly shown by the graph



Q2 P, Q and R are three bars they are kept in magnetic field for some time and their magnetic behavior is observed. The magnetization of P was much higher than that of Q and R. When they are heated after withdrawing from magnetic field Q doesn't show a change in its magnetic strength. The behavior of P is found to be same as R when it is heated to a temperature more than 1100^0C.

(i) Out of the given bars the diamagnetic behavior is shown by
(a) P (b) Q (c) R (d) None

(ii) The magnetic susceptibility is largest for
(a) P (b) Q (c) R (d) P and R both

(iii) Magnetization or intensity of magnetization is defined as
(a) Magnetic moment developed
(b) Magnetic moment developed per unit area
(c) Magnetic moment developed per unit volume
(d) Pole strength developed

(iv) Which of the following is NOT true ?
(a) P is Ferromagnetic
(b) 1100^0C is curie's temperature for P
(c) 1100^0C is curie's temperature for R
(d) Q has negative magnetic susceptibility

OR

The difference of relative magnetic permeability and magnetic susceptibility for these bars will be

(a) Zero for all
(b) 1 for all
(c) -1 for all
(d) 1 for P and R only

SOLUTIONS-

1- (i) a (ii) c (iii) b OR c (iv) a
2- (i) b (ii) a (iii) c (iv) b
3- (i) a (ii) b (iii) d OR c (iv) b

LONG ANSWER TYPE (5 MARKS QUESTIONS)

1 "Ferro-magnets are strong paramagnets". Justify by giving 2 reasons.

Define curie's temperature.

The susceptibility of a faerromagnetic material decreases by 20% when its temperature is raised from 1200K to 1250K. if these are above curie's temperature at what temperature will it fall by 50%.

2 Draw diagrams to differentiate among magnetic materials by showing the modified magnetic field lines when a different types of magnetic materials are placed in uniform magnetic field.

(a)Why the magnetization of a paramagnetic bar decreases when it is hammered?

(b) what is the value of susceptibility and relative permeability of a diamagnetic material.

3 A large number of thin identical bar magnets each of magnetic moment M are arranged to make a semicircular disc such that S-pole of each is lying at the center.Find the magnetic moment of the system and its direction if the longest side of disc is taken as X-axis center as origin.

Establish the relation between the magnetic moment and angular momentum of revolving charge. Use your result to show magnetic moment of electron in hydrogen atom is quantized

4 A bar magnet is kept in a uniform magnetic field. Derive the formula for torque acting on it. What will happen if the field is non-uniform?

A bar of diamagnetic nature is left freely in a uniform magnetic field. Draw a diagram to show in which orientation will it rest in finally. Give reason

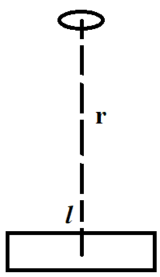
5 A bar magnet of length l is placed r away from a coil as shown where ($r >> l$).

If the magnetic field at the midpoint due to both is same find the area of coil.

Given that coil has N turns and current in it is i.

How shall they be placed so that magnetic field at the mid-point becomes zero.? Draw diagram

Draw diagram.



Give any three properties to differentiate among Dia, Para & Ferromagnetic

Materials

SOLUTIONS –

1- Refer text book
AS $\chi = C / (T - T_c)$

$\chi = C / (1200 - T_c)$ and $0.8\chi = C/(1250 - T_c)$

$0.8 = (1200 - T_c)/(1250 - T_c)$ so $T_c = 1000K$

2- Refer Text book
(a) On hammering the aligned tiny atomic magnets start to orient them in random directions so component of magnetic moment along intial direction decreases.
(b) For diamagnets susceptibility is negative and low but it lies between zero and -1. For perfectdiamagnets its -1 $-1 \leq \chi < 0$
The relative permeability lies between Zero and 1 $0 \leq \mu_r < 1$

3- Taking components of **M** along X-axis and Y-axis we see that x-components cancel out in pairs so overall magnetic moment is sum of sine components only along Y-axis so

$M_{total} = \int_0^{\frac{\pi}{2}} M \sin\theta \, d\theta = M$

For an electron in Hydrogen atom **M= -eL**/2m **L = angular momentum** (prove yourself)

As |L| = mvr = nh/2π n= 0,1,2,3……………………

As L is quantized so M is quantized also

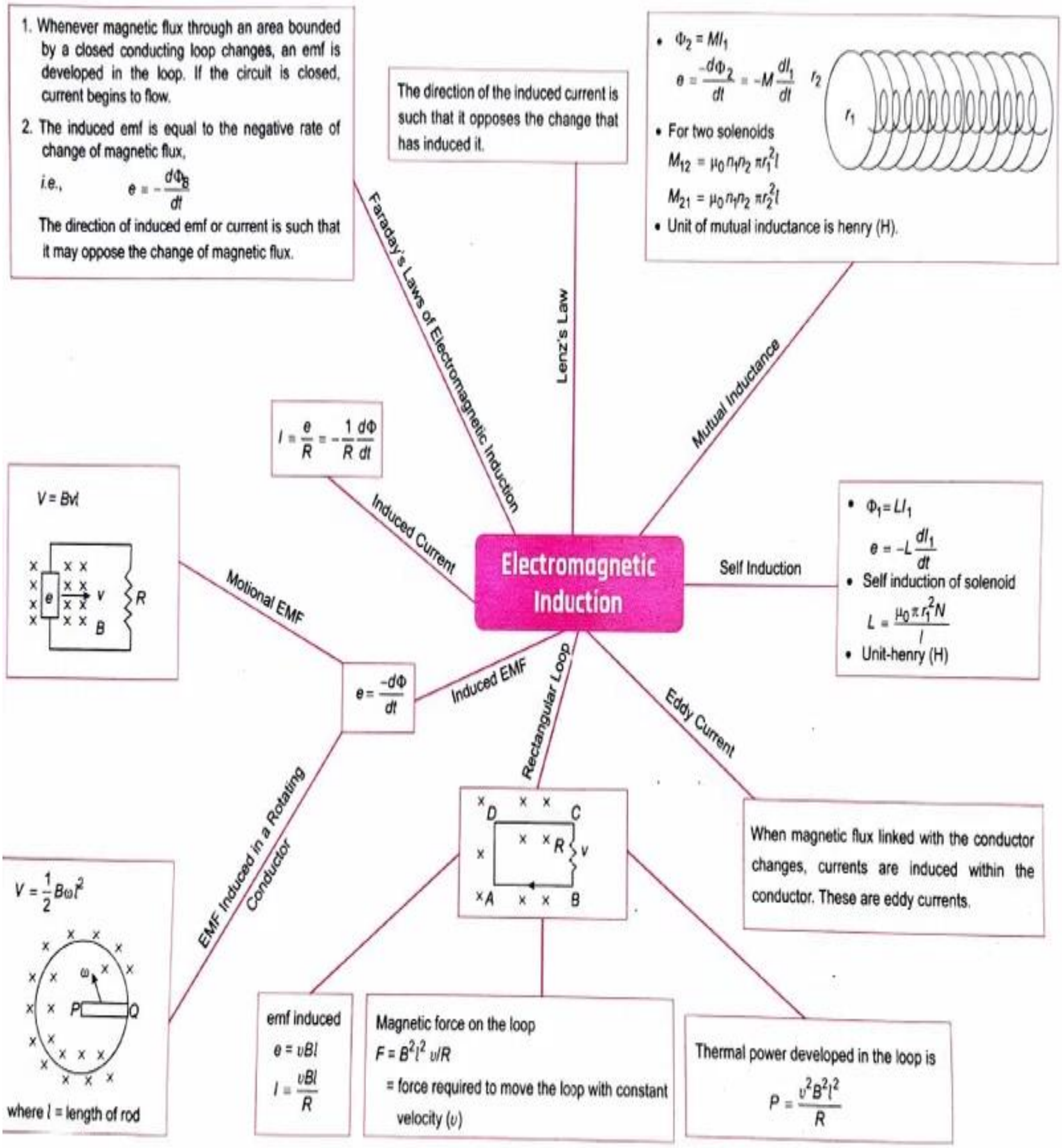
4- Refer gist of chapter and prove yourself
For Non-uniform field it will feel Force and torque both

It will align normal to field to minimize its potential energy.

5- Do yourself
Hint- coil can be replaced by an equivalent magnet.

CHAPTER 6 – ELECTROMAGNETIC INDUCTION

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



GIST OF THE CHAPTER

Area Vector($\vec{A}$) :

An area vector is a vector whose magnitude is equal to the area of a plane and direction is normal to the plane of the area.

Magnetic Flux $\emptyset_B$

GIST OF THE CHAPTER

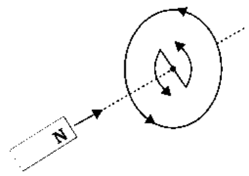
The total number of magnetic lines of force passing normally through an area placed in a magnetic field, is equal to the magnetic flux linked with that area. Net flux through the surface $\emptyset_B = \boldsymbol{B}.\mathbf{A}$= BAcosθ Magnetic flux is a scalar quantity. S.I. unit: weber (Wb), CGS unit : Maxwell or Gauss × cm^2 (1 Wb = 10 ^{8} Maxwell).

Faraday's laws of EMI

1. **First law** :(**Cause of emf**) The induced emf is due to changing magnetic flux linked with the closed loop/coil.
2. **Second law**: (**magnitude of emf**)

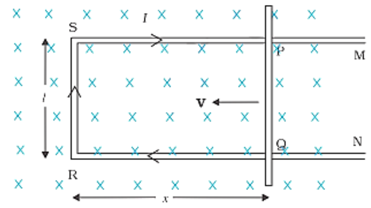
The magnitude of the induced e.m.f. is directly proportional to the rate of change of the magnetic flux. Induced e.m.f., $\varepsilon = -d\emptyset/dt = -(\emptyset_2 - \emptyset_1)/t$ .Negative sign indicates that induced emf (ε) opposes the change of flux

Lenz's Law: - This law gives the direction of induced emf/induced current. According to this law, the direction of induced emf or current in a circuit is such as to oppose the cause that produces it. This law is based upon **law of conservation of energy**



Motional EMF Due to Translatory Motion:-

If the length RQ = x (variable) and RS = l, the magnetic flux Φ enclosed by the loop PQRS will be Φ= B l x Since x is changing with time, the rate of change of flux will induce an emf given by: $\varepsilon = -\frac{d\phi}{dt} = -\frac{d(BL\,X)}{dt}$ = Bl v



The induced emf ε = B l v is called **motional emf**

Motional EMF Due to Rotational Motion:- Emf induces across the ends of the rod where ν = frequency (revolution per sec) And T = Time period.

$$\varepsilon = \frac{B\omega R^2}{2}$$

Inductance is a property of an electrical conductor (like a coil or solenoid) that describes its ability to **oppose changes in electric current** flowing through it by generating a magnetic field.

Self Inductance: Self-inductance (L) of a coil is numerically equal to the magnetic flux (∅) linked with the coil, when a unit current flow through it. ∅=L I ε =-L dI/dt , S.I. unit of self-inductance is Henry (H).

Self inductance of a long solenoid : L=$\mu_0 \mu_r N^2$ A/l = $\mu_0 \mu_r n^2$ Al

Energy stored in an inductor: U=$\frac{1}{2}LI^2$ and energy density is given by $\frac{B^2}{2\mu_0}$

Mutual Inductance: Whenever the current passing through a coil changes, the magnetic flux linked with a neighboring coil will also change. Hence an emf will be induced in the neighboring coil or circuit. This **phenomenon** is called **'mutual induction'**

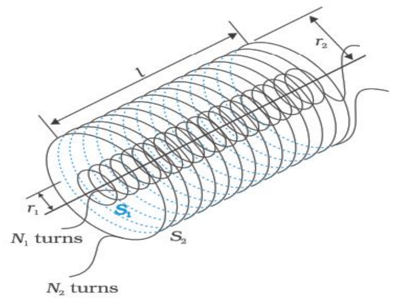
$$\emptyset = MI \quad \varepsilon = -M\,dI/dt$$

SI unit is **henry (H).**

Mutual-Inductance between pairs of long Solenoid:-

$M_{12}= (\mu_0 n_1 n_2 L\pi r_1^2)$, $M_{21}=(\mu_0 n_1 n_2 L\pi r_2^2)$

Hence $M_{12}=M_{21}$



AC generator:: It is a device which converts mechanical energy into an electrical energy and generates alternating current.

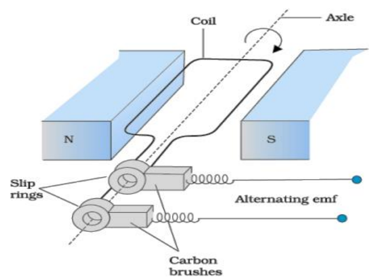
Principle: Works on principle of electro-magnetic induction.

Construction: 1. Armature coil 2. Filed magnet 3. Slip rings 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, ∅ = $\boldsymbol{B}.\boldsymbol{A}$ =NBAcosθ=NBA cosωt

The induced emf is,

$\varepsilon = -d\emptyset\ dt = -d(NBA\cos\omega t)\ dt\ V = \varepsilon = -NBA\omega\sin\omega t$



MULTIPLE CHOICE QUESTIONS

Q1 Lenz's law is a consequence of the law of:
a) conservation of energy   b) conservation of charge
c) conservation of momentum   d) conservation of mass

Q2 The SI unit of inductance is:
a) farad   b) coulomb   c) weber   d) henry

Q3 According to Lenz's law, the direction of induced current is such that it:
a) enhances the cause producing it   b) opposes the cause producing it
c) is in the direction of the cause producing it   d) may be in any direction

Q4 The induced EMF is maximum when the angle between the magnetic field and the normal to the coil is:
a) 0 degrees   b) 45 degrees   c) 90 degrees   d) 180 degrees

Q5 You are required to design an air-filled solenoid of inductance 0.016H having a length 0.81 m and radius 0.02 m. The number of turns in the solenoid should be :
a) 2592   b) 2866   c) 2976   d) 3140

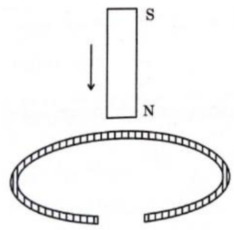
Q6 Current in a circuit falls from 5.0 A to 0.0 A in 0.1 s. If an average EMF of 200V is induced, the self-Inductance of the coil is:
a) 4H   b) 5H   c) 3H   d) 40H

Q7 A coil of area 100 cm^2 is kept at an angle of 30^0 with a magnetic field 0.1 T. The magnetic field is reduced to zero in 10^{-4} s. The induced emf in the coil is:
a) $5\sqrt{3}$ V   b) $50\sqrt{3}$ V   c) 5.0 V   d) 50.0 V

Q8 A magnetic flux linked with a coil varies as $\phi = 2t^2 - 6t + 5$ where ϕ is in weber and t is in second. The induced current is zero at
a) t = 0   b) t = 1.5s   c) t = 3s   d) t = 5s

Q9 . A coil is moved quickly out of a magnetic field. While exiting the field ,the direction of the induced current will be such that it will:
a) oppose the increase in magnetic flux   b) support the increase in magnetic flux
c) oppose the motion of the coil   d) support the motion of the coil

Q10 A vertically held bar magnet is dropped along the axis of a copper ring having a cut as shown in the figure acceleration of the falling magnet is:
(a)Zero   b) less than g
(c) g   (d) more than g



SOLUTIONS:

1 a)   2 d)
3 b) Lenz's Law states that the direction of the induced current in a conductor is such that it opposes the change in magnetic flux that produced it.
4 a)
5 b)$L=\mu_0 N^2 A/l$
6) a) $e = d\varphi/dt$ = LdI/dt , L=4H
7) a) $e = d\varphi/dt$ = LdI/dt
8) b) e=IR = $d\varphi/dt$, so if I=0 so $\frac{d\varphi}{dt} = 0$ t=1.5s
9) c)
10) c) , due to cut in the ring only emf is induced not the current , so bar magnet falls with acceleration due to gravity.

ASSERTION AND REASON TYPE QUESTIONS

Q1 **Assertion (A):** A changing magnetic flux induces an emf in a circuit.
Reason (R): The induced emf is given by Faraday's law.

Q2 **Assertion (A):** An induced current always opposes the cause that produces it.
Reason (R): This is due to Lenz's law.

Q3 **Assertion (A):** When a magnet is moved towards a coil, a current is induced in the coil.
Reason (R): The magnetic flux linked with the coil changes with time.

Q4 **Assertion (A):** A conductor moving parallel to the magnetic field experiences no induced emf.
Reason (R): The rate of change of magnetic flux is maximum when motion is along the field.

Q5 **Assertion (A):** The induced emf in a coil depends on the rate of change of current in the Neighbouring coil.
Reason (R): Mutual inductance must exist between two nearby coil.

Q6 **Assertion (A):** The self-inductance of a coil is a measure of its ability to resist a change in current.
Reason (R): When current changes in a coil, a back emf is induced opposing the change.

Q7 **Assertion (A):** An ideal transformer has 100% efficiency.
Reason (R): There is no loss of energy in the practical transformer due to heat, eddy currents, or hysteresis.

Q8 **Assertion (A):** The core of a transformer is made of soft iron and laminated.
Reason (R): This reduces eddy current losses and increases magnetic coupling.

Q9 **Assertion (A):** No emf is induced in a stationary coil placed in a constant magnetic field.
Reason (R): emf is induced only when there is a change in magnetic flux linked with the coil.

Q10 **Assertion (A):** The mutual inductance of two coils depends on their relative orientation
Reason (R): Changing the orientation affects the amount of magnetic flux linking both coils.

ANSWERS

1. B Faraday's second law states that emf induced is proportional to the rate of change of magnetic flux — directly explaining the assertion
2. A Lenz's law ensures the direction of induced current opposes the change in magnetic flux, which is the cause.
3. A Motion of the magnet changes the flux through the coil, inducing current.
4. C Motion along the field lines causes no change in flux, so no emf is induced. The rate is maximum when motion is perpendicular to the field.
5. C The emf induced in one coil is due to change of current (and thus flux) in the other, and this effect is quantified by mutual inductance.
6. A Self-inductance resists current changes due to the back emf generated by Lenz's law.
7. A In an ideal transformer, no energy losses occur, hence efficiency is 100%.
8. A Lamination reduces eddy currents and soft iron ensures strong magnetic linkage between coils.
9. A A constant field implies constant flux → no emf. Emf requires changing flux.
10. A

SHORT ANSWER TYPE QUESTIONS

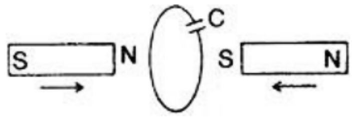
Q1 A light metal disc on the top of an electromagnet is thrown up as the current is switched on. Why? Give reason.

ANS- The induced magnetic field in the disc repels the magnetic field of the electromagnet. This repulsive force between the disc and the electromagnet exerts an upward force on the disc, causing it to be thrown up.

Q2 How does the mutual inductance of a pair of coils change when distance between the coils is increased and number of turns in the coils is increased?

ANS- When the distance between the coils is increased: Mutual inductance decreases.
Mutual inductance M is directly proportional to the product of the number of turns in both coils. M is directly prop to N_1x N_2. so, M increases on increasing no of turns.

Q3 Two bar magnets are quickly moved towards a metallic loop connected across a capacitor 'C' as shown in the figure. Predict the polarity of the capacitor.

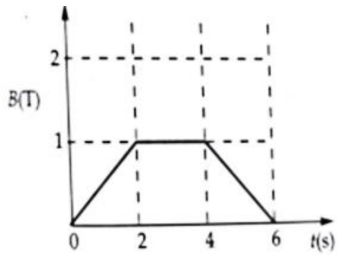


ANS. The north poles of both magnets are approaching.The loop will generate a south pole on the side facing the approaching magnets, to oppose their motion.Hence, the induced current in the loop will be clockwise (when viewed from the front). In a clockwise current, the upper plate of the capacitor gets positive and the lower plate gets negative.

Q4 Two identical coils one of copper and the other of aluminium are rotated with the same angular speed in an external magnetic field. In which of the two coils will the induced current be more?

ANS- Same emf in both coils,Lower resistance in copper coil,Hence, induced current in the copper coil will be more.

Q5 The magnetic field is perpendicular to the plane of the loop, what is the induced current in the loop during 2 to 4 seconds.



ANS- As there is NO change in magnetic field during 2 Sec to 4 Sec , so $\varepsilon = 0$, $I_{ind} = 0$ However emf will be induced between 0 to 2s and 4 to 6s. (can be calculated with the help of slope of the graph)

Q6 A coil of N turns is placed in a magnetic field $\vec{B}$ such that $\vec{B}$ is perpendicular to the plane of the coil. Magnetic field changes with time as $B=B_0 \cos(\frac{2\pi}{T}t)$ where T is time period. Calculate the time at which emf induced in the coil is maximum.

Ans: $e=\frac{d\varphi}{dt}$, $\frac{d\varphi}{dt} = - B_0 \times A \; \frac{2\pi}{T} \sin(\frac{2\pi}{T}t)$ $e=N\frac{d\varphi}{dt}$,

Magnitude of EMF is max when $\sin(\frac{2\pi}{T}t) = 1$

This occurs when , $\frac{2\pi}{T}t = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}$,……so t= T/4 , 3T/4, 5T/4 …….

Q7 Derive an expression for the self inductance of a section of a long solenoid and hence show that self inductance is proportional to the square of number of turns per unit length.

Ans: For a long solenoid, the magnetic field inside is:

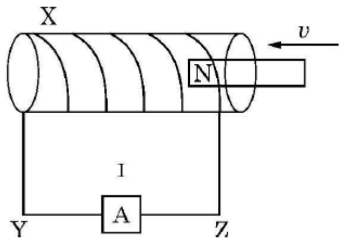
$B=\mu_0 n I$, $\Phi=B\cdot A=\mu_o n I A$ Total flux linkage for N turns:

$N\Phi=N(\mu_o n I\cdot A)$ But $N=n \times L$, so: Total flux $\Phi = nL\cdot\mu_o n I A$

$\Phi= L I = \mu_o n^2 A l I$,

Self inductance $L = \mu_o n^2 A l$ so $L \alpha n^2$

Q8 In the given figure, X is a coil wound over a hollow wooden pipe. A permanent magnet is pushed at a constant speed v from the right into the pipe and it comes out of at the left end of the pipe. During the entry and the exit of the magnet. What will be the current in the wire YZ. (draw it diagrammatically)

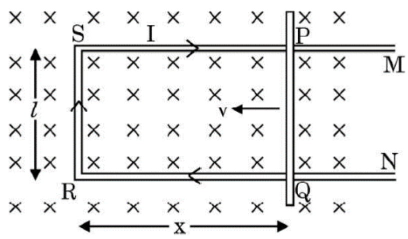


Ans: Z to Y and then Y to Z by using Lenz law.

Q9 Define mutual induction and derive the formula of coefficient of mutual inductance between two coils.

Q10 Explain how Lenz's Law applies when a metal ring is dropped into a region where a magnetic field is increasing upwards. What will be the direction of the induced current in the ring as it comes closer to the magnetic field?

Q11 Figure shows a rectangular conductor PSRQ in which movable arm PQ has a resistance 'r' and resistance of PSRQ is negligible. What are factors on which the induced emf will depend magnitude when PQ is moved with velocity v. calculate its magnitude also.



Ans: The induced emf depends on magnetic field, velocity , length of conductor PQ. Its magnitude will be given by e=Bvl.

SHORT ANSWER TYPE QUESTIONS

Q1 Two concentric circular coils, one of small radius r_1 and the other of large radius r_2, such that $r_1 << r_2$ are placed co-axially with centers coinciding. Obtain the mutual inductance of the arrangement.

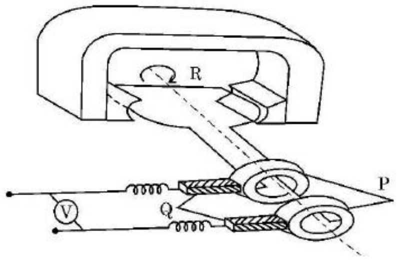
Q2 i) State Lenz law.

ii) Identify the machine in the given figure.

iii) Identify the parts P , Q and R of the machine

iv) Give the polarities of the magnetic poles.

v) Write the two ways of increasing the output voltage.



Ans: i) Lenz's law- The polarity of induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produced it.

ii) AC generator

iii) P – Slip rings   Q – Carbon brushes   R- Armature coil

iv) Left side of the magnet is North & right side is South or vice-versa.

v)write any two :

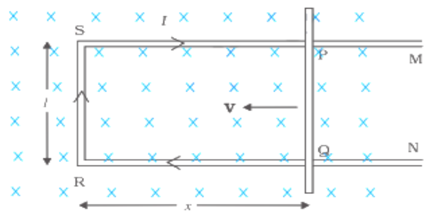
By increasing the number of turns in the armature coil.

By increasing the speed of rotation of the armature coil.

By increasing the strength of the magnetic field B.

Q3 Fig . shows, a rectangular loop PQRS, where PQ is free to move with velocity v. A uniform magnetic field acts ⊥ to loop. Assume PQ has resistance r, obtain expression for

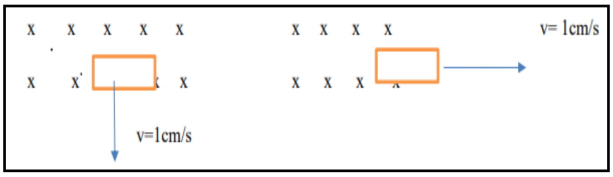
(i) current (ii) force (iii) power to move PQ.



Ans : (i) $I = \frac{Blv}{r}$ (ii) $F = B^2 l^2 \frac{v}{r}$ (iii) $P = B^2 l^2 \frac{v^2}{r}$

Q4 A rectangular wire loop of sides 8 cm and 2 cm with a small cut is moving out of a region of uniform magnetic field of 0.3 T directed normal to the loop.

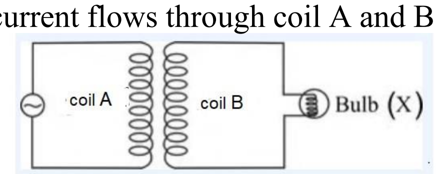
(i)What is the emf developed across the cut if the velocity of the loop is 1 cms^{-1} in a direction normal to the (a) Longer side (b) Shorter side of the loop?



Ans: (a) longer side : $\varepsilon = Blv = 2.4 \times 10^{-4}$ V ,   T=b/v= 2seconds

(b) shorter side: $\varepsilon = 0.6 \times 10^{-4}$ V ,   T= l/v = 8seconds

Q5 Figures shows an arrangement by which alternatively current flows through coil A and B is placed near A and connected to a bulb X.



Now explain the observations with reason

(i) When the switch S is closed the bulb lights up. Why?

(ii) What happens to the brightness if an iron rod is inserted in coil A.

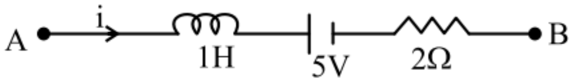
(iii) What happens to the brightness if a copper plate is inserted in the gap between the coils?

Ans: -(i) Due to mutual induction

(ii) Brightness decreases as the induced current decreases

(iii) Brightness decreases due to production of induced current set up in the copper plate which opposes passage of magnetic flux.

Q 6 Show that coefficient of self inductance is independent of flux and current passing through the coil.
Q7 AB is a part of an electrical circuit(see figure) Calculate the potential difference V_A- V_B at the instant when current of i=2A is increasing at a rate of 1A/second and in between points



Ans: $V_A - L\frac{dI}{dt} - 5 - 2x2 = V_B$ $\quad\quad$ V_A- V_B= 10V

Q8 The magnetic flux linked with a coil in Wb is given by the equation $\varphi=5t^2+3t+16$. Calculate the magnitude of induced emf in the coil at the fourth second.
Sol: $e=\frac{d\varphi}{dt}$=10t+3 emf in 4th sec is e_4-e_3=43V-33V = 10V
Q9. Calculate the self-inductance of a coil using the following data obtained when an AC source of frequency $\frac{200}{\pi}$ Hz and a DC source is applied across a coil.

AC Source		
S.No.	V (Volts)	I (A)
1	3.0	0.5
2	6.0	1.0
3	9.0	1.5

DC Source		
S.No.	V (Volts)	I (A)
1	4.0	1.0
2	6.0	1.5
3	8.0	2.0

Sol: When DC is connected there will be only resistance and when AC is connected then there will be both inductance and resistance(Z).
From the table Z = 6 Ω and R= 4 Ω
So $Z=\sqrt{R^2+X_L^2}$ $\quad$ so $X_L=\sqrt{20}$ $=2\sqrt{5}\approx 4.5\Omega$ $\quad X_L=\omega L$, $L=4.5/2\pi\nu$ $\quad$ so L=11 mH

LONG ANSWER TYPE QUESTIONS

Q1. (a) Define mutual inductance and write its SI units.
(b) Derive an expression for the mutual inductance of two long co-axial solenoids of same length wound one over the other.
Q2. (a) Draw a labelled diagram to explain the principle and working of an A.C. generator. Deduce the expression for emf generated. (b)Why cannot the current produced by an A.C. generator be measured with a moving coil ammeter?
Q3 a) State Lenz's law. Give one example to illustrate this law. "The Lenz's law is a consequence of the principle of conservation of energy." Justify this statement.
b) A long solenoid with 15 turns per cm has a small loop of area 2.0 cm^2 placed inside the solenoid normal to its axis. If the current carried by the solenoid changes steadily from 2.0 A to 4.0 A in 0.1 s, what is the induced emf in the loop while the current is changing?
Ans: b) Magnetic field , $B=\mu_o nI$ $\quad \frac{dB}{dt}=\mu_o n\frac{dI}{dt}$ $\quad , \frac{dI}{dt}$ = 20 A/s $\quad \frac{dB}{dt}$ =3.77x10^{-2} T/s $\quad$ and induced emf is e=7.54 μV

CASE STUDY BASED QUESTIONS

1. EMI is defined as the production of an electromotive force across an electric conductor in the changing magnetic field. The discovery of Induction was done by Michael Faraday in the year 1831. Electromagnetic induction finds many applications such as in electrical components which includes transformers, inductors, and other devices such as electric motors and generators.
Alternating current is defined as an electric current which reverses in direction periodically.
In most of the electric power circuits, the waveform of alternating current is the sine wave.
I. How to increase the energy stored in an inductor by four times?
(a) By doubling the current $\quad$ (b) This is not possible
(c) By doubling the inductance (d) By making current 2 times
II. Consider an inductor whose linear dimensions are tripled and the total number of turns per unit length is kept constant, what happens to the self-inductance?

(a) 9 times (b) 3 times (c) 27 times (d) 13 times

III. Lenz law is based on which of the following conservation

(a) Charge (b) Mass (c) Momentum (d) Energy

IV. What will be the acceleration of the falling bar magnet which passes through the ring such that the ring is held horizontally and the bar magnet is dropped along the axis of the ring?

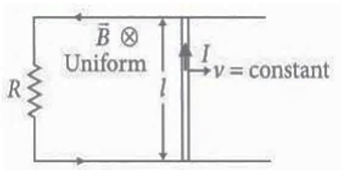
(a) It depends on the diameter of the ring and the length of the magnet

(b) equal due to gravity

(c) It is less than due to gravity

(d) It is more than due to gravity

2. The emf induced across the ends of a conductor due to its motion in a magnetic field is called motional emf. It is produced due to the magnetic Lorentz force acting on the free electrons of the conductor. For a circuit shown in figure, if a conductor of length I moves with velocity v in a magnetic field B perpendicular to both its length and the direction of the magnetic field, then all the induced parameters are possible in the circuit



I. Direction of current induced in a wire moving in a magnetic field is found using

(A) Fleming's L Hand rule (B) Fleming's Right hand

(C) Ampere's rule (D) Maxewell's Thumb rule

II.A bicycle generator creates 1.5 V at 15 km/hr. The EMF generated at 10 km/hr is

(A) 1.5 volts (B) 2volts (C) 0.5volts (D) 1 volt

III. A 0.1 m long conductor carrying a current of 50 A is held perpendicular to magnetic field of 1.25 mT. The mechanical power required to move the conductor with a speed of 1 m s^{-1} is

(A) 62.5 mW (B) 625 mW (C) 6.25 mW (D) 12.5 Mw

IV. A conducting rod of length is moving in a transverse magnetic field of strength B with velocity V. The resistance of the rod is R. The current in the rod is.

(A) BV$\boldsymbol{l}$ (B) Zero (C) $\frac{BVl}{R}$ (D) $\frac{B^2\,V^2L^2}{R}$

3. Faraday's law of electromagnetic induction, also known as Faraday's law is the basic law of electromagnetism which helps us to predict how a magnetic field would interact with an electric circuit to produce an electromotive force (EMF). This phenomenon is known as electromagnetic induction. Faraday's Experiment: Relationship Between Induced EMF and Flux. In the first experiment, he proved that when the strength of the magnetic field is varied, only then-current is induced. An ammeter was connected to a loop of wire; the ammeter deflected when a magnet was moved towards the wire. In the second experiment, he proved that passing a current through an iron rod would make it electromagnetic. He observed that when a relative motion exists between the magnet and the coil, an electromotive force will be induced. When the magnet was rotated about its axis, no electromotive force was observed, but when the magnet was rotated about its own axis then the induced electromotive force was produced. Thus, there was no deflection in the ammeter when the magnet was held stationary. While conducting the third experiment, he recorded that the Galvanometer did not show any deflection and no induced current was produced in the coil when the coil was moved in a stationary magnetic field. The ammeter deflected in the opposite direction when the magnet was moved away from the loop.

I. According to Faraday's law, EMF stands for

a) Electromagnetic field b) Electromagnetic force

c) Electromagnetic friction d) Electromotive force

II. As per Faraday's laws of electromagnetic induction, an e.m.f. is induced in a conductor whenever it

a) Lies perpendicular to the magnetic flux

b) Lies in a magnetic field

c) Cuts magnetic flux

d) Moves parallel to the direction of the magnetic field

III. For time varying currents, the field or waves will be

a) Electrostatic b) Magnetostatic c) Electromagnetic d) Electrical

IV. Find the displacement current when the flux density is given by t^3 at 2 seconds.

a) 3 b) 6 c) 12 d) 27

OR

Which of the following statements is true?

a) E is the cross product of v and B b) B is the cross product of v and E

c) E is the dot product of v and B d) B is the dot product of v and E

4. The migratory birds' patterns are one of the mysteries in the field of science. For example, every winter birds from Siberia fly unerringly to water spots in the Indian sub- continent. There has been a suggestion that electromagnetic induction may provide a clue to the migratory patterns. The earth's magnetic field has existed throughout evolutionary history. It would be of great benefit to migratory birds to use this field to determine the direction. As far as we know birds contains no ferromagnetic materials. So, electromagnetic induction seems to be the only reasonable mechanism to determine the direction. Consider the optimal case where the magnetic field B, the velocity of the bird v and two relevant points of its anatomy separated by a distance l, all three are mutually perpendicular. From the formula for motional emf i.e., Ɛ=Blv Certain kinds of fishes are able to detect small potential differences. However, in these fishes, special cells have been identified. Thus, the migration patterns of birds continue to remains a mystery.

I. An emf is produced in a coil, which is not connected to an external voltage source. This can be due to

(a) the coil being in a time varying magnetic field

(b) the coil moving in a time varying magnetic field

(c) the coil moving out of constant magnetic field

(d) All of the above

II. A circular coil expands radially in a region of magnetic field and no electromotive force is produced in the coil. This can be because

(a) the magnetic field is in the same plane as the circular coil and it may or may not vary

(b) the magnetic field has a perpendicular (to the plane of the coil) component whose magnitude is decreasing suitably.

(c) there is constant magnetic field in the perpendicular (to the plane of their coil) direction.

(d) Both (a) and (b)

III. A migratory Siberian bird is flying in the sky with a velocity of 10 m/s and the distance between two feathers is 2 cm. The earth's magnetic field B perpendicular to the feather is 4×10^{-5} T. Then emf generated between the two feathers is

(a) 4 μV (b) 6 μV (c) 8 μV (d) 10 μV

OR

An airplane having a wing span of 35 m flies due north with speed of 90 m/s, given $B = 4 \times 10^{-5}$ T, the potential difference between the tips of the wings will be

(a) 0.126 V (b) 1.26 V (c) 12.6 V (d) 0.013 V

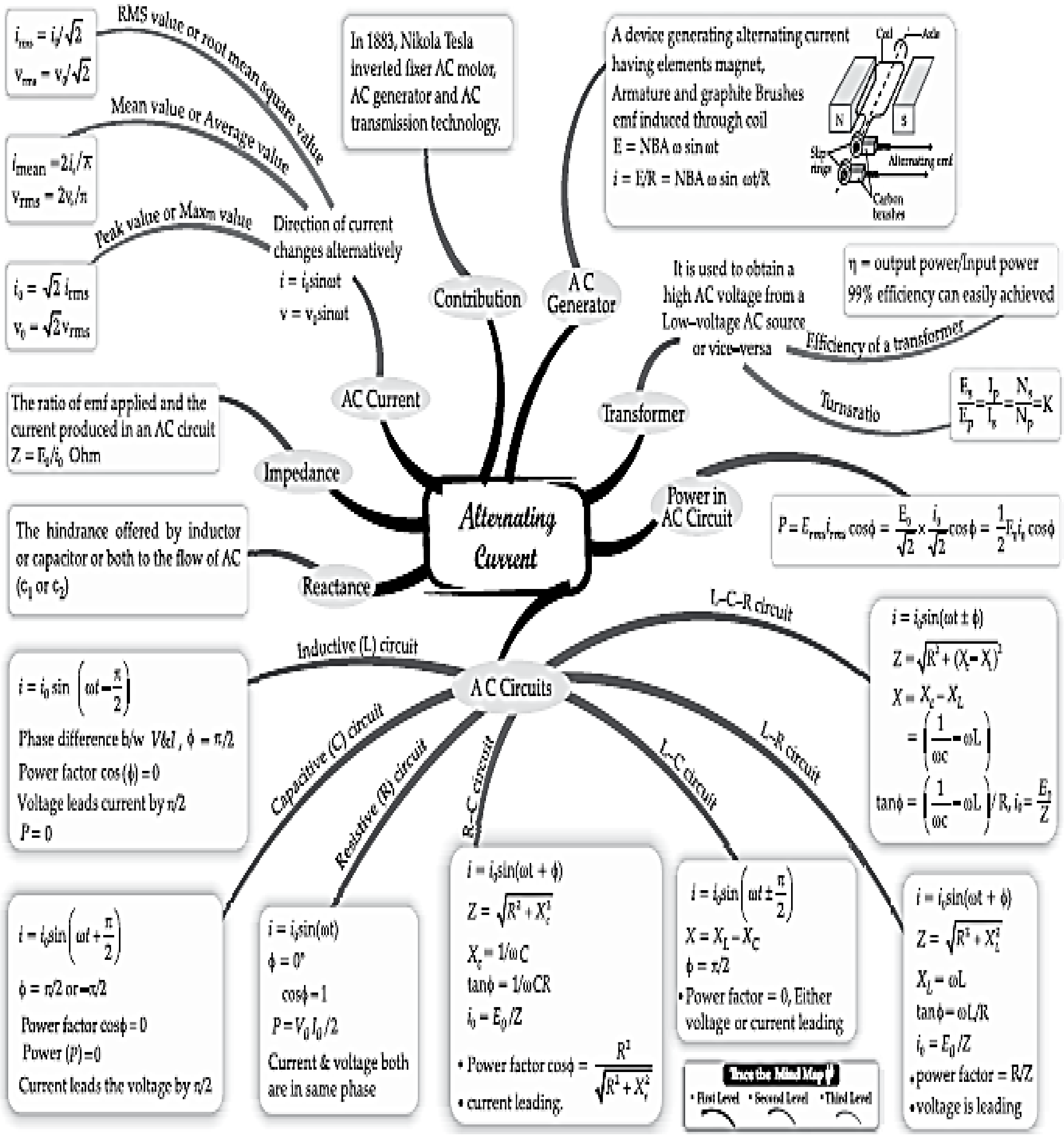
IV. A moving conductor's coil produces an induced emf. This is in accordance with

(a) Lenz's Law (b) Coulomb's Law (c) Faraday's Law (d) Ampere's Law

CHAPTER–7: ALTERNATING CURRENT

SYLLABUS: 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.

Mind map



Gist of the chapter

Alternating current and voltage: A signal changing its values periodically is called an alternating signal. & represented as $I = I_0 \sin \omega t$,

alternating voltage (or emf) is $V = V_0 \sin \omega t$

MEAN AND RMS VALUE OF ALTERNATING CURRENTS

The mean or average value of alternating current over complete cycle is zero. For half cycle it's value is given by

(I_{mean})half cycle $=\frac{2I_0}{\pi}$ = 0.636 Io V_{avg} for half cycle $=\frac{2V_0}{\pi}$ = 0.636 Vo

An ammeter or a voltmeter read its Root Mean Square value as

$I_{rms} = \frac{I_0}{\sqrt{2}}$ = 0.707 I_o $V_{rms} = \frac{V_o}{\sqrt{2}}$ = 0.707 V_o

V= Vo sin ωt then current is I = Io sin (ωt + Φ) where Φ is the phase difference between voltage and current.

The average power loss over a complete cycle is given by,

$P = E_{rms} I_{rms} \cos \Phi$ where cos Φ is called the power factor

Purely resistive circuit.

(1) Current : $i = i_0 \sin \omega t$

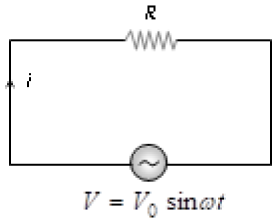
(2) Peak current : $i_0 = \frac{V_0}{R}$

(3) Phase difference between voltage and current : $\phi = 0^o$

(4) Power factor : $\cos \varphi = 1$

(5) Power : $P = V_{rms} i_{rms} = \frac{V_0 i_0}{2}$

(6) Phasor diagram : Both are in same phase

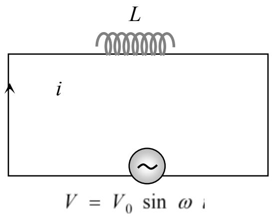


Purely Inductive Circuit (*L*-Circuit)

(1) Current : $i = i_0 \sin\left(\omega t - \frac{\pi}{2}\right)$

(2) Peak current :

$$i_0 = \frac{V_0}{X_L} = \frac{V_0}{\omega_L} = \frac{V_0}{2\pi\nu L}$$

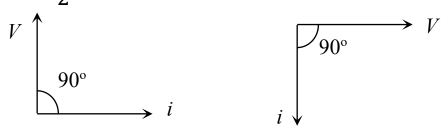


(3) Phase difference between voltage and current $\varphi = 90^o$ (or $+\frac{\pi}{2}$)

(4) Power factor : $\cos \varphi = 0$

(5) Power dissipated : $P = 0$

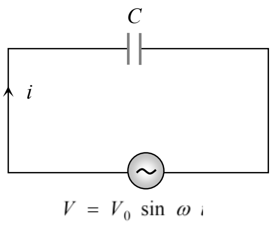
(6) Phasor diagram : Voltage leads the current by $\frac{\pi}{2}$



Purely capacitive circuit

(1) Current : $i = i_0 \sin\left(\omega t + \frac{\pi}{2}\right)$

(2) Peak current $i_0 = \frac{V_0}{X_C} = V_0 \omega C = V_0 (2\pi\nu C)$



(3) Phase difference between voltage and current :

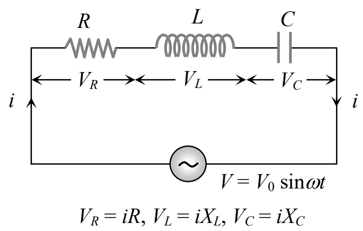
$\varphi = 90^o$ Power factor : $\cos \varphi = 0$

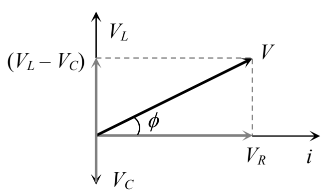
(4) Average Power : $P_{avg} = 0$

(5) Phasor diagram : Current leads the voltage by $\pi/2$

Series LCR circuit

Voltage V = V_o sinωt,





Phasor diagram

(1) $I = I_o \sin(\omega t + \Phi)$, where $I_0 = V_o/ Z$, and impedance $Z = \sqrt{R^2 + (X_L - X_C)^2}$

(2) $\tan \Phi = (X_L - X_C) / R$

(3) The average power loss over a complete cycle is given by $P = V_{rms} I_{rms} \cos \Phi$
where, the term $\cos \Phi$ is called the power factor

(4) $\cos \Phi = R/ \sqrt{R^2 + (X_L - X_C)^2}$)

(5) If net reactance is inductive: Circuit behaves as LR circuit

(6) If net reactance is capacitive: Circuit behave as CR circuit

(7) If net reactance is zero: Means $X_L - X_C = 0$ $X_L = X_C$. This is the condition of electric resonance

(8) **At resonance** (series resonant circuit)

(i) $X_L = X_C \Rightarrow Z_{min} = R$ i.e. circuit behaves as resistive circuit

(ii) $V_L = V_C \Rightarrow V = V_R$ i.e. whole applied voltage appeared across the resistance

(iii) Phase difference : $\phi = 0^o \Rightarrow$ power factor $= \cos \phi = 1$

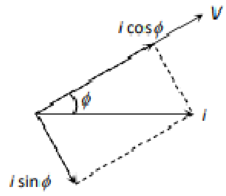
(iv) Power consumption $P = V_{rms} I_{rms}$

(v) These circuits are used for current amplification and as tuning circuits in wireless telegraphy.

(9) **Resonant frequency** (Natural frequency) : At resonance $X_L = X_C \Rightarrow w_0 L = \frac{1}{C\,\omega_0}$

$\Rightarrow w_0 L = \sqrt{\frac{1}{LC}}$ OR, $w_0 L = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$ (Resonant frequency doesn't depend upon the resistance of the circuit)

(10) **Watt less Current**

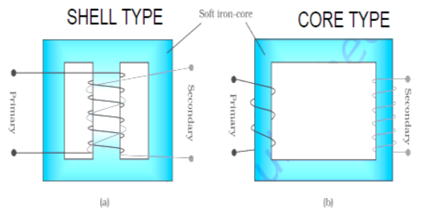


The component of current which does not contribute to the average power dissipation is called watt less current.

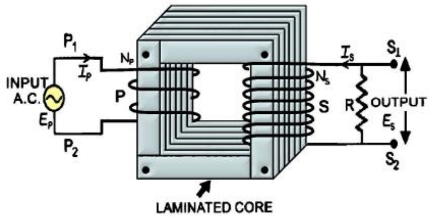
(i) The average of component of watt less component over one cycle is zero

(ii) Amplitude of watt less current = I_0 sin and r.m.s. value of watt less current= $I_{rms} \sin\theta = I_0 \sin\theta/\sqrt{2}$

Transformer:-



It is a device which Increase or decreases the voltage or current in ac circuits through mutual induction.
It does not work in DC circuit.
Principle: It is based on the principle of mutual induction.
Working: When an alternating voltage is applied to the primary coil , magnetic flux linked with it changes which links to the secondary coil and induces an emf in it due to mutual induction.



$$\frac{E_s}{E_P} = \frac{I_P}{I_s} = \frac{N_s}{N_P}$$

$$\eta = \frac{E_s I_s}{E_P I_P} \times 100\ \%$$

Types of transformer: Step-up Transformer: Ns> Np. It increases voltage and decreases current. Transformation Ratio must be greater than 1.

Step-Down Transformer: – Ns< Np; It increases current and decreases voltage. Transformation Ratio must be less than 1.

From Faraday's laws the emf induced in the primary coil

$\varepsilon_P = - N_P \frac{\Delta\phi}{\Delta t}$ ----(i) also for secondary coil $\varepsilon_s = - N_s \frac{\Delta\phi}{\Delta t}$ ---------(ii)

$\frac{\varepsilon_S}{\varepsilon_p} = \frac{N_S}{N_P}$ = k (transformation ratio) -----------(iii)

For ideal transformer input power = output power $\Rightarrow \varepsilon_P I_P = \varepsilon_s I_s$ ------(iv)

By equation (iii) and (iv)

$$\frac{\varepsilon_S}{\varepsilon_p} = \frac{N_S}{N_P} = \frac{I_P}{I_S}$$

Energy losses in a transformer:

(i) Copper loss (ii) Hysteresis loss (iii) Flux leakage (iv) Humming losses (v) Eddy current loss

MULTIPLE CHOICE QUESTIONS

Q1 A resistance 'R' draws power 'P' when connected to an AC source. If an inductance is now placed in series with the resistance, such that the impedance of the circuit becomes 'Z', the power drawn will be :

(a) $P\sqrt{\frac{R}{Z}}$ (b) $P(\frac{R}{Z})$ (c) P (d) $P(\frac{R}{Z})^2$

Q2 To reduce the resonant frequency in an L-C-R series circuit with a generator

(a) the generator frequency should be reduced

(b) another capacitor should be added in parallel to the first

(c) the iron core of the inductor should be removed

(d) dielectric in the capacitor should be removed

Q3 Average value of A.C voltage for positive half cycle is [If V_0 is its peak voltage]

(a) zero (b) $V_0/\sqrt{2}$ (c) $2V_0/\pi$ (d) V_0

Q4 An alternating current in a circuit is given by $I = 20\sin(100\pi\, t + 10.05\pi)$A . The r.m.s value of current & its frequency respectively are

(A) 10A & 100 Hz (B) 10 A & 50 Hz (C) $10\sqrt{2}$A & 50Hz (D) $20\sqrt{2}$A & 100Hz

Q5 In an ideal transformer, the no. of turns of primary and secondary coil are 500 and 400 respectively. If 220 V is supplied to the primary coil, then ratio of currents in primary and secondary coils is

(A) 4 : 5 (B) 5 : 4 (C) 5 : 9 (D) 9 : 5

Q6 The power factor of LCR circuit at resonance is

(A) 0.707 (B) 1 (C) Zero (D) 0.5

Q7 At resonance frequency in an A.C circuit containing L, C and R in series

(A) The voltage and current will be in same phase.

(B) The voltage will lead the current

(C) The voltage will lag behind the current.

(D) Phase difference depends on peak voltage of source

Q8 A voltage $v = v_o \sin wt$ applied to a circuit drives a current $i = i_o \sin(wt + \varphi)$ in the circuit. The average power consumed in the circuit over a cycle is

a) Zero b) $i_o v_o \cos\varphi$ c) $i_o v_o /2$ d) $(i_o v_o \cos\varphi)/2$

Q9 In the case of an inductor

(a) voltage lags the current by $\pi/2$ (b) voltage leads the current by $\pi/2$

(c) voltage lags the current by $\pi/3$ (d) voltage lags the current by $\pi/4$

Q10 A power transformer is used to step up an alternating e.m.f. of 220 V to 11 kV to transmit 4.4 kW of power. If the primary coil has 1000 turns, what is the current rating of the secondary? Assume 100% efficiency for the transformer

(a) 4 A (b) 0.4 A (c) 0.04 A (d) 0.2 A

Q11 An inductor, a capacitor and a resistor are connected in series across an ac source of voltage. If the frequency of the source is decreased gradually, the reactance of :

(a) both the inductor and the capacitor decreases.

(b) inductor decreases and the capacitor increases.

(c) both the inductor and the capacitor increases.

(d) inductor increases and the capacitor decreases.

ANSWERS

1 d 2 b 3 c 4 c 5 a 6 b 7 a 8 d 9 b 10 b 11 b

ASSERTION AND REASON TYPE QUESTIONS

Q1 **Assertion:** In a pure resistive circuit, voltage and current are in the same phase.
Reason: In resistors, energy is alternately stored and released.

Q2. **Assertion:** In an ideal LC circuit, the current oscillates indefinitely.
Reason: There is no energy loss in an ideal LC circuit.

Q3. **Assertion:** In an LCR circuit at resonance, the impedance is minimum.
Reason: At resonance, the inductive and capacitive reactance cancel each other.

Q4. **Assertion:** The average power consumed in a pure inductive circuit is zero.
Reason: In a pure inductive circuit, the current leads the voltage by 90^0

Q5. **Assertion:** The power factor in a purely capacitive circuit is zero.
Reason: In a capacitive circuit, the current leads the voltage by 90^0

Q6. **Assertion:** In an AC circuit containing only a capacitor, current lags the voltage by 90^0
Reason: Capacitors offer no resistance to A C current.

Q7. **Assertion:** The power consumed in an AC circuit is given by $P=V_{RMS}\ I_{RMS} \cos\phi$
Reason: The product $V_{RMS}\ I_{RMS}$ gives the apparent power.

Q8. **Assertion:** The voltage across the inductor leads the current by 90^0.
Reason: The induced emf in the inductor opposes the change in current.

Q9. **Assertion:** The quality factor of an LCR series circuit increases with increase in resistance.
Reason: Higher resistance causes sharper resonance

Q10. **Assertion:** In a transformer, higher value of alternating voltage can be converted into lower voltage and vice versa.
Reason: A transformer works on the principle of electromagnetic induction.

ANSWERS

1-C 2-A 3-A 4- C 5- A 6-D 7-B 8-B 9-D 10-B

VERY SHORT ANSWER TYPE QUESTIONS

Q1 Explain why current flows through an ideal capacitor when it is connected to an ac source but not when it is connected to a dc source in a steady state.

Ans: In DC , X_c is infinite.

Q2 Draw the graphs showing variation of inductive reactance and capacitive reactance with frequency of applied ac source.

Ans: General concept and shapes.

Q3 Prove that an ideal capacitor in an ac circuit does not dissipate any average power.

Ans: P_{avg} is propotional to $\cos\varphi$ and φ is 90^0 so average power dissipated is zero.

Q 4 In a series LCR circuit, obtain the condition under which the impedance of circuit is minimum as well as explain its one practical use.

Ans: $X_L = X_c$, to get maximum current in any circuit.

Q5 Mention any two characteristics properties of the material suitable of making the core of transformer

Ans: Mention any two.

Q6 Define 'quality factor' of resonance in series LCR circuit. What is its SI unit.

Ans: Write definition , no unit and dimensions.

Q7 A bulb B and an inductor are connected in series to the ac mains. The bulb glows with some brightness. How will the glow of the bulb change when a paramagnetic slab is introduced in side the inductor.

Ans: X_L increases so brightness decreases.

Q8 A transformer has 50 tunes in the primary and 100 in the secondary. If primary is connected to 220 V DC supply, what will he the voltage across the secondary?

Ans: Transformer does not work on DC.

SHORT ANSWER TYPE QUESTIONS

Q1A sinusoidal voltage is applied to an electric circuit containing element X in which current leads the voltage by $\frac{\pi}{2}$

(a) Identify the circuit

(b) Write the formula for its reactance.

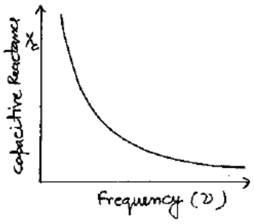
(c) Show graphically the variation of this reactance with frequency of ac voltage.

(d) Explain the behaviour of this element when it is used in (i) an ac circuit, and (ii) a dc circuit

Ans: a) Capacitor

b) $X_c=1/\omega C$

c)



(d) (i) For ac Xc is finite and therefore allows the ac to pass. For dc Xc is infinite and therefore does not allow the dc to pass.

2. With the help of a suitable phasor diagram, obtain an expression for impedance of a series LCR circuit, connected to a source $v = v_0 \sin\omega t$.

Ans : Refer textbook and gist above

3. Find the condition under which a series LCR circuit could draw maximum power from an ac source. Name the factors at which this characteristics frequency depends. Draw the frequency response curve for such a circuit.

Ans: refer textbook (Resonance in LCR circuit)

4. A series CR circuit with R=200Ωand C=50/π μF is connected across an ac source of peak voltage V= 100V and frequency ν = 50 Hz. Calculate a) impedance of the circuit(Z) b) phase angle (φ) and c) voltage across the resistor.

Ans: $Z^2=R^2+(1/2\pi \nu C)^2 = 200\sqrt{2}\Omega$

$\cos\varphi=R/Z=1/\sqrt{2}$, $\varphi=45^0$

V across R = RV/Z = $50\sqrt{2}$ V

5. An ac source $v = v_m \sin \omega t$ is connected across an ideal capacitor. Derive the expression for the (i) current flowing in the circuit, and (ii) reactance of the capacitor. Plot a graph of current i versus ωt.

Ans : refer textbook

6. A series combination of an inductor L, a capacitor C and a resistor R is connected across an ac source of voltage in a circuit. Obtain an expression for the average power consumed by the circuit. Find power factor for (i) purely inductive circuit, and (ii) purely resistive circuit.

Ans: refer textbook

7.A resistor of 30 Ωand a capacitor of 250/π μF are connected in series to a 200 V, 50 Hz ac source. Calculate (i) the current in the circuit, and (ii) voltage drops across the resistor and the capacitor. (iii) Is the algebraic sum of these voltages more than the source voltage ? If yes, solve the paradox.

Ans: $X_c=1/\omega C=40\Omega$, $Z^2=R^2+X_c^2$, Z=50 Ω ,

I=200/50 = 4A

$V_c=IX_c=160V$, $V_R=IR=120V$

The algebraic sum of the two voltages V_R and VC is 280V, which is more than the source voltage of 200V. This paradox can be removed by considering impedance triangle because VR and VC are out of phase by 90˚, therefore $V^2 = V_R^2 + V_c^2$, V= 200V This is equal to the source voltage.

8.A series LCR circuit with R = 20Ω L = 2 H and C = 50 F is connected to a 200 volts ac source of variable frequency. What is (i) the amplitude of the current, and (ii) the average power transferred to the circuit in one complete cycle, at resonance?
(iii) Calculate the potential drop across the capacitor.

Ans: (i) At resonance Z=R so I=V/R I_{rms}=10A and $I_o=I_{rms}\sqrt{2}$=14.14A
Average power transferred to the circuit in one complete cycle at resonance : $P=I^2_{rms}R$=2000W
$\omega_r=\frac{1}{\sqrt{LC}}$= 100 rad/s , $X_c=1/\omega C$, $V_c=I_{rms}X_c$=2000V

LONG ANSWER TYPE QUESTIONS

Q1 i) Write the principle of working of an ac generator. Draw its labelled diagram and explain its working.
A resistor of 400Ω , an inductor of $(\frac{5}{\pi})$ H and a capacitor of $(\frac{50}{\pi})$ uF are joined in series across an ac source v=140 sin (100π) t V. Find the rms voltages across these three circuit elements. The algebraic sum of these voltages is more than RMS voltages of source. ExplainAns: from the equation V_{rms}=100V so , $I_{rms}=V_{rms}/Z$, Z=500Ω, so I_{rms}=0.2A hence V_R=80V, V_L=100V and V_C=40V
The algebraic sum of voltages is more than the rms voltage of source because voltages across R, L and C are not in phase.
Q2 i) Name the device which can increase alternating current or voltage without increasing electric power. Write the principle of working of this device, Explain why it cannot be used for same purpose when direct current source is used?
ii) An ideal transformer is designed to convert 50 V into 250 V. It draws 200 W power from an ac source whose instantaneous voltage is given by v_i = 20 sin (100πt) V. Find
Rms value of input current
Expression for instantaneous output voltage
Expression for instantaneous output current
Ans: Transformer , EMI , Flux change Zero. I_{rms}=7.07A
$P_p=V_pI_p$, so $Ip=20\sqrt{2}$ A , Vo=100 sin(100πt) V , I_0= 4sin(100πt) A
Q3 Find the condition of resonance in a series LCR circuit connected to a source $V=V_m$ sin ωt, where ω can be varied. Give the factors on which the resonant frequency of a series LCR circuit depends. Plot a graph showing the variation of electric current with frequency in a series LCR circuit.
Ans: General concept and direct graph
Q4 i)Describe the construction and working of of a transformer and hence obtain the relation for $(\frac{V_s}{V_p})$ in terms of number of turns of primary and secondary.
ii Discuss the main causes of energy loss in a real transformer.
Ans: Direct question , see answer from the gist
Q5 i) you are given three circuit elements X , Y and Z. They are connected one by one across a given ac source. It is found that V and I are in phase of element X. V leads I by $\frac{\pi}{2}$ for element Y where I leads V by $\frac{\pi}{2}$ for element Z. Identify elements X,Y and Z.
ii) Establish the expression for total opposition offered to circuit when elements X , Y and Z are connected in series to an ac source. Show the variation of current in circuit with the frequency of the applied source when only Y & Z are connected in circuit.
iii) In a series LCR circuit obtain, the conditions under which impedance is minimum, justify why circuit becomes purely resistive at resonance?
Ans: i) X-resistor Y-inductor Z-Inductor ii) Deduce expression for Z . Graph for LC combination circuit. iii) Condition of resonance , $X_c=X_L$ so Z=R

CHAPTER-8: ELECTROMAGNETIC WAVES

SYLLABUS: 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.

MIND MAP

ELECTROMAGNETIC WAVES

DISPLACEMENT CURRENT

Produced by changing electric field

$$\varepsilon_0\left(\frac{d\Phi}{dt}\right)=i$$

Modified Ampere's law:
The source of magnetic field is: conduction current due to flowing charge.
Time rate of change of electric field

$$i=i_c+i_d=i_c+\varepsilon_0\left(\frac{d\Phi_E}{dt}\right)$$

Maxwell's equations

$$\int \vec{E}.d\vec{A}=\frac{Q}{\varepsilon_0}$$

$$\int \vec{B}.d\vec{A}=0$$

$$\int \vec{E}.d\vec{l}=-\frac{d\Phi_B}{dt}$$

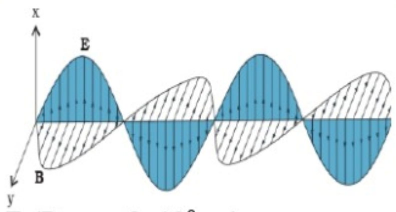
$$\int \vec{B}.d\vec{l}=\mu_0 i_c+\mu_0\varepsilon_0\frac{d\Phi_E}{dt}$$

How are EM waves produced?

Produced by accelerating or oscillating charges only.

Properties of EM waves

1. Does not require a medium for their propagation
2. Does not get deflected by electric or magnetic field
3. E and B has zero phase difference but are mutually perpendicular to each other.
4. Momentum delivered when wave is completely absorbed by the surface : p=U/c ,where U is the total energy transferred to the surface
5. momentum transferred is p=2U/c when wave is completely reflected by the surface.



$E_o/B_o = c = 3\times10^8$ m/s .

Travels with speed(c) = $\frac{1}{\sqrt{\mu_0\varepsilon_0}}$ in free space.

Both E and B are also perpendicular to the direction of wave propagation

EM spectrum and its order

The classification of EM waves according to frequency is the electromagnetic spectrum.
EM spectrum in order of increasing frequency and decreasing wavelength.

1. Radio Waves
2. Micro Waves
3. Infrared
4. Visible
5. Ultraviolet
6. X-rays
7. Gamma Rays

GIST OF THE CHAPTER

Displacement Current: -If there exists an electric current as well as changing electric field, results magnetic field & cause displacement current

$$\varepsilon_0\left(\frac{d\varphi_E}{dt}\right) = i$$

So, Ampere-Circuital Law was modified called as Ampere-Maxwell Law.

$$\oint B.dl = \mu_0 i_C + \mu_0\varepsilon_0\left(\frac{d\varphi_E}{dt}\right)$$

Electromagnetic Waves: - The electromagnetic waves are those waves in which there are sinusoidal variations of electric and magnetic field vectors to right angles to each other as well as at right angles to the direction of wave propagation. (i.e., electric current and magnetic fields vary with space and time.)

Transverse nature of electromagnetic waves: - Electric and magnetic fields oscillate sinusoidally in space and time in an electromagnetic wave. The oscillating electric and magnetic fields, E and B are perpendicular to each other, and to the direction of propagation of the electromagnetic wave.

- Conduction current & displacement current are the same.
- Conduction current arises due to flow of electrons in the conductor.
- Displacement current arises due to electric flux changing with time.

$$I_D = \varepsilon_0\, d\phi_E/dt$$

- **Maxwell's equations**

Gauss's Law in Electrostatics $\oint E.dS = Q/\varepsilon_0$

Gauss's Law in Magnetism $\oint \vec{B}.dS = 0$

• Ampere's – Maxwell law $\int \vec{B}.dl = \mu_0 I + \mu_0\varepsilon_0\, d\phi_E/dt$

- Electromagnetic Wave :- The wave in which there are sinusoidal variation of electric and magnetic fields at right angles to each other as well as right angles to the direction of wave propagation. • Velocity of EM waves in free space: $c = 1/\sqrt{\mu_o\varepsilon_o} = 3\text{x}10^8$ m/s
- The Scientists associated with the study of EM waves are Hertz, Jagdish Chandra Bose & Marconi.
- EM wave is a transverse wave because of which it undergoes polarization effect.
- Electric vectors are only responsible for optical effects of EM waves.
- The amplitude of electric & magnetic fields are related by $E/B = c$
- Oscillating or accelerating charged particle produces EM waves.
- Orderly arrangement of electromagnetic radiation according to its frequency or wavelength is electromagnetic spectrum.
- A self made easy Acronym to memorize the electromagnetic spectrum in decreasing order of its frequency.

Gandhiji's X-rays Used Vigorously In Medical Research

Here the first of each word indicates: G- gamma rays , X- rays , Ultraviolet rays ,Visible rays , I- Infrared radiations , M- Microwaves and R- Radio waves

- EM waves also carry energy, momentum.

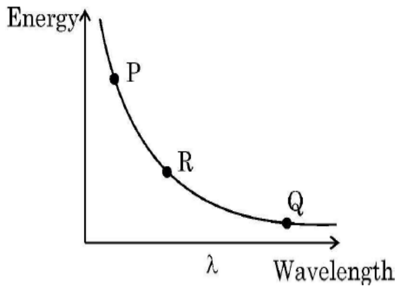
The Electromagnetic Spectrum					
Type	**Frequency Range (Hz)**	**Wavelength Range**	**Production**	**Detection**	**Uses**
Radio waves	5×10^5 Hz to 10^8 Hz	>0.1m	Rapid acceleration and de-accelerations of electrons in aerials/antenna.	Receiver's aerials	In radio and television communication system. In radio astronomy.
Micro waves	10^9 Hz to 10^{12} Hz	0.1m to 1mm	Klystron value or magnetron value.	Point contact diodes.	In radar Systems. In long distance communication systems. In microwave ovens.
Infrared	10^{11} Hz to 5×10^{14} Hz	1mm to 700nm	Vibration of atoms and molecules.	Thermopiles Bolometer, Infrared photographic film.	In remote control of TV or VCR. In Green House. In haze Photography. Treatment of muscular complaints.
Visible Light	4×10^{14} Hz to 7×10^{14} Hz	7000nm to 400nm	Electron in atoms emit light when they move from one energy level to a lower energy level.	Human eye photocells, photographic film.	It Provides us the information of the world around us. It can cause Chemical Reactions.
Ultra-violet	10^{16} Hz to 10^{17}	400nm to 1nm	Inner shell electrons in atoms moving from one energy level to a lower level.	Photocells, photographic film.	In food Preservation. In the study of invisible writings, forged documents and finger prints. In the study of molecular structure.
X-rays	10^{16} Hz to 10^{19}	1nm to 10^{-3} nm	X-ray tubes or inner shell electrons.	Photographic film, Geiger tubes, Ionization chamber.	In medical diagnosis. In the study of crystals structure. In engineering. In detective departments. In radio therapies.
Gamma rays	10^{18} Hz to 10^{22} Hz	$<10^{-3}$ nm	Radioactive decay of the nucleus.	Photographic film, Geiger tubes, Ionization Chamber	In radio Therapy. In manufacture of polyethylene from ethylene. To initiate some nuclear reactions. To preserve food stuff.

MULTIPLE CHOICE QUESTIONS

Q1 To dissociate an oxygen molecule into two oxygen atoms 5eV of energy is required. The minimum frequency of the appropriate electromagnetic radiation to achieve the dissociation lies in

(a) visible region. (b) infrared region. (c) ultraviolet region. (d) microwave region.

Q2: The given diagram exhibits the relationship between the wavelength of electromagnetic waves and the energy of photon associated with them. The three points P,Q and R marked on the diagram may correspond respectively to:



a) X-rays, microwaves, UV radiation

b) X-rays, UV radiation, microwaves

c) UV radiation, microwaves, X-rays

d) microwaves, UV radiation, X-rays

Q3 Which one of the following correctly represents the change in wave characteristics (all in vacuum) from microwaves to X rays in electromagnetic spectrum?

	Speed	Wavelength	Frequency
a)	Remains same	Decreases	Remains same
b)	Remains same	Decreases	Increases
c)	Increases	Increases	Decreases
d)	Remains same	Decreases	Remains same

Q4 X rays are more harmful to human beings than ultraviolet radiations because X-rays:

a) Have frequency lower than that of ultraviolet radiations

b) Have wavelength smaller than that of ultraviolet radiations

c) Move faster than ultraviolet radiations in air

d) Are mechanical waves but ultraviolet radiations are electromagnetic waves

Q5 Displacement current exists only when

a) electric field is changing b) magnetic field is changing

c) electric field is constant d) magnetic field is constant

Q6 A welder wears special glasses to protect his eyes mostly from the harmful effect of

a) high intensity visible light b) infrared radiations

c) ultraviolet radiations d) radio waves

Q7 An electromagnetic wave of frequency 3kHz is passing from vacuum to glass. The ratio of their frequency in vacuum and in glass is:

a) 3:1 b) 1:3 c) 1:4 d) 1:1

Q8 Which of the following electromagnetic waves has the highest momentum for a given energy?

a) Radio waves b) Microwaves c) Infrared rays d) Gamma rays

Q9 The source of an electromagnetic wave is always associated with:

a) A moving electric charge only b) An accelerating electric charge

c) A stationary electric charge d) A constant magnetic field

Q10 The ratio of the amplitudes of electric and magnetic fields in free space is equal to:

(c is the speed of light in vacuum)

a) 1 b) c c) $1/c^2$ d) 1/c

SOLUTIONS:

1) C Solution: $E=h\nu$, E=5 e V , so $\nu = 1.2\text{x } 10^{15}$ Hz , so UV range
2) B X-rays , Micro and UV as wavelength decreases in this order
3) B In vacuum , speed remains the same and going from Micro to X rays frequency increase and wavelength decreases
4) B wavelength of X is smaller than UV

5) A displacement current is $\varepsilon_0 \left(\frac{d\varphi_E}{dt}\right)$ so it exists only if electric field is changing

6) C During welding, a high-intensity electric arc is generated, which emits a large amount of ultraviolet rays

7) D Frequency of an electromagnetic wave does not change when it passes from one medium to another so 1:1

8) D because gamma rays has highest frequency so its energy will be the highest.

9) B The source of an electromagnetic wave is always associated with n accelerating electric charge or an oscillating charge.

10) B speed of light is c=E/B

ASSERTION AND REASON QUESTIONS

For each question, select the correct option:

(a) Both Assertion and Reason are true, and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are true, but Reason is not the correct explanation of Assertion.

(c) Assertion is true, but Reason is false.

(d) Assertion is false, but Reason is true.

Q1.Assertion (A): Electromagnetic waves do not require a material medium for their propagation.
Reason (R): Electromagnetic waves consist of oscillating electric and magnetic fields, which are self-sustaining in vacuum.

Q2.Assertion (A): In an electromagnetic wave, the electric and magnetic fields are always perpendicular to each other.
Reason (R): The directions of electric and magnetic fields in an EM wave are independent of the direction of wave propagation.

Q3.Assertion (A): The speed of electromagnetic waves in vacuum is equal to $1/\sqrt{\mu 0 \varepsilon 0}$
Reason (R): The values of μ_0 and ε_0 determine the properties of vacuum with respect to magnetic and electric fields, respectively

Q4.Assertion (A): X-rays can be used to detect fractures in bones.
Reason (R): X-rays have controlled penetrating power and are absorbed differently by different tissues.

Q5.Assertion (A): Ultraviolet rays are more energetic than infrared rays.
Reason (R): The frequency of ultraviolet rays is greater than that of infrared rays.

Q6.Assertion (A): Gamma rays have the longest wavelength in the electromagnetic spectrum.
Reason (R): Gamma rays have the lowest frequency among all EM waves.

Q7.Assertion (A): Microwaves are suitable for radar systems used in aircraft navigation.
Reason (R): Microwaves can penetrate through the ionosphere and reach long distances without significant attenuation.

Q8Assertion (A): Electromagnetic waves carry both energy and momentum.
Reason (R): The energy and momentum in EM waves are carried by the magnetic field only.

EXERCISE QUESTIONS-SOLUTIONS

1.(a) EM waves are self-propagating due to mutual induction of E and B fields and do not need a medium.

2. (c) The fields are perpendicular to each other and to the direction of wave propagation they are not independent.

3. (a) Speed of EM wave in vacuum is derived using these constants.

4. (a) Bones absorb more X-rays than soft tissue, producing contrast.

5. (a) Energy E = h; higher frequency = higher energy.

6. (d) Gamma rays have the shortest wavelength and highest frequency.

7. (a) Microwaves are used in radar as they can travel in the atmosphere and reflect from objects.

8.(c) Energy is shared by both electric and magnetic fields, not just magnetic.

9. (a) IR is emitted due to heat and used for thermal imaging.

10. (d) EM waves are transverse, not longitudinal; E field is perpendicular to propagation.

VERY SHORT ANSWER TYPE QUESTIONS (2 MARKS)

Q1 Why does microwave oven heats up a food item containing water molecules most efficiently?

SOL: Microwave ovens efficiently heat food containing water because microwaves excite the rotational motion of polar water molecules**,** and the resulting molecular friction generates heat. Foods with higher water content heat up faster and more uniformly.

Q2: A variable frequency a.c source is connected to a capacitor. How will the displacement current change with decrease in frequency?

SOL: Displacement current is directly proportional to frequency. As frequency decreases, the rate of change of voltage across the capacitor decreases. Therefore, the displacement current also decreases. $\varepsilon_0 \left(\frac{d\varphi_E}{dt}\right) = i_d$

For current in capacitor : I_d= C dV/dt

V=$V_o$sin wt, so I_d α w and w = 2 πf so I_d α f

Q3 The magnetic field of a beam emerging from a filter facing a floodlight is given by $B_0 = 12 \times 10^{-8} \sin(1.20 \times 10^7 z - 3.60 \times 10^{15} t)$ T. What is the average intensity of the beam?

Sol: $I_{av} = \frac{1}{2} c \frac{B_0^2}{u_0} = \frac{1}{2} 3 \times 10^8$ x $(12 \text{x} 10^{-8})^2 / 1.26 \text{ x } 10^{-6} = 1.71$ W/m^2

Q4 Professor C.V. Raman surprised his students by suspending freely a tiny light ball in a transparent vacuum chamber by shining a laser beam on it. Which property of EM waves was he exhibiting? Give one more example of this property.

Sol : EM waves exert radiation pressure. Tails of comets are due to solar radiation.

Q5 How are Infrared waves produced? Why are these waves referred to as heat waves? Give any two uses of infrared waves.

Sol: Infrared radiations are produced by hot bodies and vibrations of molecules. They are referred to as heat waves because they are rapidly absorbed by water molecules and increase their thermal energy and heat them.

Uses: i) dehydration of fruits ii) In green house effect iii) In remote switches

Q6 An E.M. wave, Y_1, has a wavelength of 1cm while another e.m. wave, Y_2, has a frequency of 10^{15} Hz. Name these two types of waves and write one useful application for each.

Sol: Y_1 has a wavelength of 1 cm, which lies in the microwave region. Y_2 has a frequency of 10^{15} Hz, which falls in the ultraviolet (UV) region.

Y_1:Microwave

Application: Used in microwave ovens for cooking food.

Y_2:Ultraviolet (UV)wave

Application: Used for sterilizing medical instruments.

SHORT ANSWER TYPE QUESTIONS (3 MARKS)

1. Electromagnetic waves of wavelengths γ_1, γ_2 and γ_3 are used in radar systems, in water purifiers and in remote switches of TV, respectively.
   Identify the electromagnetic waves, and Write one source of each of them.

Sol: γ_1: Microwaves, γ_2 : Ultraviolet (UV) rays , γ_3: Infrared (IR) rays .

Microwaves: Klystron or magnetron tubes (used in radar and microwave ovens) Ultraviolet rays: Mercury vapour lamps or sunlight.

Infrared rays: Heated objects or infrared LEDs (used in remote controls)

2. Identify electromagnetic waves which
   (i) Are used in radar systems. (ii) Affect a photographic plate. (iii)Are used in surgery.

Write their frequency range.

Sol: Electromagnetic waves used in radar systems is Microwaves**,** Frequency Range: 10^9 - 10^{11} Hz **.** Electromagnetic waves that affect a photographic plate is Ultraviolet (UV) rays**,** Frequency Range: 10^{15} –

10^{17} Hz Infrared (IR) rays (used in thermal cauterization and healing), or sometimes X-rays in precision surgery Frequency range: $10^{12} – 4 \times 10^{14}$ Hz

3. Identify the following electromagnetic radiations as per the frequencies given below. Write one application of each. (a) 10^{20} Hz   (b) 10^9Hz   (c) 10^{11}Hz

Sol: a) Gamma Rays : Used in cancer radiotherapy to destroy malignant cells. B) Microwaves. Used in radar systems and microwave ovens for cooking. C) Used in TV remote controls and thermal imaging**.**

4. Identify the part of the electromagnetic spectrum which:

(a) Produces heating effect (b) Is absorbed by the ozone layer in the atmosphere,

(c) Is used for studying crystal structure

Sol: a) Infrared radiations. IR waves are absorbed by matter and increase the kinetic energy of particles, causing a heating effect. b) Ultraviolet (UV) rays . c) X rays

5. Arrange the following electromagnetic waves in the order of their increasing wavelength:

(a) γ-rays   (b) Microwaves   (c) X-rays   (d) radio waves

How are infrared waves produced? What role does infrared radiation play in (i)maintaining the earth's warmth and (ii) physical therapy?

Sol: a) Order (increasing wavelength): γ-rays<X-rays<Microwaves<Radio waves

a) Infrared (IR) waves are produced by vibrations and rotations of atoms and molecules in a body. All objects at a temperature above absolute zero emit IR radiation due to their thermal motion.

b) Maintaining warmth of earth and Physical therapy IR radiation is used in heat lamps and therapeutic devices to relieve muscle pain, increase blood circulation, and promote healing by penetrating deep into tissues.

6. (a) Which one of the following electromagnetic radiations has least frequency:
UV radiations, X-rays, Microwaves

(b) How do you show that electromagnetic waves carry energy and momentum?

(c) How are electromagnetic waves produced by oscillating charges?

(d) State clearly how a microwave oven works to heat up a food item containing water molecules.

(e) Why are microwaves found useful for the radar systems in aircraft navigation?

Sol: a) Microwaves has least frequency and highest wavelength. Microwaves < UV < X-rays

Produced by klystrons**,** magnetrons**, or** Gunn diodes, which generate high-frequency electromagnetic oscillations.

b. EM waves consist of oscillating electric and magnetic fields that can exert force on charges, transferring energy. The energy carried is proportional to the square of the amplitude of electric and magnetic fields. The force exerted by the EM waves is given by F=p/c.

c) When charges accelerate (e.g., in an alternating current), they produce changing electric fields, A time-varying electric field creates a time-varying magnetic field, and vice versa. These changing fields propagate outward as electromagnetic waves**.**

7. Electromagnetic wave with wavelength

(i) λ_1 is used in satellite communication.

(ii) λ_2 is used to kill germs in water purifier.

(iii) λ_3 is used to detect leakage of oil in underground pipelines.

(iv) λ_4 is used to improve visibility in runways during fog and mist conditions.

(a) Identify and name the part of electromagnetic spectrum to which these radiations belong.

(b) Arrange these wavelengths in ascending order of their magnitude.

(c) Write one more application of each.

Sol:

λ_1	Satellite communication	Microwaves
λ_2	Kill germs in water purifier	Ultraviolet (UV) rays
λ_3	Detect leakage in underground pipelines	Infrared (IR) rays
λ_4	Improve visibility during fog/mist	Radio waves (or Near-IR)

a) ascending order of wavelength: λ_2(UV)<λ_3 (IR)< λ_1(Microwaves)< λ_4 (Radio/Near-IR)

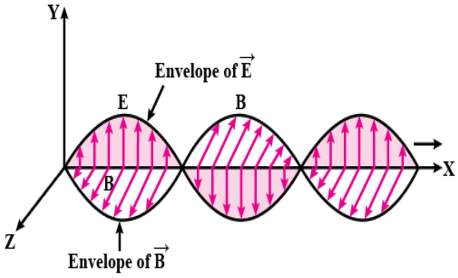
b) Microwaves (λ_1): Used in microwave ovens for cooking food.
Ultraviolet rays (λ_2): Used in sterilizing surgical instruments.
Infrared rays (λ_3): Used in remote controls and thermal imaging.
Radio waves/Near-IR (λ_4): Used in AM/FM radio broadcasting and night vision cameras.

CASE STUDY BASED QUESTIONS

Q1 Maxwell, in 1865, pointed out that when either an electric or a magnetic field is changing with time, a field of the other kind is induced in adjacent regions of space. From this Maxwell concluded that variation of electric and magnetic field vectors perpendicular to each other leads to the production of electromagnetic disturbances which show properties of waves and can travel in space even without any material medium. These waves are called electromagnetic waves.

Electromagnetic waves with macroscopic wavelengths were first produced in the laboratory in 1887 by the German physicist Heinrich Hertz. Seven years after Hertz, Jagdish Chandra Bose, working at Calcutta (now Kolkata) succeeded in producing and observing electromagnetic waves of much slower wavelength (25mm to 5mm). At around the same time, Guglielmo Marconi in Italy followed Hertz's work and succeeded in transmitting electromagnetic waves over distances of many kilometers.

Electromagnetic waves have a broad frequency range 10^3Hz to 10^{22}Hz. They can travel with speed of light(c) in vacuum. They obey the relation $c=\nu\lambda$, where ν is frequency and λ is wavelength.



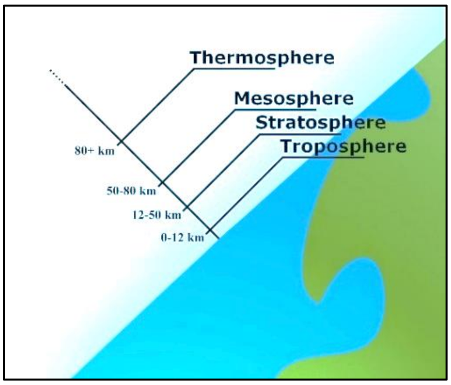
(i) Which of the following electromagnetic wave in order of increasing frequency.
(a) Microwaves<Infrared <Ultraviolet < γ-rays
(b) γ-rays < Ultraviolet < Infrared < Microwaves
(c) Ultraviolet < Infrared < Microwave < γ-rays
(d) γ-rays < Microwave < Infrared < Ultraviolet

(ii) Light wave contains
(a) Electromagnetic waves (c) Longitudinal waves
(b) Mechanical Waves (d) magnetic waves

(iii) If we want to produce electromagnetic waves of wavelength 500 km by an oscillating charge the frequency must be
(a) 600 Hz (b) 500Hz (c) 167Hz (d) 15Hz

(iv) The angle between $\vec{E}$ and $\vec{B}$ in an electromagnetic wave is
(a) 180^o (b) 120^o (c) 90^o (d) 45^o

Q2 Radio waves are produced by the accelerated motion of charges in conducting wires. Microwaves are produced by special vacuum tubes. Infrared waves are produced by hot bodies and molecules also known as heat waves. UV rays are produced by special lamps and very hot bodies like Sun.



(i) Solar radiation is
(a) transverse electromagnetic wave
(b) longitudinal electromagnetic wave
(c) both longitudinal and transverse electromagnetic waves
(d) None of these

(ii) What is the cause of greenhouse effect?
(a) Infrared rays (b) Ultraviolet rays (c) X-rays (d) Radio waves

(iii) Biological importance of ozone layer is
(a) it stops ultraviolet rays (b) It layer reduces greenhouse effect
(c) it reflects radio waves (d) None of these

(iv) Earth's atmosphere is richest in

(a) ultraviolet (b) infrared (c) X-rays (d) microwaves

Q3 According to Maxwell, an accelerating charge produces electromagnetic waves. Consider a charge oscillating harmonically with time. This is an example of an accelerating charge. This charge produces an oscillating electric field in its neighborhood. This field, in turn, produces an oscillating magnetic field in its neighborhood. The process continues because the oscillating electric and magnetic fields set as sources of each other. Hence an electromagnetic wave originates from the oscillating charge. The frequency of the electromagnetic wave is equal to the frequency of oscillation of the charge. The energy carried by the wave comes from the source which makes the charge oscillating. An electric dipole is a basic source of electromagnetic waves. An LC-circuit containing inductance L and capacitance C produces electromagnetic waves of frequency, $f = \frac{1}{2\pi\sqrt{LC}}$

(i) Electromagnetic waves are produced by

(a) Accelerated charged particle (b) Charge at rest

(c) Charge in uniform motion (d) None of these.

(ii) Light can travel in vacuum due to its

(a) Transverse nature (b) Electromagnetic nature

(c) Longitudinal nature (d) Both (a) and (c).

(iii) If a source is transmitting electromagnetic waves of frequency 8.2×10^6 Hz, the wavelength of electro-magnetic wave transmitted from the source is

(a) 36.6 m (b) 18.8 m (c) 42.8 m (d) 58 m

(iv) (A) Wavelength of infrared radiations as compared to UV radiations is

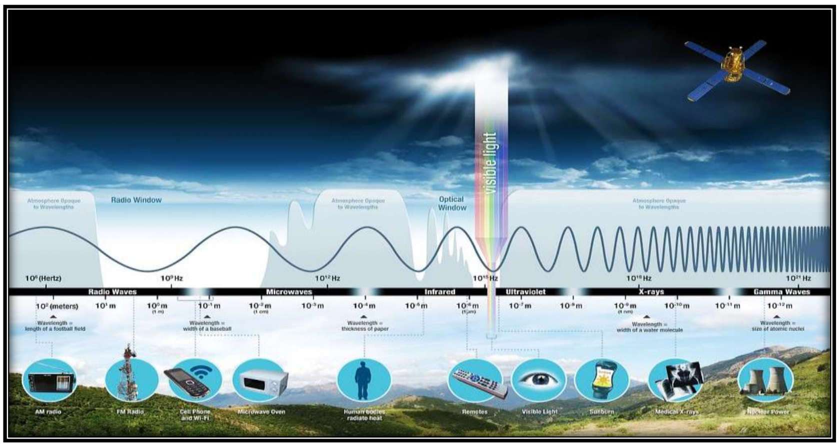
(a) shorter (b) longer (c) no comparison (d) same

OR

(B) The quantity $1/\sqrt{\mu_0\varepsilon_0}$ represents

(a) speed of sound (b) speed of light in vacuum

(c) speed of electromagnetic wave in medium (d) inverse of speed of light in vacuum



Q4

(i). Name the type of radiation that has used in luggage security checks at airports.

(a)γ-rays (b) X-rays (c) Microwaves (d) Infrared rays

(ii). Some γ-rays emitted from a radioactive source has wavelength 1.0×10^{-12}m. The frequency of the γ-rays

(a) 3×10^{20}Hz (b) 2×10^{12} Hz (c) 2.5×10^{5} Hz (d) 3.3×10^{12} Hz

(iii). Why does a microwave oven heat up a food item containing water molecules most efficiently?

(a) Microwaves are heat waves, so always produce heating

(b) Infrared waves produce heating in a microwave oven

(c) Energy from the microwaves is transferred efficiently to the kinetic energy of water molecules at their resonant frequency.

(d) The frequency of microwaves has no relation with natural frequency of water molecules.

(iv). (A) Which of the following electromagnetic radiations have the longest wavelength?

(a) X-rays (b) γ-rays (c) Microwaves (d) Radio waves.

OR

(B). If conducting current is 2A through a circuit the displacement current will be

(a) 1A (b) 2A (c) 3A (d) 4A

Sol:

Q1	**Q2**	**Q3**	**Q4**
i) A	i) a	i) a	i)d
ii) A	ii) a	ii) b	ii)a
iii)A	iii) a	iii) a	iii)c
iv)C	iv) b	iv) b or a	iv) d or b

- **Simulation for colour mixing:**

https://phet.colorado.edu/sims/html/color-vision/latest/color-vision_all.html

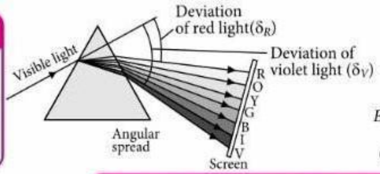
CHAPTER-9: RAY OPTICS

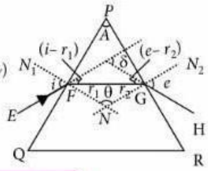
Syllabus-Reflection of light, spherical mirrors, mirror formula, refraction of light, total internal reflection and optical fibers, refraction at spherical surfaces, lenses, thin lens formula, lens maker's formula, magnification, power of a lens, combination of thin lenses in contact, refraction of light through a prism. **Optical Instruments**: Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers.

MIND MAP

RAY OPTICS

APPLICATIONS OF TIR
- Fiber optics communication
- Medical endoscopy
- Periscope (Using prism)
- Sparkling of diamond





POWER OF LENSES
Power of lens: $P = \frac{1}{f\text{ (in m)}}$

Combination of lenses:
Power: $P = P_1 + P_2 - dP_1P_2$
(d = small separation between the lenses)
For $d = 0$ (lenses in contact)
Power: $P = P_1 + P_2 + P_3 + ...$

TOTAL INTERNAL REFLECTION
TIR conditions
- Light must travel from denser to rarer.
- Incident angle $i >$ critical angle i_c

Relation between μ and i_c: $\mu = \frac{1}{\sin i_c}$

REFRACTION THROUGH PRISM
Relation between μ and δ_m

$$\mu = \frac{\sin\frac{A+\delta_m}{2}}{\sin\frac{A}{2}}$$

where, δ_m = angle of minimum deviation, A = angle of prism

or $\delta = (\mu - 1)A$ (Prism of small angle)

Angular dispersion

$$= \delta_V - \delta_R = (\mu_V - \mu_R)A$$

Dispersive power,

$$\omega = \frac{\delta_V - \delta_R}{\delta} = \frac{\mu_V - \mu_R}{\mu - 1}$$

Mean deviation, $\delta = \frac{\delta_V + \delta_R}{2}$

THIN SPHERICAL LENS
Thin lens formula: $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

Magnification: $m = \frac{v}{u} = \frac{h_i}{h_o}$

REFRACTION OF LIGHT
Snell's law: When light travels from medium a to medium b, ${}^a\mu_b = \frac{\mu_b}{\mu_a} = \frac{\sin i}{\sin r}$

Refractive index,

$$\mu = \frac{\text{velocity of light in vacuum}}{\text{velocity of light in medium}} = \frac{c}{v}$$

Real and apparent depth $\mu = \frac{\text{real depth}(x)}{\text{apparent depth }(y)}$

REFRACTION BY SPHERICAL SURFACE
Relation between object distance (u), image distance (v) and refractive index (μ)

$$\frac{\mu_{denser}}{v} - \frac{\mu_{rarer}}{u} = \frac{\mu_{denser} - \mu_{rarer}}{R}$$

(Holds for any curved spherical surface.)

Lens maker's formula

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

REFLECTION OF LIGHT
According to the laws of reflection, $\angle i = \angle r$

If a plane mirror is rotated by an angle θ, the reflected rays rotates by an angle 2θ.

REFLECTION BY SPHERICAL MIRRORS
Mirror formula, $\frac{1}{u} + \frac{1}{v} = \frac{1}{f} = \frac{2}{R}$

Magnification, $m = -\frac{v}{u} = \frac{h_i}{h_o}$

OPTICAL INSTRUMENTS

SIMPLE MICROSCOPE
Magnifying power

For final image is formed at D (least distance) $M = 1 + \frac{D}{f}$

For final image formed at infinity

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

COMPOUND MICROSCOPE
Magnifying power, $M = m_o \times m_e$

For final image formed at D (least distance) $M = \frac{L}{f_o}\left(1 + \frac{D}{f_e}\right)$

For final image formed at infinity

$$M = \frac{L}{f_o} \cdot \frac{D}{f_e}$$

TELESCOPE
Astronomical telescope

For final image formed at D (least distance) $M = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$

In normal adjustment, image formed at infinity $M = f_o/f_e$

REFLECTING TELESCOPE
Magnifying power

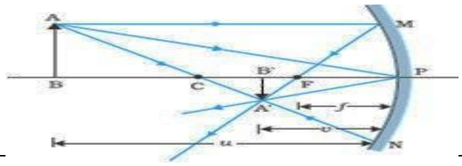
$$M = \frac{f_o}{f_e} = \frac{R/2}{f_e}$$

TERRESTRIAL TELESCOPE
For normal adjustment $M = \frac{f_o}{f_e}$

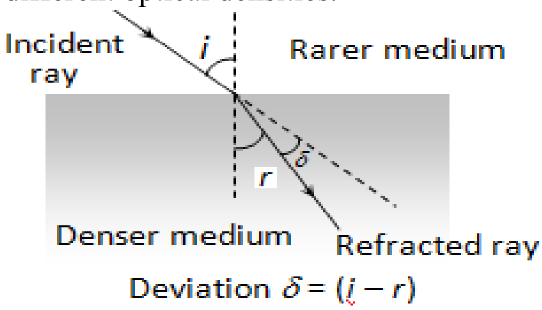
Distance between objective and eyepiece $d = f_o + 4f + f_e$

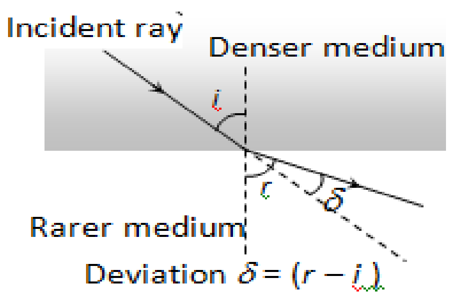
GIST OF THE CHAPTER

<u>Reflection of light</u>: - The bouncing of light back into the same medium from a surface is called reflection of light.
Laws of reflection: - i) Angle of incidence is equal to the angle of incidence.
ii) The incidence ray, the reflected ray and normal to the surface at the point of incidence all lie in the same plane.
Types of spherical mirrors: Concave and Convex. The relation between object distance, image distance and the focal length of a mirror is called mirror formula. The ratio of size of image to the size of object is called the magnification produced by the mirror.

Derivation of mirror formula: $\Delta ABC$and $\Delta A'B'C$are similar A'B'/AB = B'C/CB= PC-PB')/ (PB-PC) …..(1) ΔABP and $\Delta A'B'P$ are also similar 	A'B'/AB =PB'/PB …..(2) Compare eqn (1) and (2) … PB'/PB = (PC-PB')/ (PB-PC) -v/-u = (2f + v)/ (-u+2f) or $2uv$=$2v$f+$2uf$ Dividing by$2uv$f on both sides we get, $\frac{1}{f}= \frac{1}{u}\ \frac{-}{v}$

<u>Refraction of light</u>: - Bending of light from its actual path, when it passes obliquely from one medium to another having different optical densities.



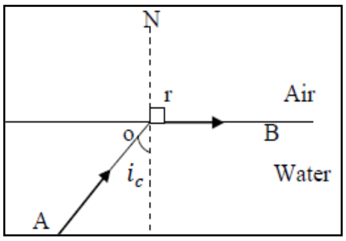


Snell's Law: -The ratio of the sine of the incident angle to the sine of the refracted angle is a constant. $\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = n_{21}$ $n_1 \sin i = n_2 \sin r$ OR$v_2 \sin i = v_1 \sin r$ Examples :- 1.Sun can be seen before actual sunrise	2. An object under water (any medium) appears to be raised due to refraction when observed inclined n = (Real depth / Apparent depth) and Shift in the position (apparent) of object is $x = t\left(1 - \frac{1}{n}\right)$ Where t is the actual depth of the medium

Critical angle (ic): - The angle of incidence in denser medium for which the angle of refraction in rarer medium is 90° is called the critical angle.

$$sini_c = n_{aw} = \frac{1}{n_{wa}}$$

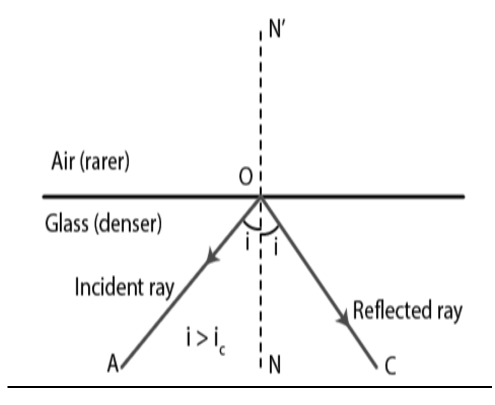
Note:- If rarer medium is not air then $sini_c = \frac{n_r}{n_d}$



Total internal reflection: - When angle of incidence of the ray incident on rarer medium from denser medium, is greater than the critical angle, the incident ray does not refract into rarer medium but is reflected back into denser medium. This phenomenon is called total internal reflection

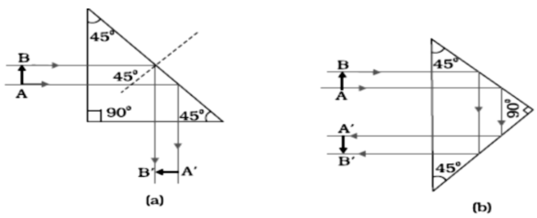
Mathematically: $n_{21} = \frac{1}{\sin C}$

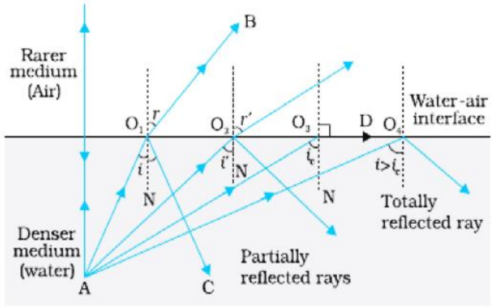
Here, n_{21} is the refractive index of the denser medium 2 w.r.t. the rarer medium 1 and C is the critical angle.



Applications of Total internal reflection:

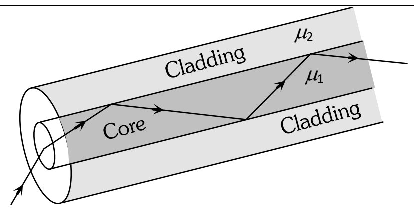
Totally reflecting prisms:- Bend the light at either 90^0 fig (a) or 180^0 fig (b)





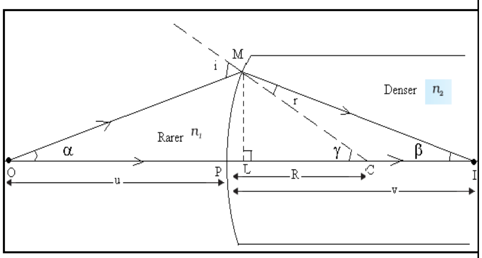
Fiber-optic: -Fine fiber of glass or quartz in which light enter from one end and comes out from another end due to total internal reflection is called optical fiber.

Used in endoscopy and communication



Here $n_{core} > n_{cladding}$

Refraction through Spherical surface:



From fig, in ΔMOC, $i = \alpha + \gamma$ -----(1)

and in Δ MCI, $\gamma = r + \beta \Rightarrow r = \gamma - \beta$------(2)

From laws of refraction, $\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$ --------(3)

For small angles, $\frac{i}{r} = \frac{n_2}{n_1} \Rightarrow n_1 i = n_2 r$------(4)

Using (1) and (2) in (4),

$n_1(\alpha + \gamma) = n_2(\gamma - \beta)$ -----------(5)

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

$\Rightarrow \frac{n_2}{PI} + \frac{n_1}{PO} = \frac{(n_2 - n_1)}{PC}$ -----------(6)

Using sign convention, $\frac{n_2}{v} - \frac{n_1}{u} = \frac{(n_2 - n_1)}{R}$

Spherical refracting surface. The portion of a refracting medium, whose curved surface forms the part of a sphere, is called a spherical refracting surface.

When object is situated in the rarer medium, the relation between n_1 (refractive index of the rarer medium), n_2 (refractive index of the spherical refracting surface) and R (the radius of curvature) with the object and image distances (u and v) is given by

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

When object is situated in the denser medium, the relation between n_1 (refractive index of the rarer medium), n_2 (refractive index of the spherical refracting surface) and R (the radius of curvature) with the object and image distances (u and v) can be obtained by interchanging n_1 and n_2. In that case, the relation becomes

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

Lens maker's formula. The relation connecting the focal length of the lens with the radii of curvature of its two surfaces and the refractive index of the material of the lens is called lens maker's formula. Mathematically:

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

Lens equation. The relation between the focal length, the object and image distances is called lens equation. Mathematically:

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

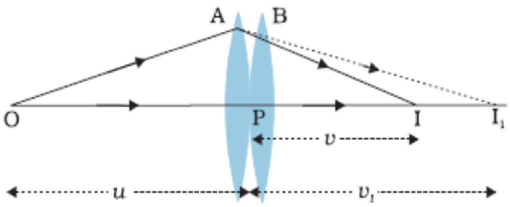
Linear Magnification. The ratio of the size of the image (formed by the lens) to the size of the object is called linear magnification produced by the lens.

Mathematically, $$m = \frac{I}{O} = \frac{v}{u} = \frac{f}{f+u} = \frac{f-v}{f}$$

Power of a lens. It is defined as the reciprocal of the focal length of the lens in metre.

Mathematically, $P = \frac{1}{f}$ or $P = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

In the above two formulae, f, R_1 and R_2 are measured in metre.

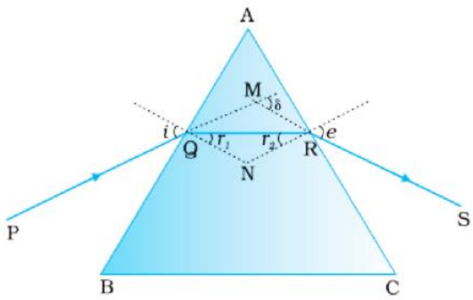


Two thin lenses placed in contact. When two lenses of focal lengths f_1 and f_2 are placed in contact, the focal length of the combination is given by

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

Power of equivalent lens: $P = P_1 + P_2$

Magnification produced by equivalent lens: $m = m_1 \times m_2$



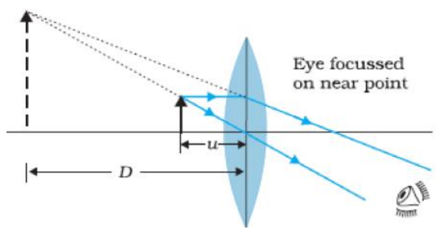
Refraction through a prism A ray of light incident on one face of the prism suffers refraction successively at the two surfaces and then emerges out of it. Mathematically,

$A = r_1 + r_2$, $A + \delta = i + e$

Prism formula: $\mu = \dfrac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$

Simple microscope. A convex lens of small focal length is called a simple microscope or a magnifying glass.

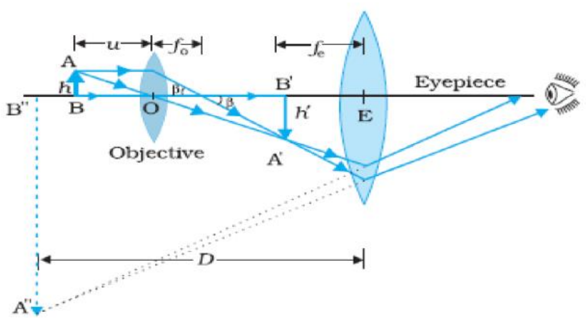
The magnifying power of a microscope is defined as the ratio of the angle subtended by the image at the eye to the angle subtended by the object seen directly, when both lie at the least distance of distinct vision.



Mathematically: $$M = \left(1 + \frac{D}{f}\right)$$

Here, D is the least distance of distinct vision

Compound microscope. A compound microscope is a two-lens system (object lens and eye lens of focal lengths f_o and f_e). Its magnifying power is very large, as compared to the simple microscope.



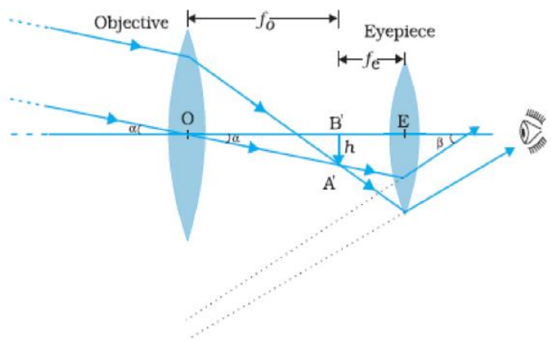
Mathematically:

$$M = \frac{v_o}{u_o}\left(1 + \frac{D}{f_e}\right) = -\frac{L}{f_o}\left(1 + \frac{D}{f_e}\right)$$

Here, u_o is distance of the object from the object lens and $v_o \approx L$, (L is the length of the tube of the microscope) is the distance at which the object lens forms the image of the object.

Astronomical telescope. It is a two-lens system and is used to observe distant heavenly objects. It is called refracting type astronomical telescope.

Normal adjustment- When the final image is formed at infinity, the telescope is said to be in normal adjustment.



The magnifying power of a telescope in normal adjustment is defined as the ratio of the angle subtended by the image at the eye as seen through the telescope to the angle subtended by the object seen directly, when both the object and the image lie at infinity.

Magnifying power in normal adjustment,

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

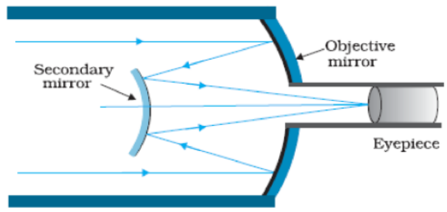
When the final image is formed at the least distance of distinct vision,

Magnifying power of the telescope,

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

Reflecting type telescope. In a reflecting type telescope, the objective is a concave spherical mirror of large aperture in place of a convex lens.

The expression for magnifying power of a reflecting type telescope is same as that for refracting type astronomical telescope.



MULTIPLE CHOICE QUESTIONS

1. A beam of light is incident at 60° to a plane surface. The reflected and refracted rays are perpendicular to each other. What is the refractive index of the surface?

(a) 1√3 (b) √3 (c) 1/3 (d) 3

2. A concave mirror of focal length f produces a real and virtual image of an object of magnification m (m> 1) when placed at two different positions. The distance between the positions of the object is :

(a) $(m-1)f$ (b) $(1-m)f$ (c) $\frac{2f}{m}$ (d) zero

3. The refractive index of the material of a prism is √2 and its refracting angle is 30°. One of the refracting surfaces of the prism is made a mirror. A beam of monochromatic light entering the prism from the other face retraces its path, after reflection from mirror surface. The angle of incidence on prism is:

(a) 0° (b) 30° (c) 45° (d) 60°

4. An astronomical refractive telescope has an objective of focal length 20 m and an eyepiece of focal length 2 cm. Then in normal adjustment:

(a) the magnification is 1000
(b) the length of the telescope tube is 20.02 m
(c) the image formed is of inverted nature.
(d) all of these

5. A particle moves towards a concave mirror of focal length 30 cm along its axis and with a constant speed of 4 cm/ sec. What is the speed of its image when the particle is at 90 cm from the mirror?

(a) 16 cm/ sec. (b) 1 cm/sec. (c) 8 cm/sec.(d) 4 cm/sec.

6. You are given four sources of light each one providing a light of a single colour – red, blue, green and yellow. Suppose the angle of refraction for a beam of yellow light corresponding to a particular angle of incidence at the interface of two media is 90°. Which of the following statements is correct if the source

of yellow light is replaced with that of other lights without changing the angle of incidence?

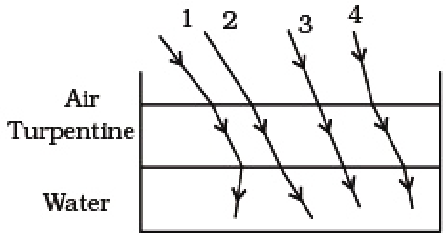
(a) The beam of red light would undergo total internal reflection.

(b) The beam of red light would bend towards normal while it gets refracted through the second medium.

(c) The beam of blue light would undergo total internal reflection.

(d) The beam of green light would bend away from the normal as it gets refracted through the second medium

7. The optical density of turpentine is higher than that of water while its mass density is lower. Fig shows a layer of turpentine floating over water in a container. For which one of the four rays incident on turpentine in Fig the path shown is correct?



(a) 1 (b) 2 (c) 3 (d) 4

8. If I is the image of a point object O formed by spherical mirror, then which of the following statement is incorrect:

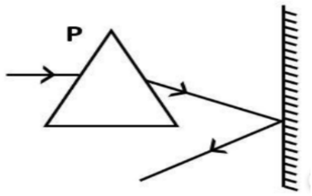
a) If O and I are on same side of the principal axis, then they have to be on opposite sides of the mirror.

b) If O and I are on opposite sides of the principal axis, then they have to be on same side of the mirror.

c) If O and I are on opposite side of the principal axis, then they can be on opposite side of the mirror as well at same side of the mirror.

d) If O is on principal axis then I may not lie on principal axis.

9. A prism having an apex angle of 4^0 and refractive index of 1.50 is located in front of a vertical plane mirror as shown. A horizontal ray of light is incident on the prism. The total angle through which the ray is deviated is



a) 4^0 clockwise b) 178^0 clockwise

c) 2^0 clockwise d) 8^0 clockwise

10. A plano concave lens of focal length 10 cm is placed on a paper on which a coin is drawn. How far above its actual position does the coin appear to be?

a) 10 cm b) 15 cm c) 50 cm d) none of these

SOLUTIONS:

1. (b) Here $i + r = 90$, $n = \frac{\sin i}{\sin r} = \frac{\sin i}{\cos i} = \tan i = \tan 60^0 = \sqrt{3}$

2. (c) For real image, $v = -um$, $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$, $\frac{1}{-f} = \frac{1}{-um} + \frac{1}{u}$, $u = \frac{(1-m)f}{m}$

For virtual image, $v = u'm$, $\frac{1}{f} = \frac{1}{v} + \frac{1}{u'}$, $\frac{1}{-f} = \frac{1}{u'm} + \frac{1}{u'}$, $u' = \frac{-(1+m)f}{m}$

$$u - u' = \frac{2f}{m}$$

3. (c)$A = 30^\circ$, $r = 30^\circ$, $n = \frac{\sin i}{\sin r}$ =>$\sqrt{2} = \frac{\sin i}{\sin 30}$ =>$i = 45^\circ$

4. (d) $m = \frac{f_o}{f_e} = 1000, L = |f_o| + |f_e|$ = 20.02 m, Image is always inverted

5. (b) $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$, $\frac{1}{-30} = \frac{1}{v} - \frac{1}{-90}$, $v = -45\, cm$, Now differentiate both sides of mirror formula with respect to time, we get $0 = \left(\frac{-1}{v^2}\right)\frac{dv}{dt} + \left(\frac{-1}{u^2}\right)\frac{du}{dt}$

Here, $\frac{du}{dt} = 4\, cm/s$ So , $\frac{dv}{dt} = 1\, cm/s$

6. (c) Order of wavelength: Red > yellow > green > blue

Order of refractive indices: Red < yellow < green <blue and $i_c \propto \frac{1}{refractive\ index}$

7. (b) 2

8. (c)

9. $\delta = (\mu - 1)A$, $\delta = 2°$, Total deviation = $180° - 2° = 178°$

10. Use lens makers formula and get position at 10 cm above its actual position

ASSERTION-REASON TYPE QUESTIONS

For these Questions two statements are given one labelled Assertion (A) and other labelled Reason (R). Select the correct answer to these questions from the options as given below

A. If both Assertion and Reason are true and Reason is correct explanation of Assertion.

B. If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.

C. If Assertion is true but Reason is false.

D. If both Assertion and Reason are false.

1. **Assertion:** A real image of a very intense virtual light source can burn a paper.
   Reason: A virtual image is one when light rays seem to be meeting at a point after reflection/refraction and for real image they actually meet.
2. **Assertion:** In passing through a lens or prism, the phase difference between two waves does not change.
   Reason: The optical path lengths of all rays are same when medium is same.
3. **Assertion:** A convex lens may be diverging.
   Reason: The nature of a lens depends upon the refractive indices of the material of lens and surrounding medium besides its geometry.
4. **Assertion:** When a glass prism is immersed in water, the deviation caused by prism decreases.
   Reason: Refractive index of glass prism relative to water is less than relative to air.
5. **Assertion:** Hollow prism forms no spectra as a solid equilateral prism of glass.
   Reason: Neglecting the thickness of hollow glass surface. The media is same. So, dispersion is not to take place.
6. **Assertion:** The images formed by total internal reflections are much brighter than those formed by mirrors or lenses.
   Reason: There is no loss of intensity in total internal reflection.
7. **Assertion:** When light enters inside perfectly spherical water droplet it should not show total internal reflection inside the water droplet.
   Reason: When light enters non perpendicular to spherical water droplet it is internally reflected.
8. **Assertion:** Law of reflection is applicable for all type of mirrors.
   Reason: Rays which are parallel to principal axis are known as paraxial rays

SOLUTIONS/HINTS

1.B A real image, being formed by actual convergence of light rays, reason does not explain *why* a real image can burn paper.

2. A When a lens or prism forms an image without aberration, the optical path length for all rays from a point on the object to the corresponding point on the image is the same. This implies no change in phase difference.

3. A A convex lens can act as a diverging lens if the refractive index of the surrounding medium is greater than that of the lens material. This is precisely explained by the reason.

4. A. The deviation produced by a prism depends on the relative refractive index. When immersed in water, the relative refractive index of glass with respect to water is less than that with respect to air, leading to a decrease in deviation

5.A The hollow prism acts as if light is passing through a uniform medium, thus no dispersion occurs. Dispersion requires a change in refractive index with wavelength, which happens when light passes from one medium to another with different properties.

6.A Images formed by total internal reflection are indeed brighter because there is ideally no loss of light intensity during total internal reflection, unlike reflection from mirrors or refraction through lenses where some light is absorbed or transmitted.

7.C Total internal reflection does not take place in perfect spherical drop.Internal reflection occurs when light travels from a denser to a rarer medium and the angle of incidence exceeds the critical angle, not simply when it enters non-perpendicularly.

8.C The law of reflection holds true for all types of mirrors. Paraxial rays are rays close to and making small angles with the principal axis, not just parallel rays

SHORT ANSWER TYPE QUESTIONS

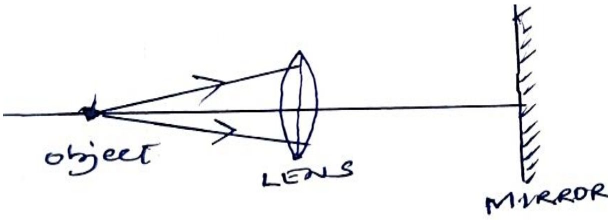
1. The refractive index of diamond is much greater than that of ordinary glass. Is this fact of some use to a diamond cutter?
2. Does the apparent depth of a tank of water change if viewed obliquely at different angles? If so, does the apparent depth increase or decrease?
3. For a glass prism ($\mu = \sqrt{3}$) the angle of minimum deviation is equal to the angle of the prism. Find the angle of the prism.
4. Justify using a diagram "To form an image using a lens all types of rays cannot be used."
5. When the object is at distances u_1 & u_2 the images formed by the same lens are real and virtual respectively and of the same size. Calculate focal length of the lens?
6. Will the focal length of a lens for red light be more, same or less than that for blue light? Justify?
7. The focal length of an equiconvex lens is equal to the radius of curvature of either face. What is the value of refractive index of the material of the lens?
8. Write advantages of reflecting type telescope over refracting type telescope.
9. Show that for a material with refractive index $\mu \geq \sqrt{2}$, light incident at any angle shall be guided along a length perpendicular to the incident face.
10. A ray of light is incident on a parallel slab of thickness t and refractive index n. If the angle of incidence θ is small, Express the displacement in the incident and emergent ray?

SOLUTIONS/HINTS

1. No , there is no relationship , it is due to its hardness.
2. Decreases as light ray traveling from denser to rarer medium (bending of light away from normal)
3. Use prism formula. $A = 60^0$
4. Paraxial rays and marginal rays shall not be included because they do not meet at one point i.e, focus.
5. $|m_1| = |m_2|$, use lens formula for real and virtual image formations, $f = \frac{u_1+u_2}{2}$
6. $refractive\ index \propto \frac{1}{wavelength}$, Use lens maker's formula [$f_{red} > f_{blue}$]
7. Use lens maker's formula. $n = 1.5$
8. No chromatic aberration, easy to provide mechanical support, can easily minimize spherical aberration
9. Use Snell's law and condition of total internal reflection
10. Use Snell's formula and approximation for small angle. Lateral displacement = $t\theta \frac{n-1}{n}$

SHORT ANSWER TYPE

1. A convex lens of focal length f is placed x metre apart from a plane mirror. As shown in figure an object is placed at x distance from the lens away from the mirror get a relation between x and f for following conditions
   a) if final image is formed at x. (at the position of object itself)
   b) if no images formed.
   c) if virtual images are formed.



2. A convex lens and a concave lens have power in ratio 3:2 when placed in contact effective focal length of combination is found 30 cm. We get real image of an object which is placed at 15 cm in front of convex

lens. This image is shifted by 20 cm when same concave lens is introduced between convex lens and image. Calculate the position of the lens introduced. Hence draw necessary ray diagram.

3.You have a concave mirror placed horizontally on a Floor. An all pin when placed at $d_1$meter above it, its real image coincide with itself'. This mirror is filled with a liquid of refractive index n_1 new image is found at D_2 if this liquid is replaced by another liquid of refractive index n_2 new image is found at D_3. If $n_1 > n_2$ give a relation between D_2 and D_3 with proper justification using a diagram.

4.A prism with angles 30˚,90˚,60˚ is placed with smallest face vertical. When a laser torch is aimed horizontally at its vertical face, angle of deviation is found 30˚. Using a diagram explain how this angle of deviation would be changed If the torch is rotated a) slightly clockwise, b) slightly anti clockwise.

5.A curved mirror forms five times magnified virtual image of an object if distance between object and images is 25 cm identify its nature and calculate its focal length.

6.In case of a concave mirror magnification is found to be - 0.5 for a certain position of object, when object is displaced by 5 cm from its position, magnification becomes 0.25.What will be the focal length of the mirror? Draw ray diagram to support your answer.

7.You have two mirrors one is concave other is convex focal of each mirror is 30 cm are placed D m apart such that their principal axis are common to each other. An object is placed between them at a point P which is 45 cm from concave mirror. It is found that final images formed on object itself Draw probable ray diagram and calculate value of D?

SOLUTIONS/HINTS

1.a) $x = 2f \ and \ f$, b) not possible c) $u > f \ => \ x > 2f$

2. $f_1 : f_2 = 2:3$, using formula $\frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{30} => f_1 = 10 \ cm \ and \ f_2 = -15 \ cm$

use lens formula to calculate the position of image formed by convex lens v = +30 cm

On introduction of concave lens, image will be shifted by 20 cm towards right. From lens formula position of concave can be calculated. Answer- 10 cm(approx..) from first image

3.Based on the experiment "to find refractive index of the liquid using concave mirror".

4. Using the concept of total internal reflection find critical angle (60^0).

a) for clockwise, $i > i_c$ (TIR takes place) b) for anticlockwise, $i < i_c$ (Refraction takes place)

5. Solution/Hint: Concave mirror, m= 5 and use mirror formula to find object and image distance $u = \frac{25}{4} cm, v = \frac{125}{4} cm, f = \frac{-125}{24} cm$

6. $v_1 = 0.5u_1, v_2 = 2f = u_1 - 30$, using mirror formula $f = 30 \ cm$

7. Use Snell's law, $n = \frac{\sin i}{\sin r} = \frac{D/2H}{x/H} = \frac{D}{2x} => x = \frac{D}{2n}$, Now x xan be these can be $\frac{D}{2}, D, D + \frac{D}{2}$, and many more.

LONG ANSWER TYPE QUESTIONS

1. a)Draw a labeled ray diagram of a simple microscope in normal adjustment.

b) A thin pencil of length (f/4) is placed coinciding with the principal axis of a mirror of focal length f. The image of the pencil is real and enlarged, just touches the pencil. Calculate the magnification produced by the mirror.

2. a)A convex lens is placed in contact with a plane mirror. A point object at a distance of 20 cm on the axis of this combination has its image coinciding with itself. What is the focal length of the lens?

b) Calculate the angle of minimum deviation of an equilateral prism. The refractive index of the prism is $\sqrt{3}$.Calculate the angle of incidence for this case of minimum deviation also.

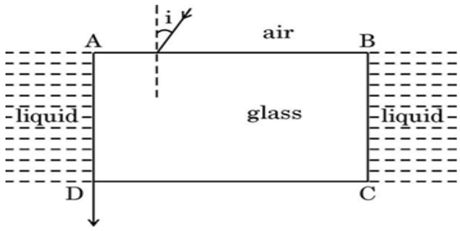
3. a) Draw a schematic arrangement of a reflecting telescope (Cassegrain) showing how rays coming from a distant object are received at the eyepiece.

b) A ray of light is incident on a refracting face AB of a prism ABC at an angle of 45^0.The ray emerges from face AC and the angle of deviation is 15^0.The angle of prism is 30^0.Show that the emergent ray is normal to the face AC from which it emerges out. Find the refractive index of the material of the prism.

4. a) For the same value of angle of incidence, the angles of refraction in three media A, B and C are 15°, 25°

and 35° respectively. In which medium would the velocity of light be minimum?

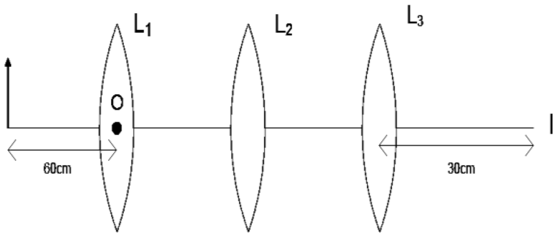
b) A rectangular glass slab ABCD ($n_1 = 1.5$) is surrounded by a transparent liquid ($n_2 = 1.25$)as shown in the figure. A ray of light is incident on face AB at an angle i such that it is refracted out grazing the face AD. Find the value of angle i.



5. a)An optical instrument uses eye-lens of power 20 D and the objective lens of power 50 D. Name the optical instrument and calculate its magnifying power if it forms the final image at infinity.

b)Three lenses L_1 L_2, L_3 each of focal length 30 cm are placed co-axially as shown in the figure. An object is held at 60 cm from the optic centre of Lens L_1. The final real image is formed at the focus of L_3. Calculate the separation between

(i) (L_1 and L_3) and (ii) (L_2 and L_3).



SOLUTION/HINTS

1. a) refer to the gist b) position of the other end $u = \frac{-7f}{4}$, $m = \frac{f}{f-u} = -4/3$

2. a) light rays from the object must fall on plane mirror normally. For this $f = u = 20\ cm$

b) use prism formula to find $\delta = 60^0$ $and\ then\ i + e = A + \delta$ ($i = 60^{\circ}$)

3. a) refer to the gist b)$i + e = A + \delta$ =>$e = 0^0$=>$r_2 = 0^0$

4.a)Use snell's law and the relation, $n = \frac{speed\ of\ light\ in\ vacuum}{speed\ of\ light\ in\ th\ medium}$ (Ans: Medium A)

b) Use the relation $\sin i_c = \frac{1}{n_{12}} = \frac{5}{6}$, $\sin r = \frac{\sqrt{11}}{6}$ Use Snell's law to find $i = \sin^{-1}\frac{\sqrt{11}}{4}$

5. a) Compound microscope, $calculate\ f_0$.For image is at infinity, $m = \frac{D}{f_0}$

b) Use lens law to find the image distance at first place, $v_1 = 60\ cm$, then the light rays must be parallel between $L_2\ and\ L_3$.Use this concept to find the answer. (i) > 90 cm (ii) any value

CASE STUDY/PASSAGE-BASED QUESTIONS

1. A prism is a portion of a transparent medium bounded by two plane faces inclined to each other at a suitable angle. A ray of light suffers two refractions on passing through a prism and hence deviates through a certain angle from its original path. The angle of deviation of a prism is, δ = (μ- 1) A,

Through which a ray deviates on passing through a thin prism of small refracting angle A. If μ is refractive index of the material of the prism, then prism formula is,$\mu = \frac{\sin\left(\frac{A+\delta m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$

(i) For which color, angle of deviation is maximum?

a) Red b) Yellow c)Violet d)Blue

(ii) When white light moves in gravity free region

a) all colors have same speed b) different colors have different speeds

c) violet has more speed than red d) red has more speed than violet.

(iii) The deviation through a prism is maximum when angle of incidence is

a) 45^0 b)70^0 c)90^0 d)60^0

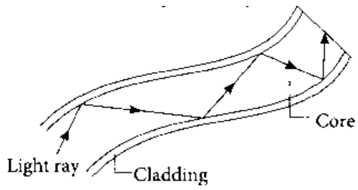
(iv) What is the deviation produced by a prism of angle 6°? (Refractive index of the material of the prism is 1.644).

a) 3.864° b)4.595° c)7.259° d)1.252°

(v) A ray of light falling at an angle of 50° is refracted through a prism and suffers minimum deviation. If the angle of prism is 60°, then the angle of minimum deviation is

a) 45° b)75° c)50° d)40°

2. An optical fibre is a thin tube of transparent material that allows light to pass through, without being refracted into the air or another external medium. It make use of total internal reflection. These fibres are fabricated in such a way that light reflected at one side of the inner surface strikes the other at an angle larger than critical angle. Even, if fibre is bent, light can easily travel along the length.



(i) Which of the following is based on the phenomenon of total internal reflection of light?

a)Sparkling of diamond b) Optical fibre communication

c)instrument used by doctors for endoscopy d)All of these

(ii) A ray of light will undergo rotal internal reflection inside the optical fibre, if it

a) goes from rarer medium to denser medium

b) is incident at an angle less than the critical angle

c) strikes the interface normally

d) is incident at an angle greater than the critical angle

(iii) If in core, angle of incidence is equal to critical angle, then angle of refraction will be

a) 0˚ b)45˚ c)90˚ d)180˚

(iv) In an optical fibre correct relation for refractive indices of core (n_1) and cladding (n_2) is

a) $n_1 = n_2$ b)$n_1 > n_2$ c)$n_1 < n_2$ d)$n_2 = 2$

(v) If the value of critical angle is 30° for total internal reflection from given optical fibre, then speed of light in that fibre is

a) 10^8 m s^{-1} b)1.5 x 10^8 m s^{-1} c)6 x 10^8 m s^{-1} d) 4.5 x 10^8 m s^{-1}

SOLUTIONS /HINTS:

1. i. c)$Deviation \propto \frac{1}{wavelength}$ ii. a)a gravity-free region is essentially a vacuum for the purpose of light propagation

iii. c)The deviation is maximum when the ray either just enters the prism (grazing incidence) or just exits the prism (grazing emergence).iv.a) use formula $\delta = (\mu - 1) A$

v) d) use formula $i + e = \delta + A$

2. i. d) ii. d) iii. c) iv. c) For TIR, light must travel from a denser medium to a rarer medium v. b) Using formula $\sin i_c = \frac{1}{n_{21}} and\ then\ use\ Snell's formula$

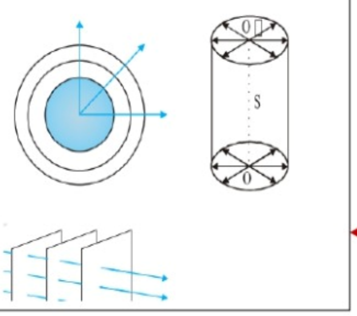
CHAPTER- 10 : WAVE OPTICS

Chapter–10: 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).

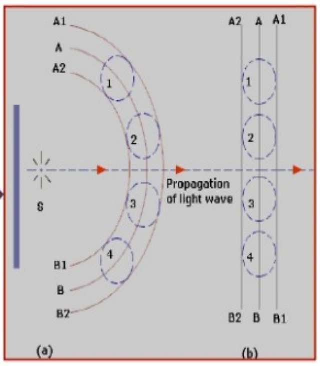
WAVE OPTICS

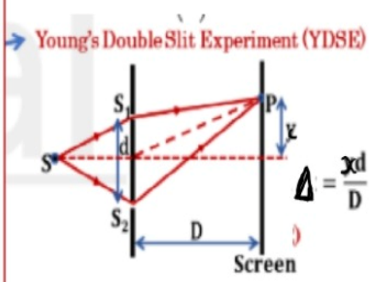
A wavefront is a surface of constant phase

Shape of Wave front



Huygen's principle of the secondary wavelets-Each point on the wavefront is the source **of a secondary wavelets.**





d is distance between slits S_1 and S_2

D is distance between slit and screen

y	0	$\frac{\lambda D}{2d}$	$\frac{\lambda D}{d}$	$\frac{3\lambda D}{2d}$	$\frac{2\lambda D}{2d}$
Max /Mina	Central Maxima	1st Minima	1st Maxima	2nd Minima	2nd Maxima

Path difference $\triangle = \frac{xd}{D}$

Position of nth bright fringe $x_n = \frac{nD\lambda}{d}$ (where **n=0,1,2,3...)**

Position of nth dark fringe $x_n = \frac{(2n-1)D\lambda}{2d}$(where **n=1,2,3...**

Fringe width $\beta = x_n - x_{n-1} = \beta_{bright} = \beta_{dark} = \frac{\lambda D}{d}$

Fringe width in medium $\beta_{med} = \frac{\beta_{vac}}{\mu}$

Angular width of fringe $\theta = \frac{\beta}{D} = \frac{\lambda}{d}$

Interference of light

- Phase difference does not change with time – coherent sources
- $A^2 = A_1^2 + A_2^2 + 2A_1A_2 \cos\phi$
- $I = I_1 + I_2 + 2\sqrt{I_1I_2}\cos\phi$

YDSE

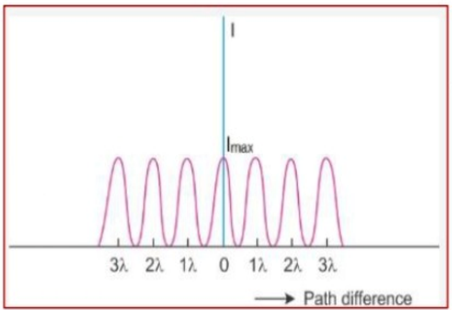
- Fringe width, $\beta = \frac{\lambda D}{d}$
- Position of n_{th} bright fringe,

$y_{bright} = \frac{n\lambda D}{d}$

- Position of n_{th} dark fringe,

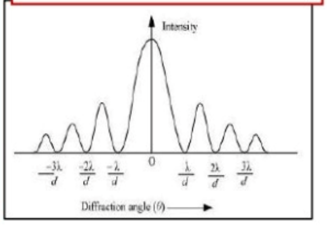
$y_{bright} = \frac{(2n-1)\lambda D}{2d}$

- For bright fringe, $\Delta x = n\lambda$
- For dark fringe, $\Delta x = \left(n + \frac{1}{2}\right)\lambda$



Diffraction

1.Path difference△= BP-AP = BE =a sin θ2. **Position of minima-** Position of n[th] dark fringe **a sin θn = nλ** (where **n =1,2,3...)**
3.**Position of secondary maxima- a sin θn' = (2n+1) λ/2** where **n =1,2,3...4.angular width of central maxima = 2θ =2λ/a5. Linear width of central maxima= 2x or D(2θ) = 2λD/a**

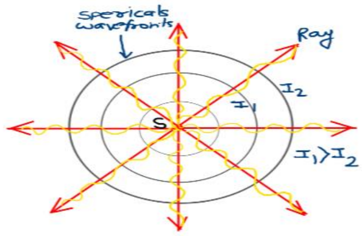
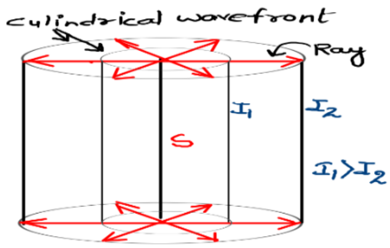
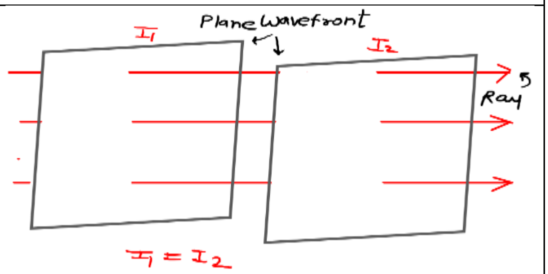


WAVE OPTICS: CONCEPT OF WAVEFRONT.

1.Nature of light-The phenomena like interference, diffraction and polarization establish the wave nature of light. Whereas the phenomena like photo electric effect, Raman effect, Compton effect establish the particle nature of light.

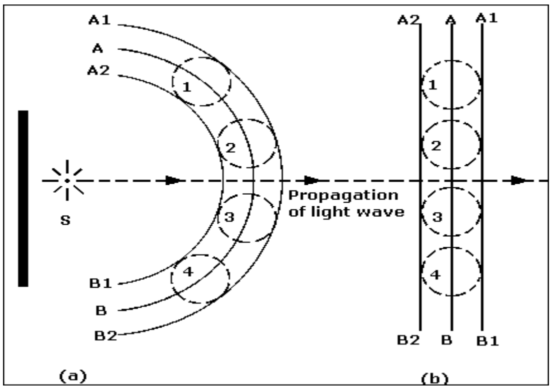
2.Wavefront-It is defined as the continuous locus of all the particles of the medium vibrating in the same phase at any instant. A wavefront is a surface of constant phase. The speed with which the wavefront moves outwards from the source is called the phase speed (wave speed).Note-1. Rays are perpendicular to wavefronts. .2. No backward wavefront is possible.

3.Types of wavefront-It is depends on the source of disturbance.

Spherical wavefront	Wavefront formed by the point source	
Cylindrical wavefront	Wavefront formed by linear or cylindrical shape source	
Plane wavefront	As a spherical or cylindrical wavefront advances, its curvature decreases, so small portion of such a wavefront at a large distance from the source will be a plane wavefront	

4. Huygen's principle of the secondary Wavelets-It is the basis of wave theory of light. It tells how a wavefront propagates through a medium. It is based on the following assumptions

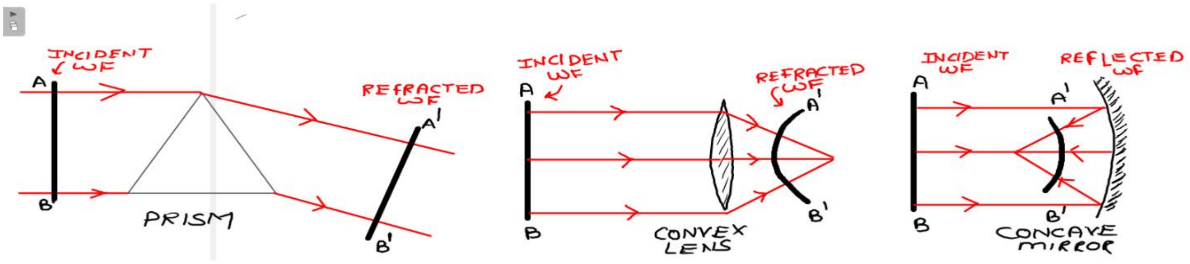
i)Each point on a wavefront acts as a source of new disturbance called secondary wavelets. These secondary wavelets spread out in all directions with the speed of light in the given medium ii)The wavefront at any later time is given by the forward envelope of the secondary wavelets at that time.

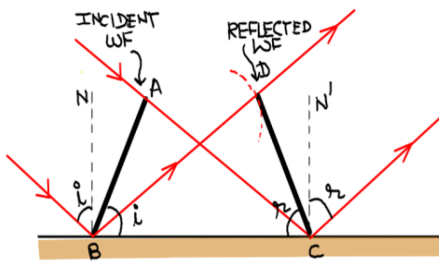
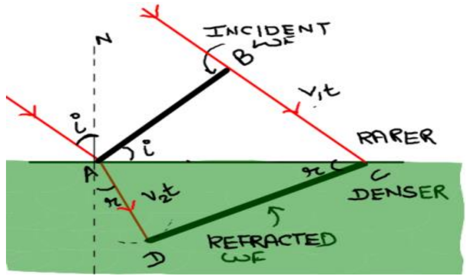
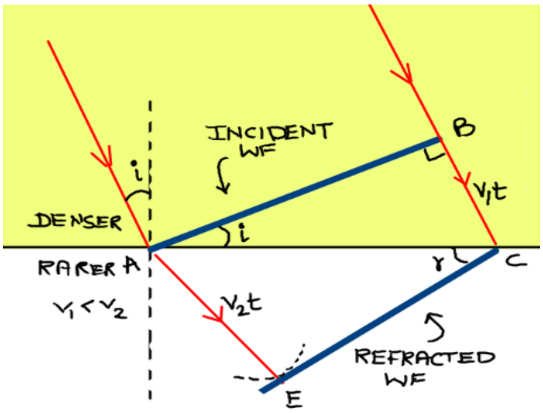


5.During refraction- Frequency of light remains constant, wavelength and speed of light get changed depending on the refractive index. ($\lambda' = \lambda/\mu$ and $v' = v/\mu$) (here μ is the refractive index)

6.Behaviour of a prism, lens and mirror-

7.



	Reflection on the basis of wave theory	Refraction on the basis of wave theory
i)		
ii)	In triangle △ABC and △DCB ∠BAC=∠CDB (Each 90º) BC=BC AC=BD (each equal to ct) ∴△ABC ≅ △DCB Hence ∠i=∠r	From △ABC, sin i =BC/AC From △ADC, sin r = AD/AC $\therefore \frac{\sin i}{\sin r} = \frac{BC}{AD} = \frac{v_1 t}{v_2 t}$ Or $\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \mu_{21}$(refractive index of second medium wrt first medium)
	Note-for denser to rarer medium	

8.Coherent and Incoherent Sources-Two sources are coherent if they have the same frequency and with a constant phase difference. They are incoherent if phase difference is not constant.

9.Interference of light-When two light waves of the same frequency and having constant phase difference(coherent), travelling in the same direction superpose each other, the intensity gets redistributed, becoming maximum at some points and minimum at others, this phenomenon is called interference of light.

Let two waves from two coherent source of light be $y_1 = a\sin\omega t$ and $y_2 = b\sin(\omega t + \emptyset)$

Where a and b are amplitudes and ∅ is the phase difference

So y = $y_1 + y_2$ after solving we get $\mathbf{y = A\sin(\omega t + \theta)}$

- Where A is the resultant amplitude so $\mathbf{A_{net} = \sqrt{(a^2 + b^2 + 2ab\cos\emptyset}}$
- And Resultant intensity is $\mathbf{I_{net} = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\emptyset}$

- Resultant amplitude when a =b $\quad A_{net} = 2a\cos\frac{\emptyset}{2}$
- Resultant intensity when I_1=I_2=I $\quad I_{net} = 4I\cos^2\frac{\emptyset}{2}$

NOTE- Ratio of maximum intensity to minimum intensity

$$\frac{I_{max}}{I_{min}} = \left(\frac{a+b}{a-b}\right)^2 = \left(\frac{\sqrt{I_1}+\sqrt{I_2}}{\sqrt{I_1}+\sqrt{I_2}}\right)^2$$

10.Types of Interference-

s.no	Constructive interference	Destructive interference
1	Point where resultant intensity is max	Point where resultant intensity is minimum
2	• For $I_{max} \rightarrow \cos\phi = +1$ • Phase difference $\phi = 0, 2\pi, 4\pi, \ldots, 2n\pi$ where $n = 0, 1, 2, \ldots$ • Path difference $\Delta = 0, \lambda, 2\lambda, \ldots, n\lambda$ • $A_{max} = a + b$ • $I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$	• For $I_{min} \rightarrow \cos\phi = -1$ • Phase difference $\phi = \pi, 3\pi, 5\pi, \ldots, (2n-1)\pi$ where $n = 1, 2, 3, \ldots$ • Path difference $\Delta = \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}, \ldots, \frac{(2n-1)\lambda}{2}$ • $A_{min} = a - b$ • $I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2$
3	Resultant intensity at a point is maximum when the phase difference is even multiple of π or path difference is an integral multiple of wavelength λ	Resultant intensity at a point is minimum when the phase difference is odd multiple of π or path difference is an odd multiple of wavelength λ/2

11.Young's Double Slit Experiment-It is the practical verification of interference. In this we get two coherent source by dividing wavefront. We always get bright fringe at the center of the screen and both side alternately bright and dark fringes are made.

a) Fringe width in YDSE-

In$\triangle S_1S_2L$ $\quad \sin\theta = \frac{S_2L}{S_1S_2} = \frac{\triangle}{d}$

Now in $\triangle$DOP $\tan\theta = \frac{x}{D}$

If ɵ is small sinɵ ≈tanɵ ≈ ɵ

So $\frac{\triangle}{d} = \frac{x}{D}$

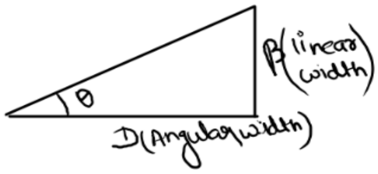
b)Path difference $\quad \triangle = \frac{xd}{D}$

c)Position of n[th] bright fringe $\quad x_n = \frac{nD\lambda}{d}$ where **n=0,1,2,3…**

d)Position of n[th] dark fringe $\quad x_n = \frac{(2n-1)D\lambda}{2d}$ where **n=1,2,3…**

e) Fringe width –Separation between position two consecutive maxima or minima. Width of bright and dark fringe will be same.

$$\boldsymbol{\beta = x_n - x_{n-1} = \beta_{bright} = \beta_{dark} = \frac{\lambda D}{d}}$$



f)Fringe width in medium $\boldsymbol{\beta_{med} = \frac{\beta_{vac}}{\mu}}$

g)Angular width of fringe $\boldsymbol{\theta = \frac{\beta}{D} = \frac{\lambda}{d}}$

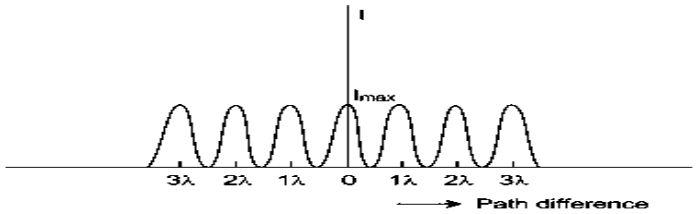
h) overlapping of fringes

if n_1^{th}bright fringe overlapped on n_2^{th} bright fringe then $n_1\lambda_1=n_2\lambda_2$

if bright overlapped dark $n_1\lambda_1=(2n_2 -1)\lambda_2/2$

i)Dependence of fringe width$\beta = \frac{\lambda D}{d}$($\beta \propto \lambda$, $\beta \propto D$, $\beta \propto 1/d$)

j) Intensity distribution curve-

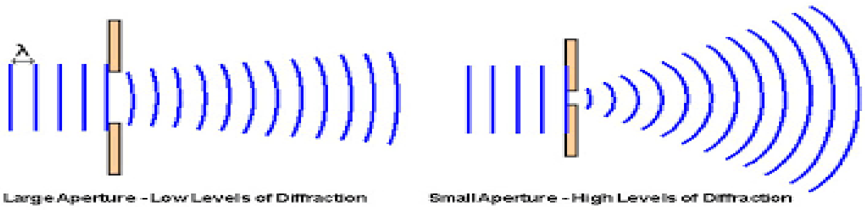


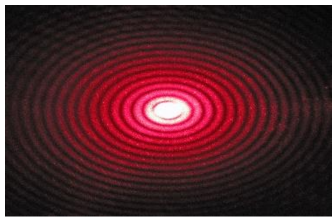
k) Condition for sustained interference-

i)Two source of light must be coherent(ii) Having same frequency (iii)source should be monochromatic (iv)wave must travel in same direction(v) for a better contrast amplitude of waves should be approximately equal

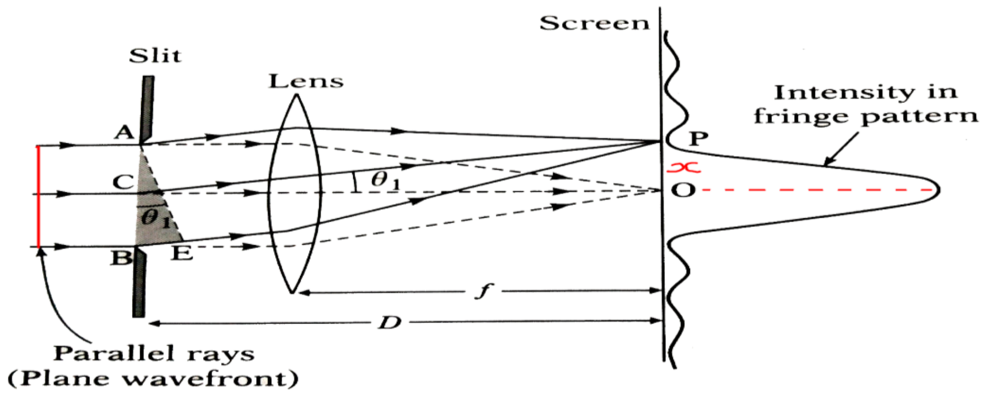
12.Diffraction

It is the phenomena of bending of light around corners of an obstacle or aperture in the path of light. Due to this bending, light goes into the geometrical shadow region of the obstacle or aperture.This bending becomes more when the dimensions of the aperture or the obstacle are comparable of the wavelength of light.





13.Diffraction of light from a single slit-



a) Central maxima-maximum intensity at point o because path difference at o is zero.

b) Path difference $\triangle$**=BP-AP = BE =a sin** θ

c)Position of minima- Position of n^{th} dark fringe

a sin $\theta_n = n\lambda$ where **n =1,2,3…**

d)Position of secondary maxima-

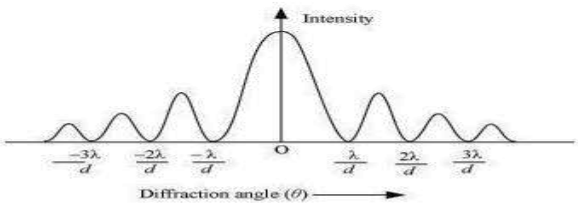
a sin $\theta_n' = (2n+1)\lambda/2$ where **n =1,2,3…**

Note-width of secondary maxima $\alpha \frac{1}{slit\ width}$

e) width of central maxima- the direction of first minima $\theta = \lambda/a$**,** this angle is called half angular width of central maxima **angular width of central maxima =** $2\theta = 2\lambda/a$

f) Linear width of central maxima= 2x or D(2θ) = $2\lambda D/a$

g) Graph



MULTIPLE CHOICE QUESTIONS

1. The resultant amplitude of a vibrating particle by the superposition of the two waves $y_1 = a \sin(\omega t + \pi/3)$ and $y_2 = a \sin \omega t$ is :-
   a) a b) $\sqrt{2}$ a c)2a d)$\sqrt{3}$ a
2. A double slit experiment is performed with light of wavelength 500 nm. A thin film of thickness 2μm and refractive index 1.5 is introduced in the path of the upper beam. The location of the central maximum will

   a) Remain unshifted b)Shift downward by nearly two fringes
   c) Shift upward by nearly two fringe d)Shift downward by 10 fringes
3. Which of following is a true statement, if in Young's experiment, separation between the slits is gradually increased :
   a) fringe width increases and fringes disappear
   b) fringe width decreases and fringes disappear
   c) fringes become blurred
   d) fringe width remains constant and fringes are more bright
4. In an interference of yellow light derived from two slit apertures, if at some point on the screen, yellow light has a path difference of $3\lambda/2$, then the fringe at that point will be :
   a) yellow in colour b) white in colour c)dark d)bright
5. Two beams of light having intensities I and 4I interfere to produce a fringe pattern on a screen. The phase difference between the beam is $\pi/2$ at point A and 2π at point B. Then find out the difference between the resultant intensities at A and B.
   a) 2I b)5I c)I d)4I
6. In an interference pattern of two waves fringe width is β . If the frequency of source is doubled then fringe width will become :
   a) (1/2) β b)β c)2β d)(3/2) β
7. Find the half angular width of the central bright maximum in the Fraunhofer diffraction pattern of a slit of width 12×10^{-5} cm when the slit is illuminated by monochromatic light of wavelength 6000 Å.
   a) 40° b)45° c)30° d)60°
8. A light source of 5000Å wave length produces a single slit diffraction. The first minima in diffraction pattern is seen, at a distance of 5mm from central maxima. The distance between screen and slit is 2metre. The width of slit in mm will be :
   a) 0.1 b)0.4 c)0.2 d)2

SOLUTIONS/HINTS

1.d use the formula $A^2 = A_1^2 + A_2^2 + 2A_1A_2 \cos \phi$

2.bThe optical path difference introduced by the film is (n−1)t, where n is the refractive index and t is the thickness. The central maximum (where the path difference is zero) will shift to a point where the path difference due to the film is compensated by the path difference due to the geometrical shift

Optical path difference introduced by the film $=(1.5-1)\times2\times10^{-6}$ m$=0.5\times2\times10^{-6}$ m$=1\times10^{-6}$ m.

Wavelength $\lambda=500$ nm$=500\times10^{-9}$ m$=0.5\times10^{-6}$ m.

Number of fringes shifted, N=λ Optical path difference$=0.5\times10^{-6}$ m1×10^{-6} m=2.

3.b Use formula, β=λD/d If the separation between the slits (d) is gradually increased, then the fringe width (β) will decrease. As the fringes become narrower, they become harder to distinguish, and eventually, they will disappear

4.c path difference,3λ/2 as $(1 + \frac{1}{2})\lambda$-condition for dark fringe

5.d Use the formula $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \phi$

6.a) use the formula $\beta = \frac{\lambda D}{d} = \frac{cD}{\nu d}$

7.c condition for the first minimum is $a \sin\theta = \lambda$

8.c use the formula $y = \frac{\lambda D}{a}$

ASSERTION-REASON QUESTION

For these Questions two statements are given one labelled Assertion (A) and other labelled Reason (R). Select the correct answer to these questions from the options as given below

A. If both Assertion and Reason are true and Reason is correct explanation of Assertion.
B. If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.
C. If Assertion is true but Reason is false.
D. If both Assertion and Reason are false.

1. **Assertion:** In YDSE if a monochromatic source of light is placed in front of one slit we do not get any interference pattern.
   Reason: in YDSE source shall be placed at equal distance from two slits.
2. **Assertion:** Two equal wavelengths meet at point when coming from opposite direction may give brightest spot at the point of meeting.
   Reason: Two waves moving in opposite directions meet in opposite phase.
3. **Assertion:** The two slits in YDSE are illuminated by two different sodium lamps emitting light of same wavelength. No interference pattern will be observed.
   Reason: Two independent light sources (except LASER) cannot be coherent.
4. **Assertion:** In calculating the disturbance produced by a pair of superimposed incoherent wave trains, you can add their intensities.
   Reason: $I = I_1 + I_2 + 2(I_1 I_2)^{1/2}\cos\Theta$. The average value of cos Θ = 0, for incoherent waves.
5. **Assertion:** Thin films such as soap bubble or thin layer of oil spread on water show beautiful colors when illuminated by white light.
   Reason: It is due to interference of Sun's light reflected from upper and lower surfaces of the film.
6. **Assertion:** In YDSE central fringe may not be a bright fringe.
   Reason: If path difference at central fringe is zero then it will be a bright fringe.
7. **Assertion:** Fringe width in single slit experiment depends upon refractive index of the medium.
   Reason: Refractive index changes optical path of ray of light forming fringe pattern also changes.
8. **Assertion:** In YDSE a monochromatic source of light is placed symmetrically in front of two slits placed in vertical line at small separation. If lower half of the setup is filled with water no pattern is obtained at the screen.
   Reason: Due to water wavelength of light changes hence no pattern is seen.

ANSWERS

1. D, both are wrong, General concept
2. C, Direction of motion do not have definite relation with phase difference
3. D, both are wrong, only coherent sources can produce interference
4. A, can be calculated, Correct explanation
5. A, both are correct, General concept, Correct explanation
6. A, both are correct, General concept, Correct explanation
7. A, β α λ & λ depends on μ, Correct explanation
8. D, both are wrong, no interference but another pattern will be seen

VERY SHORT ANSWER TYPE

1. Three wavelength λ_1, λ_2 & λ_3 are used in YDSE experiment respectively. If N_1, N_2 & N_3 are number of fringes obtained at the screen respectively. If $N_1 - N_2 = 2N_3$ and $3N_3 - N_1 = 2N_2$. Arrange λ_1, λ_2 & λ_3 in ascending order.

2.If a monochromatic source of light is placed symmetrically near two slits of slightly unequal width. Explain pattern of fringes obtained at the screen? How would it be changed if monochromatic source of light is placed asymmetrically?

3.When white light is used in YDSE we say Central band is white surrounded by colored bands with inner edge as red and outer edge violet. justify it, as well as explain pattern of width of fringes obtained.

4.In a single-slit diffraction experiment, the width of the slit is made double the original width. How does this affect the size and intensity of the central diffraction band. What happen if it is made extremely narrow

5.Answer the following questions: (i) In what way is diffraction from each slit related to the interference pattern in a double slit experiment? (ii) When a tiny circular obstacle is placed in the path of light from a distance source, a bright spot is seen at the center of the shadow of the obstacle. Explain, why.

6. (a) The ratio of the widths of two slits in Young's double slit experiment is 4: 1. Evaluate the ratio of intensities at maxima and minima in the interference pattern. (b) Does the appearance of bright and dark fringes in the interference pattern violate, in any way, conservation of energy?

7. Two plane monochromatic waves propagating in the same direction with amplitudes A and 2A and differing in phase by $\pi/3$ superimpose. Calculate the amplitude of resulting wave.

8. Two spectral lines of sodium D_1 and D_2 have wavelengths approximately 5890Åand 5896Å. A sodium lamp sends incident plane wave on to a slit of width 2 micrometer. A screen is located 2m from the slit. Find the spacing between the first maxima of two sodium lines as measured on the screen.

SOLUTIONS/HINTS

1. For same distance,$N_1\lambda_1 = N_2\lambda_2 = N_3\lambda_3$,by solving we get $N_2 = 5N_3$and $N_1 = 7N_3$
   => $N_1 > N_2 > N_3$ => $\lambda_3 > \lambda_2 > \lambda_1$
2. If width is unequal $I_1 \neq I_2$ – Bright and dark fringe (bands) have less contrast
   Central band may not be bright
3. Since white light is a combination of all visible colors, the superposition of all colors at the central maximum results in a bright white band. Also the position of bright fringe is directly proportional to the wavelength of light. Thus, the first order bright fringe will be a spectrum with violet light at the inner edge and red light at the outer edge.
4. For small angles, $\theta \approx \frac{\lambda}{a}$ So, the angular width $\propto \frac{1}{a}$. If the slit width 'a' is doubled, the angular width of the central maximum will be halved. The linear width of the central maximum= $\frac{2\lambda D}{a}$. So, the central band becomes narrower. $I \propto A^2 \propto a^2$ central band becomes four times more intense. If the slit is made extremely narrow (i.e., a≈λ or a<λ), the condition for the first minimum (a sinθ=λ) implies that sin θ becomes large, The intensity of the diffracted light will be very low because the amount of light passing through an

extremely narrow slit is very small or no diffraction takes place if become less than wavelength of light.

5.(i) The observed double-slit interference pattern is actually the interference pattern modulated by the single-slit diffraction pattern.

(ii) Due to the symmetry of the circular obstacle, the diffracted wavelets from all points along the circumference of the obstacle's edge travel the *same optical path length* to the exact center of the shadow. Because they travel the same path length, they arrive in phase at the center of the shadow. This in-phase superposition leads to constructive interference at the exact center of the shadow, resulting in a bright spot.

6. $Itensity \propto width\ of\ slit$ and use the formula $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$ Ans. 9:1

7. Use the formula $A^2 = A_1^2 + A_2^2 + 2A_1A_2\cos\phi$ Ans $A\sqrt{7}$

8. Postion of first maximum for $D_1, y_1 = \frac{3\lambda D}{2a}$ = 0.8835 mm

Postion of first maximum for $D_2, y_2 = \frac{3\lambda D}{2a}$ = 0.8844 mm Ans. 0.0009

SHORT ANSWER TYPE

1. What is the effect on the interference fringes if the monochromatic source is replaced by a source of polychromatic light. In Young's double slit experiment, the two slits 0.15 mm apart are illuminated by monochromatic light of wavelength 450 nm. The screen is 1.0 m away from the slits. (a) Find the distance of the second (i) bright fringe, (ii) dark fringe from the central Maximum.
(b) How will the fringe pattern change if the screen is moved away from the slits?

2. In a modified set-up of Young's double slit experiment, it is given that $SS_2 - SS_1 = \lambda/4$, i.e. the source 'S' is not equidistant from the slits S_1 and S_2.
(a) Obtain the conditions for constructive and destructive interference at any point P on the screen in terms of the path difference $\delta = S_2P - S_1P$.
(b) Does the observed central bright fringe lie above or below 'O'? Give reason to support your answer P_3 .

3.A parallel beam of monochromatic light falls normally on a narrow slit of width 'a' to produce a diffraction pattern on the screen placed parallel to the plane of the slit. Use Huygens' principle to explain that
(i) the central bright maxima is twice as wide as the other maxima.
(ii) the intensity falls as we move to successive maxima away from the centre on either side.

4.(a) Why are coherent sources necessary to produce a sustained interference pattern?
(b) In Young's double slit experiment using mono-chromatic light of wavelength λ , the intensity of light at a point on the screen where path difference is λ, is K units. Find out the intensity of light at a point where path difference is 2λ.

5.Define the term wave front. State Huygen's principle.
Consider a plane wave front incident on a thin convex lens. Draw a proper diagram to show how the incident wave front traverses through the lens and after refraction focuses on the focal point of the lens, giving the shape of the emergent wave front.

6.A coloured alternate bands of diffraction pattern appears on a screen due to a specific wavelength λ passing through a single slit of width 1.5 mm. If this wavelength is replaced with another wavelength 2.5λ and whole apparatus is immersed in a liquid of refractive index 1.2 to what width should you change the slit in order to get the original pattern back? (Ignore effect on focal length of the lens due to change in wavelength or medium)

7.Which of the following statements DOES NOT correctly comply with Huygens' Principle of constructing a secondary wavefront from a primary wavefront? Justify each case?
a) After some time interval, the new position of the wave front is the surface tangent to the secondary wavelets.
b) Secondary wavelets propagate outward through a medium with speeds characteristic of waves in that medium.
c) A secondary wavefront is always a plane wavefront irrespective of whether the primary wavefront is

planar or spherical.

8. (a) In a Young's double slit experiment, the two slits are illuminated by two different lamps having same wavelength of light. Explain with reason, whether interference pattern will be observed on the screen or not.

(b) Light waves of intensities I_o each from two coherent sources arrive at two points on a screen with path differences of $5\lambda/2$ and 5λ. Find the intensities at the points.

SOLUTIONS/HINTS

1. fringes will become coloured near to edge of central band lower wavelength will be seen.

i) Distance of second bright fringe is = $\frac{2\lambda D}{d}$ =6mm

ii) Distance of second dark from central maxima , = $\frac{\lambda D}{2d}$ =1.5mm

iii) Increase since $\beta=\frac{\lambda D}{d}$

2. a) $(SS_2-SS_1)=\Delta=xd/D$, net path difference = $\lambda/4 + xd/D$

For constructive interference $\lambda/4+xd/D=n\lambda$, $(4n-1)\lambda D/4d=(x_n)$bright

for destructive interference , $\lambda/4+xd/D = (2n-1)\lambda D/4d$

(x_n)dark$=(4n-3)\lambda D/4d$

b)For central bright fringe n=0 and hence (x_0)bright$=-\lambda D/4d$. Thus, the observed central bright fringe shifts towards the line of slit S_2 because the optical path of light coming from S_1 will increase.

3. i) Describe single slit exp using wave theory ii) This is because the waves diffracting from different parts of the slit interfere with each other, and the interference pattern creates both bright and dark fringes (minima). The central bright fringe is the brightest and widest, and the intensity of the secondary maxima (bright fringes) decreases as you move further away from the center.

4. a) if sources are not coherent then phase difference will be time varying.

b) phase difference=$\phi=2\pi/\lambda \times 2\lambda= 4\pi$ intensity $I=I_0\cos^2(\frac{\phi}{2})$, I_o=K . so I=K

5. general concepts and definitions, refer gist of the chapter.

6. on immersing the apparatus , wavelength decreases by μ so $\lambda'= \lambda/\mu$,

The angular position of the minima is given by $a\sin\theta=n\lambda$

Since we want the same pattern, the angular positions of the minima must be the same in both wavelength and refractive index. So $n_1\lambda_1= n_2\lambda'$ so $a_1=a_2(2.5/1.2)$, new slit width is 0.72mm.

7. a) It is always perpendicular and not tangential

b) Speed depends on refractive index of the medium.

c) Secondary and primary wavefront are of the same nature always

8. : a) no interference pattern will be observed as the sources are two independent sources.

b) use direct formula and values will be 0 and $4I_o$ respectively.

THREE MARKS QUESTIONS

1. State the essential condition for diffraction of light to take place. Use Huygen's principle to explain diffraction of light due to a narrow single slit and the formation of a pattern of fringes obtained on the screen. Sketch the pattern of fringes formed due to diffraction at a single slit showing variation of intensity with angle θ.

2. Red colour of light of wavelength λ is passed from two narrow slits which are distance *d* apart and interference pattern is obtained on the screen distance *D* apart from the plane of two slits. Then find the answer to following parts assuming that slit widths are equal to produce intensity I_0 from each slit.

a. Intensity at a point on the screen, situated at a distance 1/4 th of fringeseparation from centre.

b. Intensity in the screen, if the sources become incoherent by using twodifferent lamps behind lamps *S*1 and *S*2.

c. Angular position of 10th maxima, and the angular width of that fringe.

d. Find the distance between 5th maxima and 3rd minima, at same side ofcentral maxima.

3. (a) In a diffraction experiment, the slit is illuminated by light of wavelength 600 nm. The first minimum of the pattern falls at $\theta = 30^o$ .Calculate the width of the slit.

(b) Show that the angular width of the first diffraction fringe is half of that of the central fringe.

(c) If a monochromatic source of light is replaced by white light, what change would you observe in the diffraction pattern?

4. (a) In Young's double slit experiment, derive the condition for (i) constructive interference and (ii) destructive interference at a point on the screen.

(b) A beam of light consisting of two wavelengths, 800 nm and 600 nm is used to obtain the interference fringes in a Young's double slit experiment on a screen placed 1.4 m away. If the two slits are separated by 0.28 mm, calculate the least distance from the central bright maximum where the bright fringes of the two wavelengths coincide.

5.Explain Huygen's principle. Name the types of wavefronts that corresponds to a beam of light

(a) coming from a convex lens when point source placed at focus.

(b)coming from very far off source.

(c) coming from a convex lens μ = 1.1 when point source placed at its focus inside water μ= 1.33.

(d)wave front from a distant source fall perpendicular to an equilateral hollow prism placed in side water.

SOLUTIONS/HINTS

1. Essential condition for diffraction: the size of the obstacle or aperture (slit) must be comparable to the wavelength of the light being used. For another part of the question refer the gist of the chapter

2. a) $\Delta x = \frac{yd}{D} = \frac{\lambda}{4}$; $\Phi = \frac{\Pi}{2}$; $I = 4I_0 \cos\frac{\Phi}{2}^2 = 2I_0$

b) No interference pattern observed,$I_{total} = 2I_0$

c)$d sin\,\theta = 10\lambda$, find θ using this formula ; Angular width,$\Delta\theta = \frac{\lambda}{d}$

d) distance = $|y_5 - y_3|$ Ans - $5\lambda D/_{2d}$

3. a) Condition for minima; asin $\theta = n\lambda$ use this formula to find a = 1.2 nm

b) Condition for first minimum, asin $\theta = \lambda$; $\theta_1 = \frac{\lambda}{a}$ $\theta_2 = -\frac{\lambda}{a}$

Angular width=$2\theta_1 = 2\lambda/_a$

c) The central maximum will remain white, secondary maxima will become colored fringes and the overlapping of different colored secondary maxima will increase.

4. a) Refer to the gist of this chapter

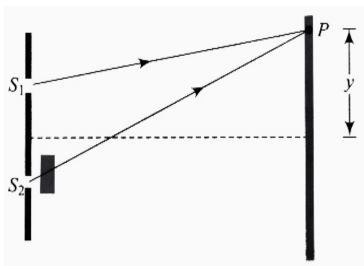
b)Here $y_1 = y_2$ to find the order of the bright fringes. Then calculate the position of this coinciding fringe using both pair of values. Ans:12 mm

5. Refer to the gist of this chapter for Huygen's principle

a) plane wavefronts b) plane wavefronts c) Using lens maker's formula, we will find that lens will behave diverging. So we get diverging wavefront d) Plane wavefront

CASE STUDY/PASSAGE-BASED QUESTIONS

1. Interference of light:- If double slit apparatus is immersed in a liquid of refractive index μ, the wavelength of light reduces to λ/μ and fringe width also reduces to β′=β/μ. The given figure shows a double-slit experiment in which coherent monochromatic light of wavelength A from a distant source is incident upon the two slits, each of width w (w >> λ) and the interference pattern is viewed on a distant screen. A thin piece of glass of thickness t and refractive index n is placed between one of the slit and the screen, perpendicular to the light path.



(i) In Young's double slit interference pattern, the angular fringe width

(a) can be changed only by changing the wavelength of incident light

(b) can be changed only by changing the separation between the two slits

(c) can be changed either by changing the wavelength or by changing the separation between two sources

(d) is a universal constant and hence cannot be changed

(ii) If the width w of one of the slits is increased to 2w, The amplitude due to slit become from a to:

a) 1.5a b)2a c)√2a d)no change

(iii) In YDSE, let A and B be two slits. Films of thicknesses t_A and t_B and refractive indices μ_A and μ_B are placed in front of A and B, respectively. If $\mu_A t_A = \mu_B t_B$ then the central maxima will

(a) not shift (b) shift towards A (c) shift towards B

(d) shift towards A if $t_B > t_A$ and shift towards B if $t_B < t_A$

(iv) In Young's double slit experiment, a third slit is made in between the double slits. Then

(a) fringes of unequal width are formed.

(b) contrast between bright and dark fringes is reduced

(c) intensity of fringes totally disappears

(d) only bright light is observed on the screen

(v) In Young's double slit experiment, if one of the slits is covered with a microscope cover slip, then

(a) fringe pattern disappears

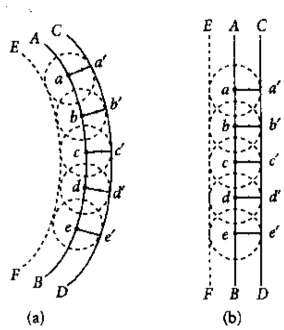
(b) the screen just gets illuminated

(c) in the fringe pattern, the brightness of the bright fringes will decreases and the dark fringes will become more dark

(d) bright fringes will be more bright and dark fringes will become more dark

2. Read the following case/passage and answer the following questions:

Huygen's principle is the basis of wave theory of light. Each point on a wavefront acts as a fresh source of new disturbance, called secondary waves or wavelets. The secondary wavelets spread out in all directions with the speed light in the given medium. An initially parallel cylindrical beam travels in a medium of given refractive index , I is the intensity of the light beam.



(i) The initial shape of the wavefront of the beam from the sun is

(a)Planar (b)convex (c) concave (d)spherical

(ii) According to Huygens Principle, the surface of constant phase is

(a) called an optical ray (b) called a wave

(b) (c) called a wavefront (d) called a wavelet

(iii) As the parallel beam enters the denser medium, it will

(a)becomes narrower (b) diverges (c) converges (d) becomes broader

(iv) Two plane wavefronts of light, one incident on a thin convex lens and another on the refracting face of a thin prism. After refraction at them, the emerging wavefronts respectively become

(a) plane wavefront and plane wavefront (b) plane wavefront and spherical wavefront

(c) spherical wavefront and plane wavefront (d) spherical wavefront and spherical wavefront

(v) Which of the following phenomena support the wave theory of light?

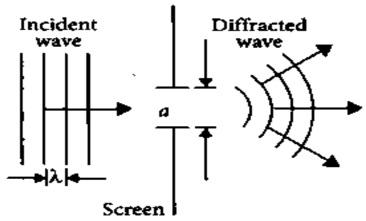
1. Scattering 2.Interference 3.Diffraction

4.Velocity of light in a denser medium is less than the velocity of light in the rarer medium

(a) 1,2,3 (b)1,2,4 (c)2,3,4 (d)1,3,4

3.Read the following case/passage and answer the following questions:

The phenomenon of bending of light around the sharp corners and the spreading of light within the geometrical shadow of the opaque obstacles is called diffraction of light. The light thus deviates from its linear path. The deviation becomes much more pronounced, when the dimensions of the aperture or the obstacle are comparable to the wavelength of light.



(i) Light seems to propagate in rectilinear path because

a) its spread is very large
b) its wavelength is very small
c) reflected from the upper surface of atmosphere
d) it is not absorbed by atmosphere

(ii) In diffraction from a single slit the angular width of the central maxima does not depends on

(a) λ of light used (b)width of slit
(c) distance of slits from the screen (d) ratio of λ and slit width

(iii) For a diffraction from a single slit, the intensity of the central point is

(a) infinite
(b) finite and same magnitude as the surrounding maxima
(c) finite but much larger than the surrounding maxima
(d) finite and substantially smaller than the surrounding maxima

(iv). Resolving power of telescope increases when

(a) wavelength of light decreases (b) wavelength of light increases
(c) focal length of eye-piece increases (d) focal length of eye-piece decreases

(v) In a single diffraction pattern observed on a screen placed at D metre distance from the slit of width d metre, the ratio of the width of the central maxima to the width of other secondary maxima is (approx.)

(a) 2: 1 (b) 1: 2 (c)1: 1 (d)3: 1

Answers: 1 i) c, Direct formula $\theta = \lambda/a$
ii) c, Intensity α Area of slit
iii) d , Solve using Shift = $(\mu-1)tD/d$
iv) b , Third slit also act like a coherent source and contribute in superposition
v) a, It is opaque , we will get lidht from one slit only

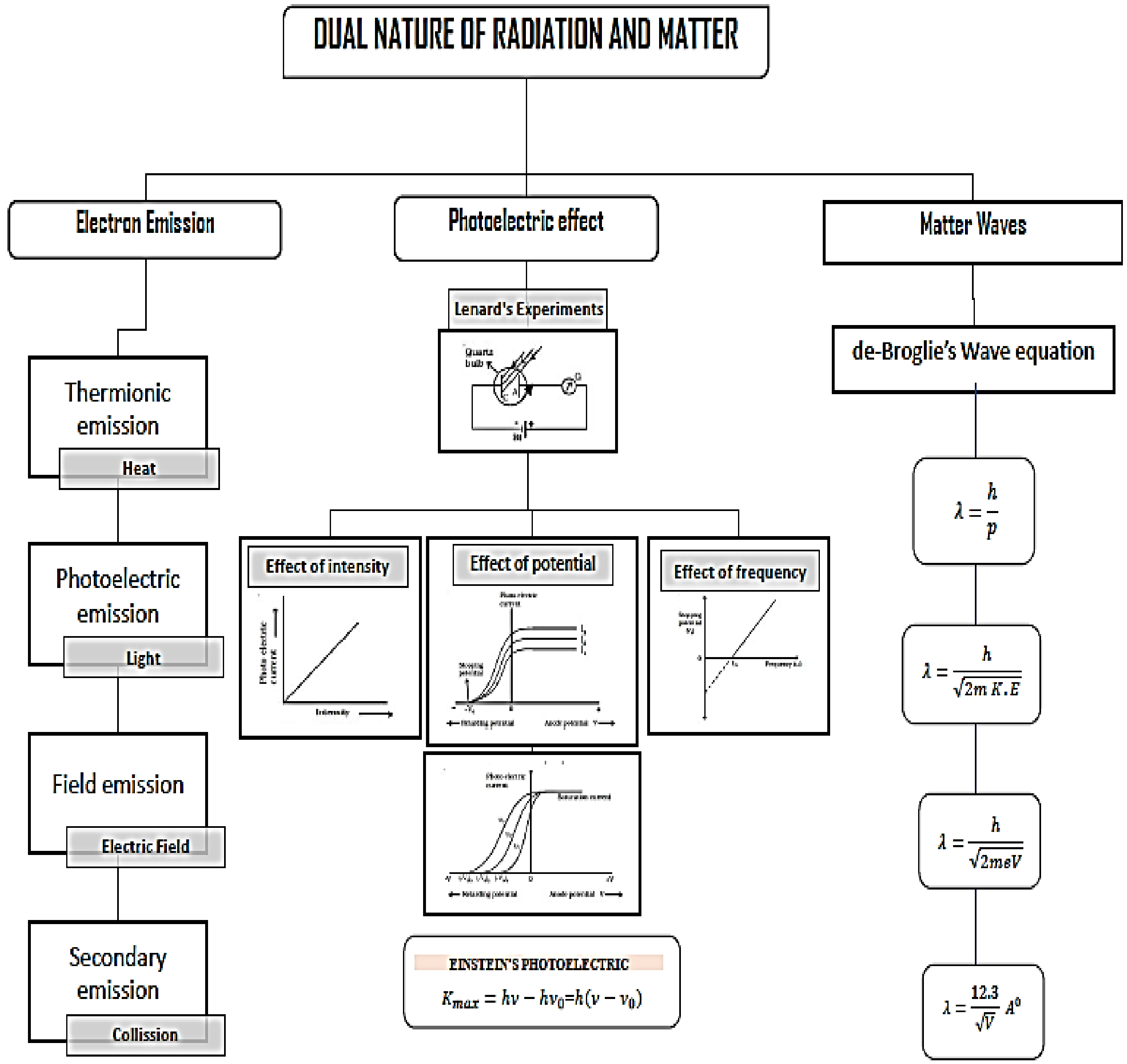
2. i) d, Sun is spherical source ii) c , Definition of wave front
iii) d , Can be seen by diagram iv) c, First is converged , Second remains as it is
v) a, General concept

3. i) a , General concept ii) c , Direct formula $2\theta = 2\lambda/a$
iii) c , General concept iv) a , Resolution α $1/\lambda$
v) a, General concept

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.

MINDMAP



GIST OF THE CHAPTER

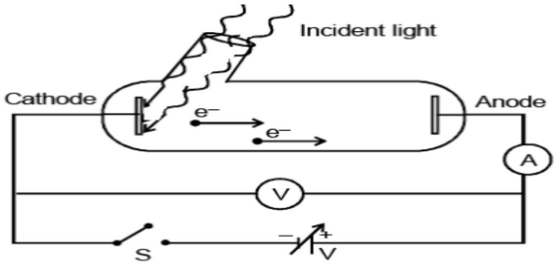
- **Electron Emission:** The phenomenon of emission of electron from a metal surface.

1. Thermionic emission (when metal is heated)
2. Field emission: (by applying very strong electric field to a metal)
3. Photo-electric emission (when light of suitable frequency illuminates a metal surface)

- **Work Function**: The minimum amount of energy required to be given to an electron to escape from the metal surface. It is generally denoted by ϕ_0 and unit is electron volt (eV).

1 eV = 1.602 × 10^{-19} J
Work function of platinum is 5.65 eV (metal having highest work function)
Work function of caesium is 2.14 eV (lowest work function)

- **Photoelectric Effect:** The phenomenon of emission of electrons from the metal surface, when light of suitable frequency illuminates it. (Discovered by Heinrich Hertz)
- **Lenard's Experimental setup:**



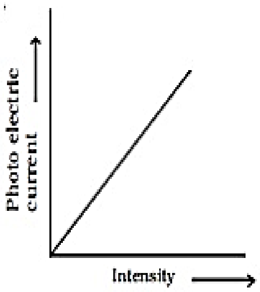
- **Effects on Photoelectric Current**

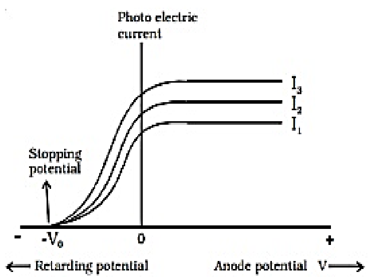
1. Effect of intensity: Photoelectric current increases linearly with intensity of incident light, keeping frequency and voltage constant.
2. Effect of potential.

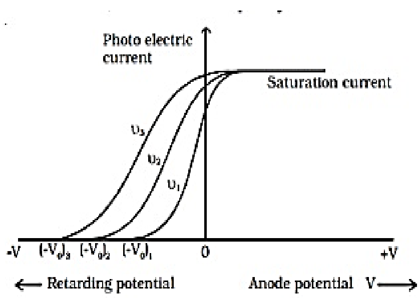
▪ Increasing positive potential increases current until saturation.
▪ Negative retarding potential decreases current. At a certain negative voltage (stopping potential), current becomes zero.
▪ Stopping Potential (V_0): Minimum negative potential to stop photoelectric current for a given frequency. - Independent of intensity, depends only on frequency. - Kinetic energy and stopping potential: $K_{max} = eV_0$

3. Effect of frequency:

▪ Greater frequency → greater stopping potential → greater K_{max}
▪ Saturation current remains same (constant intensity)







Laws of Photoelectric Effect

1. Photoelectric current ∝ intensity of radiation (fixed frequency)
2. Saturation current ∝ intensity; stopping potential is independent of intensity.
3. No emission occurs below threshold frequency (ν_0).
4. K_{max} ∝ frequency of incident radiation (ν); independent of intensity.
5. Photoelectric emission is instantaneous (delay ≈ 10^{-9} s)

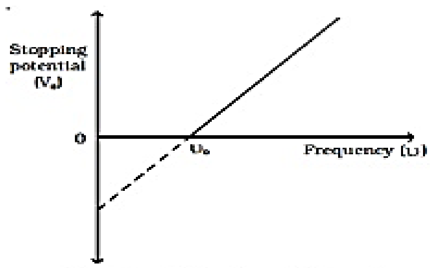
- **Failure of Classical Theory:** Wave theory predicts electron absorbs energy continuously.

Contradictions: a. K_{max} should depend on intensity (observed: depends on frequency)
b. Any frequency should cause emission (observed: only above threshold frequency)
c. Should be delayed process (observed: instantaneous)

- **Einstein's Photoelectric Equation**: Photon energy = $h\nu = K_{max} + \phi_0 \Rightarrow K_{max} = h(\nu - \nu_0)$

▪ Explanation Laws of Photoelectric Effect:
- Intensity increases photon number → increases current. - $\nu < \nu_0$ →negative K which is impossible → no emission. - Photon-electron interaction is instantaneous → no time lag.

▪ Graph (freq vs Stopping potential) : $V_0 = (h/e)\nu - \phi_0/e$ → straight line. Slope = h/e, y-intercept = $-\phi_0/e$



Particle Nature of Light

▪ Light interacts with matter as photons.

- Photon energy: hν, momentum: hν/c
- Photon: no charge, not deflected by E or B fields
- Photon collisions conserve energy and momentum, but number of photons may change.
- Compton scattering confirmed particle nature of light.

- **Dual Nature of Radiation**

- Wave nature: Interference, diffraction, polarisation. - Particle nature: Photoelectric effect, Compton scattering. ⇒ Light shows wave-particle duality

- **Dual Nature of Matter:** Louis de Broglie (1924) proposed particles have wave nature.

- de-Broglie Equation: $\lambda = h/p = h/mv = h/\sqrt{2mK} = h/\sqrt{2meV}$
- Davisson-Germer experiment confirmed electron wave nature experimentally.

MULTIPLE CHOICE QUESTIONS

1. Which of the following cannot be observed by an increase in the intensity of light alone?
   (A) Increase in photocurrent (B) Increase in stopping potential
   (C) Increase in number of emitted electrons (D) Increase in rate of emission
2. In an experiment, intensity of light is increased but photoelectric current remains constant after sometime. This is due to:
   (A) saturation current has been reached
   (B) frequency of light is below threshold
   (C) work function is larger than incident photon energy
   (D) electrons are absorbed back
3. The photoelectric current becomes zero when:
   (A) The intensity of light is zero (B) Frequency is below the threshold
   (C) Work function is very high (D) Any of the above
4. In a photoelectric experiment with light of intensity I, the current is I_0. When light is filtered to allow only 50% photons through, the current becomes:
   (A) $2\ I_0$ (B) $I_0/2$ (C) $\sqrt{2}\ I_0$ (D) Remains same
5. Consider a photoelectric tube where magnitude of negative anode potential is gradually increased. The photoelectric current decreases to zero because:
   (A) Kinetic energy of electrons is reduced
   (B) All photons are absorbed
   (C) Potential suppresses even fastest electrons
   (D) Frequency becomes less than threshold
6. In an experiment, when frequency is increased, the stopping potential increases linearly. This verifies:
   (A) Planck's quantization (B) de Broglie relation
   (C) Einstein's photoelectric equation (D) Wave-particle duality
7. Which observation supports the quantum nature of light?
   (A) Instantaneous emission (B) KE ∝ frequency
   (C) Threshold frequency exists (D) All of the above
8. In photoelectric emission, a radiation whose frequency is 2 times threshold frequency of a certain metal is incident on the metal. Then the maximum possible velocity of the emitted electron will be:
   (A) $\sqrt{\frac{h\nu_0}{m}}$ (B) $\sqrt{\frac{2h\nu_0}{m}}$ (C) $2\sqrt{\frac{h\nu_0}{m}}$ (D) $\sqrt{\frac{6h\nu_0}{m}}$
9. For two particles with equal momenta, which of the following is true regarding their de Broglie wavelengths?
   (A) The heavier particle has smaller wavelength (B) Both have same wavelength
   (C) The faster particle has smaller wavelength (D) Depends on nature of the particles

ANSWERS

1. (B) The stopping potential is determined by the energy of the photons, which is related to their frequency, not their intensity.
2. (A) When intensity increases, more photons hit the metal, but once all available electrons are ejected, the current cannot increase further.
3. (D)
4. (B) The current in the photoelectric effect is proportional to the number of emitted electrons, which in turn depends on the number of photons hitting the metal. Reducing the number of photons to 50% will halve the number of emitted electrons, thus halving the current.
5. (C) As the stopping potential increases, it eventually becomes strong enough to prevent even the fastest emitted electrons from reaching the anode, causing the photoelectric current to drop to zero.
6. (C) Einstein's photoelectric equation shows that the kinetic energy (and hence stopping potential) of photoelectrons increases linearly with the frequency of incident light. This linear relationship confirms the equation $K_{max} = h(\nu - \nu_0)$.
7. (D)
8. (B) $KE = h\nu - h\nu_0 = 2h\nu_0 - h\nu_0 = h\nu_0$; $\frac{1}{2}mv_{max}{}^2 = h\nu_0$

$$Maximum\ velocity = \sqrt{\frac{2h\nu_0}{m}}$$

9. (B) $\lambda_1 = \frac{h}{p_1}$ and $\lambda_2 = \frac{h}{p_2}$ Given: $p_1 = p_1 \Rightarrow \lambda_1 = \lambda_2$

ASSERTION & REASON TYPE QUESTIONS

1. **Assertion:** In an experiment, two monochromatic light beams of the same frequency but different intensities are incident on identical photo-emissive surfaces. The beam with higher intensity results in greater photoelectric current.
   Reason: Higher intensity implies more photons per unit time, which increases the number of emitted photoelectrons even though their energy remains unchanged.
2. **Assertion:** At a fixed frequency above the threshold, doubling the intensity of light doubles the stopping potential.
   Reason: Stopping potential is proportional to the energy of the photoelectrons, which increases with intensity.
3. **Assertion:** In a photoelectric experiment, even when a very high positive potential is applied to the collector plate, the photoelectric current eventually saturates.
   Reason: The number of photoelectrons emitted depends only on the intensity of the incident light and not on the applied potential.
4. **Assertion**: Even when monochromatic light falls on a metal surface, the emitted photoelectrons have varying kinetic energies.
   Reason: Electrons originating from within the metal lose part of their energy due to collisions with other atoms before escaping the surface.
5. **Assertion:** If frequency is below threshold, increasing light intensity results in emission of photoelectrons.
   Reason: Higher intensity photons can collectively give enough energy to an electron to escape.
6. **Assertion:** A time delay is observed before photoelectrons are emitted from a metallic surface under light exposure.
   Reason: According to Einstein's theory, electrons take time to absorb sufficient energy from the incoming wavefront.
7. **Assertion:** A heavier particle moving slowly can have a longer de Broglie wavelength than a lighter

particle.

Reason: The de Broglie wavelength is independent of the particle's mass and velocity.

8. **Assertion:** An infinite time delay is observed when light of frequency less than the threshold is incident on a metal surface.

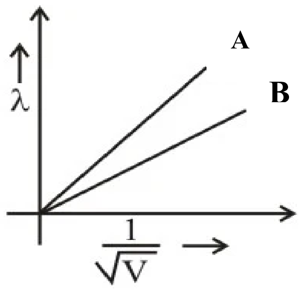
   Reason: According to Einstein's theory, electrons need to accumulate energy over time from multiple photons to be emitted.

ANSWERS

1. **(A)** – Higher intensity means more photons, hence more photoelectrons and current.
2. **(D)** – Stopping potential depends on photon energy, not intensity.
3. **(A)** – Current saturates due to limited photoelectrons; intensity controls emission.
4. **(A)** – When a light of single frequency falls on the electrons of inner layer of metal, then this electron comes out of the metal surface after a large number of collisions with atom of it's upper layer.
5. **(D)** – No emission below threshold frequency, regardless of intensity.
6. **(D)** – No time delay; photons transfer energy instantly.
7. **(C)** – $\lambda \propto 1/p$, depends on mass and velocity; reason is false.
8. **(C)** – Below-threshold frequency causes no emission, but energy can't be accumulated over time per Einstein's theory.

VERY SHORT ANSWER TYPE QUESTIONS (2 MARKS)

1. Find the change in energy of a photon of red light (λ= 700 A^0) when the light enters glass medium of refractive index 1.5 from air.
2. Two lines, A and B, in the plot given below show the variation of de-Broglie wavelength, λ versus $\frac{1}{\sqrt{V}}$, where V is the accelerating potential difference, for two particles carrying the same charge. Which one of two represents a particle of smaller mass?



3. An electron, an alpha particle and a proton have the same kinetic energy, which one of these particles has (i) the shortest and (ii) the largest, de, Broglie wavelength?
4. An electron is accelerated through a potential difference of 100 volts. What is the de-Broglie wavelength associated with it? To which part of the electromagnetic spectrum does this value of wavelength correspond?
5. If an electron has a wavelength, does it also have a colour?
6. A parallel beam of monochromatic light of wavelength 663 nm is incident on a totally reflecting plane mirror. The angle of incidence is 60° and the number of photons striking the mirror per second is 1.0×10^{19}. Calculate the force exerted by the light beam on the mirror.
7. Ultraviolet radiations of different frequencies ν_1 and ν_2, are incident on two photosensitive materials having work functions W_1 and W_2 ($W_1 > W_2$) respectively. The kinetic energy of the emitted photoelectrons is same in both the cases. Which one of the two relations will be of the higher frequency?
8. Electrons are emitted from the surface when green light is incident on it, but no electrons are ejected when yellow light is incident on it. Do you expect electrons to be ejected when surface is exposed to (i) Red light and (ii) Blue light?
9. de-Broglie wavelength associated with an electron accelerated through a potential difference V is λ. What will be the de Broglie wavelength when the accelerating potential is increased to 4V?

ANSWERS

1. The energy of a photon is given by: $E = {hc}/{\lambda}$

When light enters a medium like glass, its speed and wavelength change, but frequency remains the same, and so does the energy of the photon. Therefor change in energy = 0

2. For a particle accelerated by a potential V, the de-Broglie wavelength is:

$\lambda = \frac{h}{\sqrt{2mqV}}$ ∴ $\lambda \propto \frac{1}{\sqrt{m}}.\frac{1}{\sqrt{V}}$

So, when we plot λ versus $\frac{1}{\sqrt{V}}$, the slope is $\frac{1}{\sqrt{m}}$. Larger slope ⇒ smaller mass.

Line A has more slope than B ⇒ Particle A has smaller mass

3. $\lambda = \frac{h}{\sqrt{2mK}}$

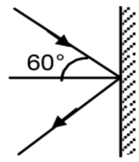
If the KE is same then: $\lambda \propto \frac{1}{\sqrt{m}}$ ⇒ Hence, α – particle has the shortest de Broglie wavelength and electron has the longest wavelength.

4. $\lambda = \frac{12.27}{\sqrt{V}} = \frac{12.27}{\sqrt{100}} = 1.227\ A°$. This wavelength corresponds to X-rays.

5. Colour is a characteristic of electromagnetic waves. Electrons behave as a de- Broglie wave because of their velocity. A de-Broglie wave is not an electromagnetic wave and is one dimensional. Hence, no colour is shown by an electron.

6. $\lambda = 663 \times 10^{-9}$ m, $\theta = 60°$ n = 1×10^{19},

$\lambda = \frac{h}{p} \Rightarrow p = \frac{h}{\lambda} = 10^{-27}$



Force exerted on the wall = n(mvcosθ − (−mvcosθ)) = 2n mvcosθ = 2n pcosθ

$= 2 \times 1 \times 10^{19} \times 10^{-27} \times ½ = 1 \times 10^{-8}$ N.

7. According to Einstein's photoelectric equation, kinetic energy of photoelectrons,

$$K = h\nu - W$$

As E_k is same, $h\nu_1 - W_1 = h\nu_2 - W_2 \Rightarrow h\nu_1 - h\nu_2 = W_1 - W_2$

$$\Rightarrow \nu_1 - \nu_2 = \frac{W_1 - W_2}{n}$$

As, $W_1 > W_2$, $\nu_1 > \nu_2$ That is, frequency of radiation ν_1 is higher.

8. The wavelength of red light is longer than threshold wavelength, hence no electron will be emitted with red light. The wavelength of blue light is smaller than threshold wavelength, hence electrons will be ejected.

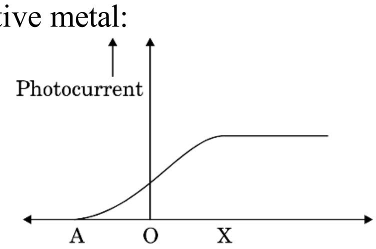
9. de Broglie wavelength associated with electron is,

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

∴ $\lambda \propto \frac{1}{\sqrt{V}}$ ⇒ when accelerating potential becomes 4V, the de-Broglie wavelength reduces to half.

SHORT ANSWER TYPE QUESTIONS (3 MARKS)

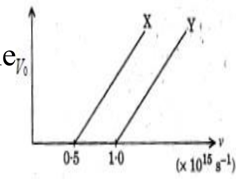
1. The following graph shows the variation of photocurrent for a photosensitive metal:
   a) Identify the variable X on the horizontal axis.
   b) What does the point A on the horizontal axis represent?
   c) Draw this graph for three different values of frequencies of incident radiation ν_1, ν_2 and ν_3 ($\nu_1 > \nu_2 > \nu_3$) for same intensity.
   d) Draw this graph for three different values of intensities of incident radiation I_1, I_2, and I_3 ($I_1 > I_2 > I_3$) having same frequency.



2. In a plot of photoelectric current versus anode potential, how does?
   a) The saturation current vary with anode potential for incident radiations of different frequencies but same intensity?
   b) The stopping potential vary for incident radiations of different intensities but same frequency?
   c) Photoelectric current vary for different intensities but same frequency of incident radiations?

Justify your answer in each case.

3. The following graph shows the variation of stopping potential V_0 with the frequency ν of the incident radiation for two photosensitive metals X and Y:



   a) Which of the metals has larger threshold wavelength? Give reason.
   b) Explain, giving reason, which metal gives out electrons, having larger kinetic energy, for the same wavelength of the incident radiation.
   c) If the distance between the light source and metal X is halved, how will the kinetic energy of electrons emitted from it change? Give reason.
4. Two neutral particles are kept 1m apart. Suppose by some mechanism some charge is transferred from one particle to the other and the electric potential energy lost is completely converted into a photon. Calculate the longest and the next smaller wavelength of the photon possible.
5. Why do different metals emit electrons only when exposed to light of certain minimum frequencies? The threshold frequency of a metal is f_0. When the light of frequency $2f_0$ is incident on the metal plate, the maximum velocity of electrons emitted is v_1 . When the frequency of the incident radiation is increased to $5f_0$ the maximum velocity of electrons emitted is v_2. Find the ratio of v_1 to v_2.
6. An electron and a photon each have a wavelength 1.00 nm. Find:
   a) Their momenta, b) The energy of the photon and,
   c) The kinetic energy of electron
7. Explain by giving reasons for the following:
   a) Photoelectric current in a photocell increases with the increase in the intensity of the incident radiation.
   b) The stopping potential (V_0) varies linearly with the frequency (ν) of the incident radiation for a given photosensitive surface with the slope remaining the same for different surfaces.
   c) Maximum kinetic energy of the photoelectrons is independent of the intensity of incident radiation.

ANSWERS

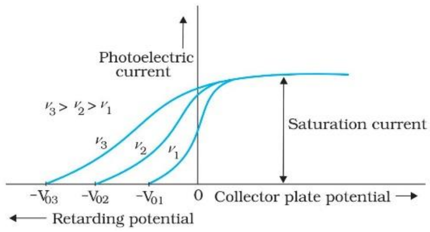
*(*Substitute the values for quantities before final answer in each numerical question*)

1.

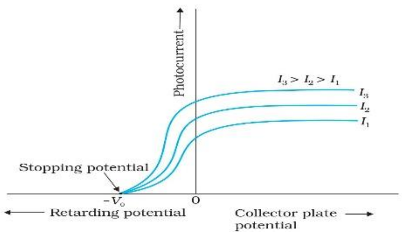
a. X is collector plate potential.

b. A is stopping potential.

c. Graph for different frequencies.

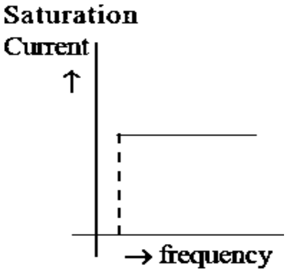


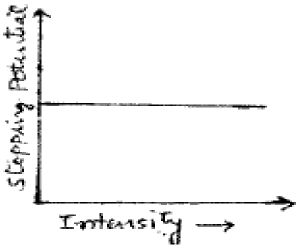
d. Graph for three different Intensities

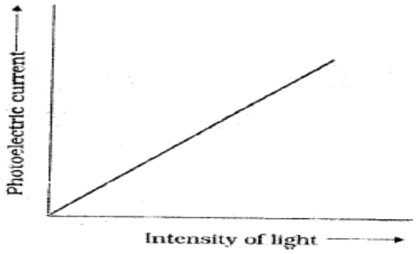


2.

i. Saturation current does not change. ii. Stopping potential does not change. iii. Photoelectric current increases with increase in intensity.







3.
   a) 'X' as it has smaller threshold frequency.
   b) $KE_{max} = h\nu - \phi_0$
   Since $\phi_y > \phi_x \Rightarrow K_y < K_x$ therefore 'X' gives out electrons with larger KE.
   c) No change as KE of photoelectron does not depend on the intensity of incident radiations.

4. r = 1m
   Potential Energy= $\frac{kq^2}{r} = \frac{kq^2}{1}$, Energy of photon=$\frac{hc}{\lambda} = \frac{kq^2}{1} \Rightarrow \lambda = \frac{hc}{kq^2}$
   For max λ, 'q' should be min, i.e q = e = 1.6×10^{-19} C
   Substituting we get, $\lambda_{max} = 863\ m$
   For next smaller wavelength, $q = 2e$ and $\lambda = {}^{863}/_{4} = 215.74\ m.$

5. There is minimum energy required to free an electron from its surface binding called work function.
   Einstein's photoelectric equation is $h\nu = h\nu_0 + \frac{1}{2}mv^2$
   In first case $\nu = 2f_0$, $\nu_0 = f_0$, $v = v_1$
   $$\mathbf{h(2f_0) = hf_0 + \frac{1}{2}m\,v_1^2 \Rightarrow \frac{1}{2}m\,v_1^2 = hf_0}$$
   Similarly in second case we get, ${}^{1}/_{2}m\,v_2^2 = 4hf_0$
   Dividing both we get, $\frac{v_1}{v_2} = \sqrt{\frac{hf_0}{4hf_0}} = \frac{1}{2}$

6. $\lambda_e = \lambda_{photon} = 1.00\text{nm} = 10^{-9}\text{m}.$
   a) For electron or photon, momentum p =$\frac{h}{\lambda} = \frac{6.63\times10^{-34}}{10^{-9}} = 6.63 \times 10^{-25}$ kg m/s
   b) Energy= $\frac{hc}{\lambda}$ = 19.89×10^{-17} J (≈ 124 eV)
   c) Kinetic energy of electron= $\frac{p^2}{2m} = 2.42 \times 10^{-19}J = 1.51\ eV$

7. a) The collision of a photon can cause emission of a photoelectron (above the threshold frequency). As intensity increases, number of photons increases. Hence the current increases.
   b) We have, $eV_s = h(\nu - \nu_o)$
   $$V_s = \frac{h}{e}\nu + (-\frac{h}{e})\nu_o$$
   ∴ Graph of V_s with ν is a straight line and slope (h/e) is a constant.
   c) According to Einstein's photoelectric equation ($KE_{max} = h\nu - \phi_0$), KE is independent of intensity.

CASE STUDY BASED QUESTIONS (4 MARKS)

Case Study: Smart Door Lock with Fingerprint Scanner

1. In modern homes and offices, smart biometric door locks that use fingerprint scanning have become popular. These devices work based on the photoelectric effect, a concept that demonstrates the dual nature of radiation. When you place your finger on the scanner, a beam of light, usually from a laser or LED source, illuminates your fingerprint. The light consists of photons (particles of light) that strike the surface of the finger. The ridges and valleys of the fingerprint reflect this light differently. Some parts absorb the photons, while others reflect them back to a sensor.

Inside the sensor, semiconducting materials absorb the incident photons, causing electrons to be emitted from their surface—this is the photoelectric effect. These emitted electrons generate a current that the device reads as a specific digital signal, unique to your fingerprint. This process is not explainable by the wave theory of light alone, and instead demonstrates light's particle nature.

i. **Why can't the wave theory of light alone explain the working of fingerprint scanners based on the photoelectric effect?**
(A) The wave theory fails to explain reflection of light.
(B) The wave theory does not account for the threshold frequency required to emit electrons.
(C) The wave theory suggests light can't interact with electrons.
(D) The wave theory explains the continuous emission of light, not its speed.

ii. **What would happen if the intensity of light increased but its frequency remains below the threshold frequency in a fingerprint scanner?**
(A) More electrons would be emitted with higher energy.
(B) The fingerprint image would become clearer.
(C) Electrons would emit with the same energy as before.
(D) The emission of electrons would not occur.

iii. **How does the concept of de Broglie wavelength support the miniaturization and efficiency of the fingerprint scanner's electronic components?**
(A) By allowing light to be diffracted and focused more accurately.
(B) By explaining how heat is dissipated in semiconductors.
(C) By enabling high-resolution imaging using wave properties of electrons.
(D) By reducing the speed of electron movement in circuits.

iv. **Which technological limitation would most directly challenge the use of wave nature of electrons in fingerprint sensor development?**
(A) Requirement for extremely small de Broglie wavelengths for high resolution
(B) Slow scanning speed
(C) Difficulty in focusing particle beams
(D) Interference from ambient light

OR

Suppose a new fingerprint scanner is designed using blue light instead of red light. What would be the most likely outcome regarding the photoelectric effect?
(A) The emitted electrons would have lower kinetic energy.
(B) The emission of electrons would decrease due to lower intensity.
(C) The emitted electrons would have higher kinetic energy due to higher photon frequency.
(D) The resolution of the scanner would decrease.

ANSWERS:

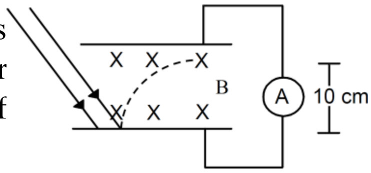
1. Ans: i) B ii) D iii) C iv) A or C

LONG ANSWER TYPE QUESTIONS (5 Marks)

1. a) Light of a particular wavelength does not eject electrons from the surface of a given metal. Should the wavelength of the light be increased or decreased in order make ejection of electrons possible? Justify.

b) In an experiment on photoelectric effect, the emitter and the collector plates are placed at a separation of 10 cm and are connected through an ammeter without any cell. A magnetic field B exists parallel to the plates.

The work function of the emitter is 2.39 eV and the light incident on it has wavelengths between 400 nm and 600 nm. Find the minimum value of B for which the current registered by the ammeter is zero. Neglect any effect of space charge.



2. a) A particle of mass M at rest decays into two particles of masses m_1 and m_2 having non-zero velocities. What is the ratio of de Broglie wavelengths of the two particles?

   b) Determine the value of the de Broglie wavelength associated with the electron orbiting in the ground state of hydrogen atom. How will the de Broglie wavelength change when it is in the first excited state?

ANSWERS

1. a) The wavelength should be decreased because photon energy is inversely proportional to wavelength ($E=hc/\lambda$). Decreasing the wavelength increases the energy of incident photons, making it possible to overcome the metal's work function and eject electrons.

b) $\phi_0 = 2.39$ev $\lambda_1 = 400$ nm, $\lambda_2 = 600$ nm

for B to be minimum, energy should be maximum $\therefore \lambda$ should be minimum (i.e. λ_1)

$$K = \frac{hc}{\lambda} - \phi_0 = 3.105 - 2.39 = 0.715\ eV = 1.144 \times 10^{-19} J$$

The presence of magnetic field will bend the beam and there will be no current if the electron does not reach the other plate.

$$r = \frac{mv}{qB} = \frac{\sqrt{2mK}}{qB} \Rightarrow B = \frac{\sqrt{2mK}}{qr} = \frac{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.144 \times 10^{-19}}}{1.6 \times 10^{-19} \times 0.1} = 2.85 \times 10^{-5}\ \text{T}$$

2. a) According to the law of conservation of momentum, the momentum of a system remains conserved.

$$Mv = m_1v_1 + m_2v_2 \Rightarrow 0 = m_1v_1 + m_2v_2 \Rightarrow m_1v_1 = -m_2v_2$$

   So, we can write, $p_1 = p_2 \Rightarrow \frac{hc}{\lambda_1} = \frac{hc}{\lambda_2} \Rightarrow \frac{\lambda_1}{\lambda_2} = 1$

   b) In ground state, the kinetic energy of the electron is, $K = 13.6\ eV = 2.18 \times 10^{-18} J$

$$\lambda_0 = \frac{h}{\sqrt{2mK}} = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 2.18 \times 10^{-18}}} = 3.32 \times 10^{-10}\ m$$

   In the first excited state, $K = \frac{13.6}{2^2} = \frac{13.6}{4}$ so we get $\lambda_1 = 2 \times \lambda_0 = 6.64 \times 10^{-10}\ m$

CHAPTER–12: ATOMS

Content: 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).

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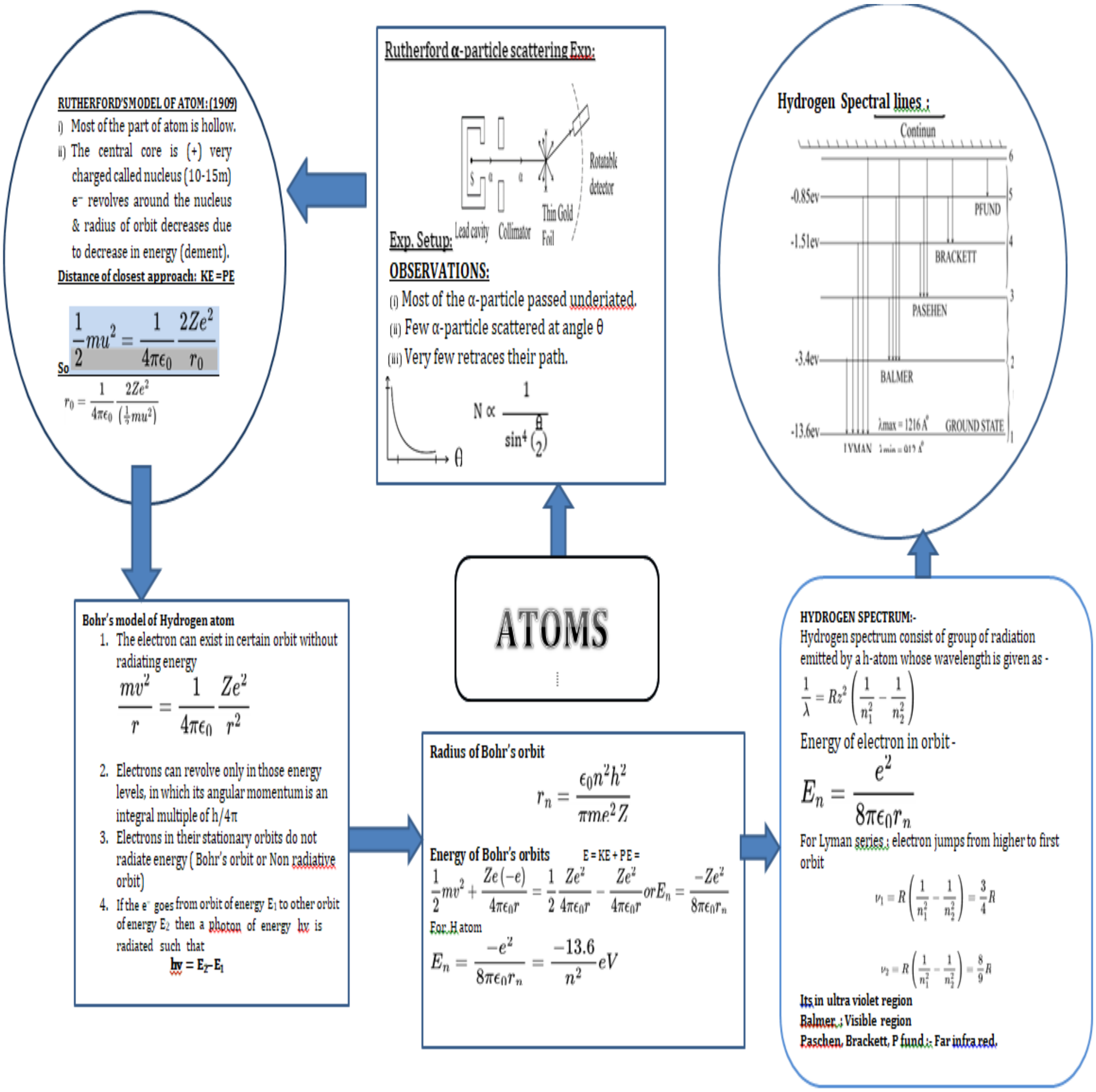


GIST OF CHAPTER: ATOMS

Rutherford's Atomic Model

On the basis of this experiment, Rutherford made following observations

(i)The entire positive charge and almost entire mass of the atom is concentrated at its centre in a very tiny region of the order of 10-15 m, called nucleus.

(ii)The negatively charged electrons revolve around the nucleus in different orbits.

(iii)The total positive charge 011 nucleus is equal to the total negative charge on electron. Therefore atom as a overall is neutral.

(iv)The centripetal force required by electron for revolution is provided by the electrostatic force of attraction between the electrons and the nucleus.

Distance of Closest Approach

$r_o = 1 / 4\pi \varepsilon o . 2Ze2 / E_k$ where, E_k = kinetic energy of the cc-particle.

Impact Parameter

The perpendicular distance of the velocity vector of a-particle from the central line of the nucleus, when the particle is far away from the nucleus is called impact parameter.

Impact parameter

where, Z = atomic number of the nucleus, E_k = kinetic energy of the c- particle and θ = angle of scattering.

Rutherford's Scattering Formula

where, N(θ) =number of c-particles, Ni = total number of α-particles reach the screen. n = number of atoms per unit volume in the foil, Z = atoms number, E = kinetic energy of the alpha particles and t = foil thickness

Limitations of Rutherford Atomic Model

(i)About the Stability of Atom According to Maxwell's electromagnetic wave theory electron should emit energy in the form of electromagnetic wave during its orbital motion. Therefore. radius of orbit of electron will decrease gradually and ultimately it will fall in the nucleus. (ii) About the Line Spectrum Rutherford atomic model cannot explain atomic line spectrum.

Bohr's Atomic Model

Electron can revolve in certain non-radiating orbits called stationary or bits for which the angular momentum of electron is an integer multiple of (h / 2π)

$$mvr = nh / 2\pi$$

where n = I, 2. 3,… called principle quantum number.The radiation of energy occurs only when any electron jumps from one permitted orbit to another permitted orbit. Energy of emitted photon

$hv = E_2 - E_1$ where E1 and E2are energies of electron in orbits.

Radius of orbit of electron is given by $r = n^2h^2 / 4\pi^2 mK Ze2 \Rightarrow r \propto n^2 / Z$

where, n = principle quantum number, h = Planck's constant, m = mass of an electron,

K = 1 / 4 π ε, Z = atomic number and e = electronic charge.

Velocity of electron in any orbit is given by $v = 2\pi KZe^2 / nh \Rightarrow v \propto Z / n$

Frequency of electron in any orbit is given by $v = KZe^2 / nhr = 4\pi^2Z^2e^4mK^2 / n3\ h^3$

⇒ v prop; $Z3 / n^3$

Kinetic energy of electron in any orbit is given by $E_k = 2\pi^2me^4Z^2K2 / n^2\ h2 = 13.6\ Z^2 / n^2$ eV

Potential energy of electron in any orbit is given by

$E_p = - 4\pi^2me^4Z^2K^2 / n^2\ h^2 = 27.2\ Z^2 / n^2 \quad \Rightarrow Ep = \propto Z^2 / n^2$

Total energy of electron in any orbit is given by $E = - 2\pi^2me^4Z2K^2 / n^2\ h^2 = - 13.6\ Z2 / n^2$ eV

$\Rightarrow Ep = \propto Z^2 / n^2$ In quantum mechanics, the energies of a system are discrete or quantized. The energy of a particle of mass m is confined to a box of length L can have discrete values of energy given by the relation $En = n^2\ h2 / 8mL2$; n < 1, 2, 3,…

Hydrogen Spectrum Series

Each element emits a spectrum of radiation, which is characteristic of the element itself. The spectrum consists of a set of isolated parallel lines and is called the line spectrum.

Hydrogen spectrum contains five series **(i) Lyman Series** When electron jumps from n = 2, 3,4, …orbit to n = 1 orbit, then a line of Lyman series is obtained. This series lies in ultra violet region.

(ii)Balmer Series When electron jumps from n = 3, 4, 5,… orbit to n = 2 orbit, then a line of Balmer series is obtained. This series lies in visual region.

(iii)Paschen Series When electron jumps from n = 4, 5, 6,… orbit to n = 3 orbit, then a line of Paschen series is obtained. This series lies in infrared region

(iv)Brackett Series When electron jumps from n = 5,6, 7…. orbit to n = 4 orbit, then a line of Brackett series is obtained. This series lies in infrared region.

(v)Pfund Series When electron jumps from n = 6,7,8, … orbit to n = 5 orbit, then a line of Pfund series is obtained. This series lies in infrared region.

MCQ WITH SOLUTION - ATOMS

1. When alpha particles are sent through a thin gold foil, most of them go straight through the foil, because
   (a) Alpha particles are positively charged
   (b) Mass of alpha particle is more than mass of electron
   (c) Most of the part of an atom is empty space
   (d) Alpha particles moves with high velocity
2. In an experiment of scattering of alpha particle showed for the first time that the atom has,
   (a) Electron (b) Proton (c) Neutron (d) Nucleus
3. In Geiger Marsden experiment, the expression of distance of closest approach to the nucleus of a alpha particle before it comes to momentarily at rest and reverse its direction is,
   (a) $\frac{Ze^2}{4\pi\epsilon_0 k}$ (b) $\frac{Ze^2}{2\pi\epsilon_0 k}$ (c) $\frac{Ze^2}{2\epsilon_0 k}$ (d) $\frac{Ze^2}{4\epsilon_0 k}$
4. The angular momentum of the electron in the nth allowed orbit is;
   (a) $\frac{Ph}{2\pi}$ (b) $\frac{h}{2\pi}$ (c) $\frac{2h}{\pi}$ (d) $\frac{nh}{2\pi}$
5. In equation, what does this $E_n = \frac{-13.6}{n^2}eV$ negative sign indicates.
   a) Electrons are free to move
   b) Electron is bound with nucleus.
   c) Kinetic energy is equal to potential energy
   d) Atom is radiating energy
6. Kinetic energy of electron in hydrogen atom is
   a.) $\frac{e^2}{4\pi\epsilon_0 r}$ b. $\frac{e^2}{8\pi\epsilon_0 r}$ c. $\frac{e^3}{8\pi\epsilon_0 r}$ d. $\frac{e^2}{3\pi\epsilon_0 r}$
7. Energy required to excite an electron in hydrogen atom to its ground state to its first excited state is .
   (a). 6.2eV (b). 3.40eV (c). 10.2eV (d). -13.6eV
8. What is the angular momentum of an electron revolving in the 3rd orbit of an atom?

   a. 31.5×10^{-34} *J*.sec b. 3.15×10^{-34} *J*.sec c. 315×10^{-34} *J*.sec d. 0.315×10^{-34} *J*.sec
9. If the electron in hydrogen atoms is excited to n = 5 state, the number of different frequencies of radiation which may be emitted is:
   (a) 4 b) 10 c) 8 d) 5

ANSWERS:-

1 : (c) Explanation : When alpha particles are sent through a thin gold foil, most of them go straight through the foil, because of lots of empty space present in the atom.

2: (d) Nucleus Explanation : few alpha particles were bouncing back which concluded that a part of the atom consists of a positively charged which was called as nucleus.

3 :(b) Explanation : Let *d* be the distance of closest approach then by the conservation of energy. Initial kinetic energy of incoming α-particle *K*
= Final electric potential energy *U* of the system
as $K=1/4\pi\varepsilon0\times (2e)(Ze)/d/d$
$\therefore d= Ze^{2/}2\pi\varepsilon_0 1k$

4 : (d) explanation : Bohr's third postulate states that the angular momentum of an electron revolving around the nucleus of an atom is quantized. The angular momentum is an integral multiple of h/2π where h is the Planck's constant.
That is,mvr=nh/2π Here, n has integer values and is the principal quantum number. It denotes the orbit in which the electron resides.

5 (b) Explanation the negative sign in the energy of an electron in the nth shell represents the energy decrease resulting from the electron's binding to the atom and its position relative to the nucleus. It signifies that the electron is in a lower energy state than it would be if it were free from the atom's influence.

6 : (b) $\frac{e^2}{8\pi\epsilon_0 r}$

7 (C) 10.2eV soln- E_2-E_1=-3.40-(-13.6)= 10.2eV

8 (b) explanation : Here n = 3; h = 6.6 x 10-34 Js

Angular momentum L = $nh/2\pi$ = (3 × 6.6 × 10^{-34})/2 × 3.14 = 3.15 x 10^{-34} Js

9: (b) Explanation : Orbital Frequency of electron -

- wherein $f \alpha \frac{Z^2}{h^3}$
- $f = \frac{mz^2e^4}{4\epsilon_0^2 n^3 h^3}$

Number of frequency emitted from n^{th} orbital is $\frac{n(n-1))}{2}$

$\because n = 5$ => number of frequency emitted = $\frac{5 \times 4}{2}$ = 10

ASSERTION AND REASONING : ATOMS

Directions: These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.

(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) If the Assertion is correct but Reason is incorrect.

(d) If both the Assertion and Reason are incorrect.

1. **Assertion (A):** According to Bohr's theory in the hydrogen atom, the electron revolves in circular orbits.
   Reason (R): The centripetal force is provided by the electrostatic attraction between the proton and the neutron.
2. **Assertion (A):** The frequency of radiation emitted or absorbed by an atom is related to the difference in energy between two energy levels.
   Reason (R): The energy of the photon emitted or absorbed is equal to the difference in energy between the two levels.
3. **Assertion (A):** The ground state of an atom is its highest energy state.
   Reason (R): In the ground state, the electron occupies the farthest possible orbit to the nucleus.
4. **Assertion (A):** The Bohr model of the atom explains the line spectra of hydrogen atom.
   Reason (R): The energy levels of the electron in the hydrogen atom are quantized, leading to discrete spectral lines.
5. **Assertion (A):** The angular momentum of an electron in a Bohr orbit is quantized.
   Reason (R): The angular momentum of the electron is an integral multiple of h/4π.
6. **Assertion (A):** The emission spectrum of an element is characteristic of the element.
   Reason (R): The energy levels of electrons in an atom are unique to each element.
7. **Assertion (A):** The ionization energy of an atom is the energy required to remove an electron from the atom in its ground state.
   Reason (R): Ionization energy is a measure of the binding energy of the protons in the ground state.
8. **Assertion (A):** The wavelength of light emitted in an electronic transition is inversely proportional to the energy difference between the initial and final states.
   Reason (R): The energy of a photon is inversely proportional to its wavelength.
9. **Assertion (A):** The energy levels in an atom are quantized due to the wave nature of electrons.
   Reason (R): Electrons exhibit both particle and wave properties

ANSWERS (ASSERTION AND REASONING)

1: (c)Explanation : The centripetal force is provided by the electrostatic attraction between the proton and the electron.
2: (A)Explanation : Both A and R are true and R is the correct explanation of A.
3: (D) both the Assertion and Reason are incorrect.
Explanation : The ground state of an atom is its lowest energy state.
In the ground state, the electron occupies the closest possible orbit to the nucleus.
4: (A) Explanation : Both A and R are true and R is the correct explanation of A.
5: (c) Explanation : The angular momentum of the electron is an integral multiple of h/2π.
6: (a) Explanation : Both A and R are true and R is the correct explanation of A.
7: (c) Explanation : Ionization energy is a measure of the binding energy of the electron in the ground state.
8: (a) Explanation : Both A and R are true and R is the correct explanation of A.
9: (b) both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

SHORT ANSWER QUESTIONS: (02 MARKS)

1. What is the shortest wavelength present in the Paschen series and Balmer series of hydrogen spectrum?
2. In the Rutherford's scattering experiment the distance of closest approach for an α −particle is d_0. If α −particle is replaced by a proton, how much kinetic energy in comparison to α particle will it require to have the same distance of closest approach d_0?
3. Find the ratio of Bohr's radius in ground state and 1st excited state of H-atom?
4. The value of ground state energy of hydrogen atom is −13.6 eV.
(i) what does the negative sign signify?
(ii) How much energy is required to take an electron in this atom from the ground state to the first excited state?
5. Use Rydberg formula to determine the wavelength of H_α & H_β line.
(Given: Rydberg's constant R =1.03 X 10^7 m^2)
6. Calculate the shortest wavelength of the spectral lines emitted in Balmer series. [Given Rydberg constant, R = 10^7 m^{-1}].
7. When an electron in hydrogen atom jumps from the third excited state to the ground state, how would the de Broglie wavelength associated with the electron change? Justify your answer.

SOLUTIONS FOR SHORT ANSWER QUESTIONS: (02 MARKS)

1. solution

. $\lambda = Rhc\left(\frac{1}{1^2} - \frac{1}{2^2}\right)$
$n_1=3$, n_2=infinity,
$\lambda = 9/R$
$= 8204$ Å

2. $$E_{K_\alpha} = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(2e)}{d_0} \& E_{K_p} = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(e)}{d_0} \Rightarrow E_{K_p} = \frac{1}{2}E_{K_\alpha}$$

3. Solution : $R_2/R_0 = 4\,a_0/a_o$ = 4: 1

4. Solution : (i) Negative sign shows that electron is bound with the nucleus by electrostatic Force
(ii) $E_n = -\frac{13.6}{n^2}$ eV& For ground state n =1 and for first excited state n =2

5. Solution

For H_α line, n_1=2 and n_2=3

$$\Rightarrow \frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{3^2}\right] = R\left[\frac{1}{4} - \frac{1}{9}\right] = \frac{5R}{36} \Rightarrow \lambda = \frac{36}{5R} = \frac{36}{5 \text{ X } 1.03 \text{ X} 10^7} = 6990\ A^0$$

6. (Hint: for shortest wavelength of Balmer series $n_i = \infty$, $n_f = 2$)
Answer: Wavelength = 4×10^{-7} m

7. Answer: 970×10^{-10} m, It lies in the ultra-violet region.

QUESTIONS : (03 MARKS)

Q.1:- Write two important limitations of Rutherford model which could not explain the observed features of atomic spectra. How were these explained in Bohr's model of hydrogen atom? Use the Rydberg formula to calculate the wavelength of the Hα line.

(Take $R = 1.1 \times 10^7\ m^{-1}$).

Q2 **:-** Calculate the shortest wavelength in the Balmer series of hydrogen atom. In which region (infra-red, visible, ultraviolet) of hydrogen spectrum does this wavelength lie?

Q.3:- Show that the radius of the orbit in hydrogen atom varies as n^2, where n is the principal quantum number of the atom.

Q.4:-An α-particle moving with initial kinetic energy K towards a nucleus of atomic number z approaches a distance 'd' at which it reverses its direction. Obtain the expression for the distance of closest approach 'd' in terms of the kinetic energy of α-particle K.

Q.5:- Using Rutherford model of the atom, derive the expression for the total energy of the electron in hydrogen atom. What is the significance of total negative energy possessed by the electron?

Q.6 . A hydrogen atom initially in the ground state absorbs a photon which excites it to the n- 4 level. Determine the wavelength of the photon.

(i) The radius of innermost electron orbit of a hydrogen atom is 5.3×10^{-11}m. Determine its radius in n = 4 orbit.

Q7. (i) In hydrogen atom, an electron undergoes transition from 2nd excited state to the first excited state and then to the ground state. Identify the spectral series to which these transitions belong.

(ii) Find out the ratio of the wavelengths of the emitted radiations in the two cases.

SOLUTIONS FOR 3MARKS QUESTIONS

1. Limitations of Rutherford Model : (i) Electrons moving in a circular orbit around the nucleus would get, accelerated, therefore it would spiral into the nucleus, as it looses its energy. (ii) It must emit a continuous spectrum.

Explanation according to Bohr's model of hydrogen atom :

(ii) Electron in an atom can revolve in certain stable orbits without the emission of radiant energy. (ii) Energy is released/absorbed only, when an electron jumps from one stable orbit to another stable orbit. This results in a discrete spectrum. Wavelength of Hα line :

Hα line is formed when an electron jumps from $n_f = 3$ to $n_i = 2$ orbit. It is the Balmer series

After calculations λ = 65.3 nm

2. In Balmer series, an electron jumps from higher orbits to the second stationary orbit (nf = 2). Thus for this series : λ = 4/R = 3646 Å

3. Answer: When an electron moves around hydrogen nucleus, the electrostatic force between electron and hydrogen nucleus provides necessary centripetal force.

Also we know from Bohr's postulate, $mv^2/r = (1/4\pi\varepsilon_0)\, e^2/r^2$

$mvr = nh/2\pi$ or $m^2v^2r^2 = n^2h^2/4\pi^2$

from both equations $r = (n^2h^2/4\pi^2 m e^2) \times 4\pi\varepsilon_0$ therefore $r \propto n^2$

4. At the distance d, the KE (K) gets converted into PE (P) of the system.

Therefore PE at distance (d) = $(1/4\pi\varepsilon_0)(2e \times Ze)/d = (1/4\pi\varepsilon_0)2Ze^2/d = K$

Therefore $d = (1/4\pi\varepsilon_0)\, 2Ze^2/K$

5. Expression for total energy of electron in H-atom using Rutherford model : As per Rutherford model of atom, centripetal force (Fc) required to keep electron revolving in orbit is provided by the electrostatic force (Fe) of attraction between the revolving electron and nucleus.

The negative sign indicates that the revolving electron is bound to the positive nucleus.

$F_c = F_e$

$mv^2/r = ee/4\pi\varepsilon_0 r^2$ so, $r = e^2/4\pi\varepsilon_0 mv^2$

$KE = \frac{1}{2} mv^2 = e^2/ 8 \pi \varepsilon_0 r$

$PE = e(-e)/ 4 \pi \varepsilon_0 r = e^2/ 4 \pi \varepsilon_0 r$

$TE = KE + PE = -e^2/ 8 \pi \varepsilon_0 r$

6. Energy of the ground state = -13.6 eV

Energy of (n= 4) state = -13.6/16 eV

Therefore energy of photon absorbed $E = hc/ \lambda = 12.75 \times 1.6 \times 10^{-19}$ J

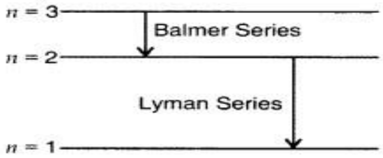
$\lambda = hc/(12.75 \times 1.6 \times 10^{-19}) = 97$ nm

Radius of (n=4) orbit = $(4)^2 \times (5.3 \times 10^{-11})$m = 8.48 A°

7

(i) $n_f = 2, \quad n_i = 3$ *Balmer series*

$n_i = 2, \quad n_f = 1$ *Lyman series*



(ii) $\frac{1}{\lambda_B} = R\left[\frac{1}{2^2} - \frac{1}{3^2}\right] = R\left[\frac{1}{4} - \frac{1}{9}\right] = \frac{5}{36}R$

...where λ_B is the wavelength for Balmer series. λ_L is the wavelength for Lyman series.

CASE BASED QUESTIONS

1. *The spectral series of hydrogen atom were accounted for by Bohr using the relation*

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

where, R=Rydberg constant = 1.097×10^7 m^{-1}

Lyman series is obtained when an electron jumps to first orbit from any subsequent orbit. Similarly,

Balmer series is obtained when an electron jumps to 2nd orbit from any subsequent orbit. Paschen series is obtained when an electron jumps to 3rd orbit from any subsequent orbit. Whereas Lyman series in U.V. region, Balmer series is in visible region and Paschen series lies in infrared region. Series limit is obtained when n2=∞.

Q.1:- What is the ratio of minimum to maximum wavelength in Balmer series?

(a) 5:2 (b) 5:9 (c) 5:8 (d) 9:5

Q.2:- Which series of hydrogen spectrum can we see through naked eye?

(a) Laymen (b) Balmer Series (c) paschan (d) none

Q.3:-What is the wavelength of first spectral line of Lyman series?

(a) 1215.4 (b) 5121.4 (c) 2115.4 (d) 4211.5

Q.4 :-What is the frequency of first spectral line of Balmer series?

(a) 4.57×10^{14} Hz (b) 5.57×10^{14} Hz (c) 7.57×10^{14} Hz (d) 0.57×10^{14} Hz

2. Lyman series is obtained when an electron jumps to first orbit from any subsequent orbit. Similarly, Balmer series is obtained when an electron jumps to 2nd orbit from any subsequent orbit. Paschen series is obtained when an electron jumps to 3rd orbit from any subsequent orbit. Whereas Lyman series in U.V. region, Balmer series is in visible region and Paschen series lies in infrared region. Series limit is obtained when n2=∞.

(i) The wavelength of first spectral line of Lyman series is

(a) 1215.4 A^0 (b)1215.4 cm (c) 1215.4 m (d)1215. 4 mm

(ii) The wavelength limit of Lyman series is

(a) 951.6 A^0 (b) 511.9 A^0 (c)1215.4 A^0 (d) 911.6 A^0

(iii) The frequency of first spectral line of Balmer series is

(a) 1.097×10^7 Hz (b) 4.57×10^{14} Hz (c) 4.57×10^{15} Hz (d) 4.57×10^{16} Hz

(iv) Which of the following transitions in hydrogen atom emit photon of highest frequency?

(a) n=1 to n=2 (b) n=2 to n=6 (c) n=6 to n=2 (d) n=2 to n=1

CHAPTER–13: NUCLEI

Syllabus:-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.

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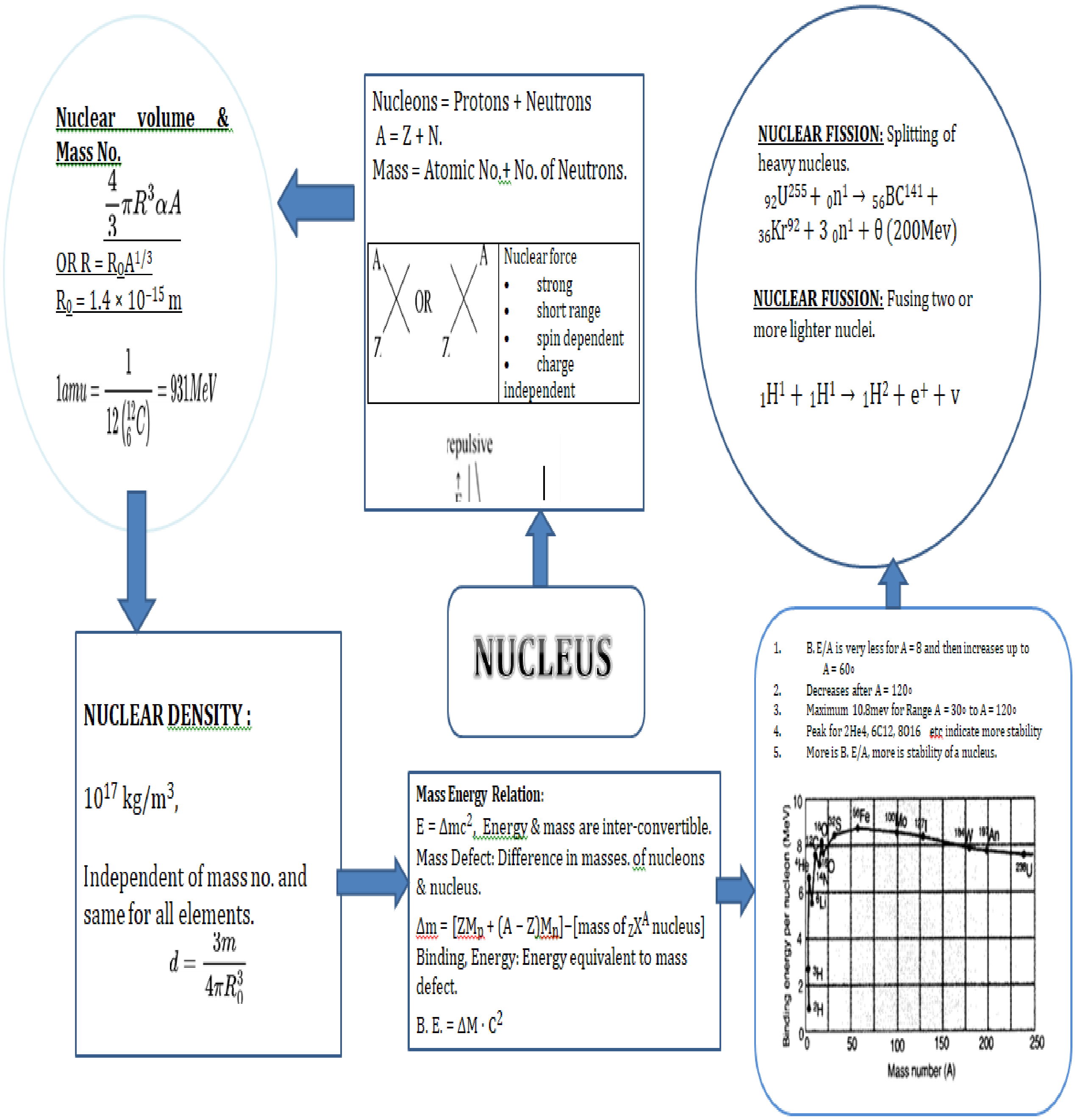


GIST – NUCLEUS

Nucleus: The small, dense region consisting of protons and neutrons at the center of an atom is the atomic nucleus. In every atom, the positive charge and mass are densely concentrated at the central core of the atom, which forms its nucleus. More than 99.9% mass of the atom is concentrated in the nucleus.

Nucleons: The nucleus of an atom consists of protons and neutrons. They are collectively called nucleons.

Atomic Mass Unit (amu) :The unit of mass used to express mass of an atom is called atomic mass unit.

Atomic mass unit is defined as 1/12th of the mass of carbon (126C) atom.
1 amu or 1 u=1.660539 x10-27 kg (1) Mass of proton (m_p)=1.00727 u
(2) Mass of neutron (m_n)=1.00866 u (3) Mass of electron (m_e) =0.000549 u Relation between amu and MeV 1 amu=931 Mev
Composition of Nucleus
The composition of a nucleus can be described by using the following.
Atomic Number (Z) :Atomic number of an element is the number of protons present inside the nucleus of an atom of the element.
Atomic number (Z) = Number of protons = Number of electrons (in a neutral atom)
Mass Number (A): Mass number of an element is the total number of protons and neutrons inside the atomic nucleus of the element.
Mass number (A)= Number of protons(Z) +Number of neutrons(N)
= Number of electrons +Number of neutrons A=Z+N
Size of Nucleus: According to the scattering experiments, nuclear sizes of different elements are assumed to be spherical, so the volume of a nucleus is directly proportional to its mass number. If R is the radius of the nucleus having mass number A, then
$R \propto A^{1/3}$ $R=R_0 A^{1/3}$
Where, R_0= 1.2×10^{-15} m is the range of nuclear size. It is also known as nuclear radius.

Nuclear Density Density of nuclear matter is the ratio of mass of nucleus and its volume. $\rho=m/(4/3\pi R_0^3)$ => $\rho = 2.38 \times 10^{17} kg/m^3$ where, m = average mass of one nucleon and R_o=1.2 fm = 1.2×10^{-15}**m =>The nuclear density (ρ) does not depend on A (mass number). Mass Defect** The sum of the masses of neutrons and protons forming a nucleus is more than the actual mass of the nucleus. This difference of masses is known as mass defect.
$\Delta m = Zm_p + (A-Z)m_n - M$ where, Z= atomic number, A= mass number, m_p = mass of one proton, m_n= mass of one neutron and M= mass of nucleus.
Mass-Energy Relation Einstein's mass-energy equivalence equation is given by $E = mc^2$, (where E is the energy and c is the speed of light =3×10^8 m/s and m = mass of nucleus)
Nuclear Forces Short ranged (2-3 fm) strong attractive forces which hold protons and neutrons together in against of Colombian repulsive forces between positively charged particle is called nuclear force. The nuclear force between neutron-neutron, proton-neutron and proton-proton is approximately the same. The nuclear force does not depend on the electric charge.
Nuclear Energy When nucleons form a nucleus, the mass of nucleus is slightly less than the sum of individual masses of nucleons. This mass is stored as nuclear energy in the form of mass defect. Also, transmutation of less stable nuclei into more tightly bound nuclei provides an excellent possibility of releasing nuclear energy. Two distinct ways of obtaining energy from nucleus are Number of nucleons given below
The phenomenon of splitting of heavy nuclei (usually A>230) into lighter nuclei of nearly equal masses is known as nuclear fission, e.g.

$${}_{92}U^{235} + {}_0n^1 \text{ -------->} \quad {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\ {}_0n^1 + Q$$

Nuclear Fusion
The phenomenon of fusing or combining of two lighter nuclei into a single heavy nucleus is called nuclear fusion, e.g.

$${}_1H^1 + {}_1H^1 \text{ ---------->} \quad {}_1H^2 + e^1 + v + 0.42\ MeV$$

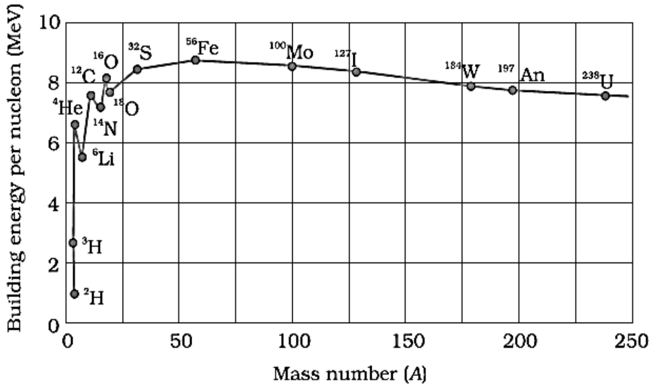
[The energy released during nuclear fusion is known as thermonuclear energy.]
Binding Energy
The binding energy of a nucleus is defined as the minimum energy required to separate its nucleons and place them at rest at infinite distance apart. Using Einstein's mass-energy relation, $\Delta E= (\Delta mc^2)$, the binding energy of the nucleus is$\Delta E =[Zm_p + (A-Z)m_n - M]c^2$

Average Binding Energy Per Nucleon of a Nucleus

It is the average energy required to extract a nucleon from the nucleus to infinite distance. It is given by total binding energy divided by the mass number of the nucleus.

Binding energy curve:

It is a plot of the binding energy per nucleon versus the mass number A for a large number of nuclei as shown below:



The binding energy per nucleon as a function of mass number.

Binding energy per nucleon as a function of mass number :It is used to explain phenomena of nuclear fission and fusion.

Nuclear Stability

The stability of a nucleus is determined by the value of its binding energy per nucleon. The constancy of the binding energy in the range 30< A<170 is a consequence of the fact that the nuclear force is short-ranged.

MCQ - QUESTIONS : NUCLEI)

1.The binding energy per nucleon of a nucleus is a measure of its:

a) Stability b) Instability c) Radioactivity d) Mass defect

2. The binding energy per nucleon is maximum for nuclei with a mass number around:

a) 50 b) 100 c) 150 d) 200

3. The binding energies per nucleon for a deutron and an α- particle are x_1 and x_2 respectively. The energy Q released in reaction$1H^2 + 1H^2 \rightarrow {}^4{}_2He + Q$ is

(a) 4 $(x_1 + x_2)$ (b) 4 $(x_1 - x_2)$ (c) 2 $(x_1 + x_2)$ (d) 2 $(X_1 - x_2)$.

4. Let m_n and m_p be the masses of a neutron and a proton respectively. M_1 and M_2 are the masses of a ${}^{20}{}_{10}Ne$ nucleus and a ${}^{40}{}_{20}Ca$ nucleus respectively. Then

(a) $M_2 < 2M_1$ (b) $M_2 > 2M_1$ (c) $M_2 = 2M_1$ (d) $M_1 < 10 (m_n + m_p)$.

5. One requires an energy E_n to remove a nucleon from a nucleus and an energy E_e to remove an electron from an atom. Then

(a) $E_n = E_e$ (b) $E_n > E_e$ (c) $E_n < E_e$ (d) $E_n > E_e$.

3. When the number of nucleons in nuclei increases, the binding energy per nucleon numerically

(a) increases continuously with mass number.

(b) decreases continuously with mass number. (c) First increases and then decreases with increase of mass number.

(d) Remains constant with mass number.

7. Consider the fission reaction : ${}^{236}{}_{92}U \rightarrow x^{117} + Y^{117} + {}_0n^1 + {}_0n^1$i.e., two nuclei of same mass numbers 117 are formed plus two neutrons. The binding energy per nuclear of X and Y is 8.5 MeV whereas U^{236} is 7.6 MeV. The total energy liberated will be about:

(a) 2 MeV (b) 20 MeV (c) 2,000 MeV (d) 200 MeV

8. Fusion takes place at high temperature because:

(a) Atom are ionised at high temperature

(b) Molecules break up at high temperature

(c) Nuclei break up at high temp.

(d) Kinetic energy is high enough to overcome repulsion between nuclei

9. The binding energy per nucleon for the parent nucleus is E1 and that for the daughter nuclei is E2. Then

(a) E1 > E2 (b) E2 > E1 (c) E1 = 2E2 (d) E2 = 2E1

ANSWERS MCQ

1. Ans : a Explanation : Binding energy per nucleon refers to the **average energy that holds a nucleus together**, calculated by dividing the total binding energy of the nucleus by the number of nucleons (protons and neutrons) it contains.
2. Ans : b Explanation : Excluding the lighter nuclei, the average binding energy per nucleon is about 8 MeV. The maximum binding energy per nucleon occurs at around mass number **A = 50**, and corresponds to the most stable nuclei.
3. Answer: (b) 4 $(x_1 – x_2)$

Explanation : Number of nucleon on reactant side = 4 Binding energy for one nucleon = x1 Binding energy for 4 nucleons = 4x1 Similarly on product side binding energy = 4x2 Now, Q = change in binding energy = $4(x_1 – x_2)$.

4. Answer: (a) Explanation : it is found that the mass defect increases with increase in mass number So, $20(m_n + m_p) – M_2 > 10 (m_p + m_n) – M_1$

Or $10(m_n + m_p) > (M_2 - M_1)$

Or $M_1 + 10 (m_n + m_p) > M_2$

i.e. $M_2 < M_1 + 10 (m_n + m_p)$ but $M_1 < 10 (m_n + m_p)$ $\therefore M_2 < 2M_1$

5. Answer: (b) $E_n > E_e$ Explanation : the work function for nuleon is much greater than the electron.
6. Answer: (c) First increases and then decreases with increase of mass number.
7. Answer: (d) 200 MeV Explanation : The total energy liberated will be the difference between the binding energy of two sides. Binding energy of nucleus $=236×7.6MeV$

Binding energy of product $=117×8.+117×8.5 =2×117×8.5$

Hence, net binding energy = Binding energy of product - Binding energy of nucleus

$=234×8.5−234×7.6 =1989−1793.6=195.4MeV ≈200MeV$

Thus, in per fission of uranium nearly $200MeV$ energy is released

8.Answer (d) Kinetic energy is high enough to overcome repulsion between nuclei

Explanation: This happens because at high temperature, there is enough kinetic energy to overcome the repulsion and the strong interaction pulling the protons together is stronger than repulsion pushing the protons apart, the atoms will fuse together forming a new atom containing protons of both atoms we pushed together.

9.Answer : (b) E2 > E1

Explanation: When a heavy nucleus of higher mass number (less stable) splits into two lighter nuclei the daughter nucleus is of less mass number and becomes more stable, having more binding energy per nucleon. Therefore, E2 > E1

ASSERTION AND REASONING : NUCLEI

Directions: These questions consist of two statements; each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.

(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) If the Assertion is correct but Reason is incorrect.

(d) If both the Assertion and Reason are incorrect.

1. **Assertion (A):** The mass of a nucleus is less than the sum of the masses of its constituent protons and neutrons.
   Reason (R): The mass defect is converted into binding energy, which holds the nucleus together.
2. **Assertion (A):** The binding energy per nucleon is a measure of the unstability of a nucleus. **Reason (R):** A higher binding energy per nucleon means the nucleons are not tightly bound and the nucleus is more stable.
3. **Assertion (A):** Heavy nuclei tend to be unstable and undergo radioactive decay.

Reason (R): In heavy nuclei, the repulsive electrostatic forces between protons are sufficiently balanced by the attractive nuclear forces.

4. **Assertion (A):** Nuclear fission is accompanied by the release of a large amount of energy. **Reason (R):** The binding energy per nucleon of the fission fragments is greater than that of the original nucleus.
5. **Assertion(A):** Nuclear fusion requires extremely high temperatures. **Reason (R):** High temperatures provide the necessary kinetic energy to overcome the electrostatic repulsion between nuclei.
6. **Assertion (A):** The mass number of a nucleus is the sum of the number of protons and neutrons. **Reason (R):** Protons and neutrons are the nucleons that make up the nucleus.
7. **Assertion(A):** Distance of closest approach of α-particle to the nucleus is always greater than the size of the nucleus.
   Reason(R): Strong nuclear repulsion does not allow α-particle to reach the surface of nucleus

ANSWERS FOR ASSERTION AND REASONING.

1. Answer: (a) Explanation : Both A and R are true and R is the correct explanation of A
2. Answer: (d) Both A and R are false, Explanation : The binding energy per nucleon is a measure of the stability of a nucleus. A higher binding energy per nucleon means the nucleons are more tightly bound and the nucleus is more stable.
3. Answer: (c), Explanation : In heavy nuclei, the repulsive electrostatic forces between protons are not sufficiently balanced by the attractive nuclear forces.
4. Answer: (a), Explanation : Both A and R are true and R is the correct explanation of A.
5. Answer: (a), Explanation : Both A and R are true and R is the correct explanation of A.
6. Answer: (a), Explanation : Both A and R are true and R is the correct explanation of A.
7. Answer : (a) Explanation : Both A and R are true and R is the correct explanation of A.

CASE BASED QUESTIONS (NUCLEI)

1. Einstein was the first to establish the equivalence between mass and energy. According to him, whenever a certain mass (Δm) disappears in some process the amount of energy released is $E = \Delta m\, c^2$, where c is the velocity of light in vacuum $=3 \times 10^8$ m/s. The reverse is also true i.e. whenever energy E disappears an equivalent mass $\Delta m = E/c^2$ appears.

i) What is the energy released when 1a.m.u mass disappears in a nuclear reaction?

a) 1.49×10^{-10} J b) 1.49×10^{-7} Jc) 1.49×10^{10} J d) 1.49×10^{-10} MJ

ii) Which of the following process releases energy?

a) Nuclear Fission b)Nuclear Fusion c)Both (a) and (b) d)None

iii) Which process is used in today's nuclear power plant to harness nuclear energy?

a) Nuclear Fission b)Nuclear Fusion c)Both (a) and (b) d)None

iv) Which process releases energy in Atom Bomb?

a) Nuclear Fission b)Nuclear Fusion c)Both (a) and (b) d)None

OR

Which of the following is used as Moderator in a Nuclear Reactor?

(a) Deuterium Water b)Normal Water c)Mineral Water d)Soft water

ANS: 1(a) 2(c) 3(a) 4(a) or 4(a)

2. Neutrons and protons are identical particle in the sense that their masses are nearly the same and they are bounded with the force, called nuclear force. Nuclear force is the strongest force. Stability of nucleus is determined by binding energy per nucleon or the neutron proton ratio or packing fraction. Density of nucleus independent on the mass number. Whole mass of the atom (nearly99%) is present at the nucleus

(i) The force between a neutron and a proton inside the nucleus is

(a) Only nuclear attractive
(b)Only Coulomb force
(c) Both of the above
(d)None of these

(ii) Outside a nucleus

(a)Neutron is stable
(b)Proton and neutron both are stable
(c) Neutron is unstable
(d)Neither neutron nor proton is stable

(iii) Nuclear force is

(a)Short range and charge dependent
(b)Short range and charge independent
(c) Long range and charge independent
(d) Long range like electrostatic type

(iv) If F_{pp} , F_{pm} and F_{nn} are the magnitudes of net force between proton-proton, proton-neutron and neutron-neutron respectively, then

(a.) Fpp = Fpn = Fnn (b) Fpp < Fpn < Fnn (c) Fpp > Fpn >Fnn (d) Fpp = Fpn < Fnn

ANSWER : (i) (a) (ii) (d) (iii) (b) (iv) (a)

SHORT ANSWER (02 MARKS)

1. What is mass defect of a nucleus? Express it mathematically. What light does it throw on the binding energy of nucleus?
2. Calculate the energy release in MeV in the deuterium fusion reaction

$_1H^2 + _1H^3$------------------ $_2He^4$ +n , Using the following data

m($_1H^2$)= 2 014102 u, m($_1H^3$)= 3 016049 u, m($_2H^4$)= 4 002603 u, m_n= 1 008665 . u 1u =931.5MeV

3. A nucleus with mass number, A = 240 and BE /A = 7. 6 MeV breaks into two fragments each of A = 120 with BE /A = 8. 5 MeV Calculate the released energy.
4. What do you mean by binding energy of nucleus? Obtain an expression for binding energy. How binding energy per nucleon explains the stability of nucleus?
5. Obtain the binding energy (in MeV) of a nitrogen nucleus ($_7N^{14}$) given m ($_7N^{14}$) =14.00307u
6. Draw the graph showing the variation of binding energy per nucleon with mass number. What inference you get from this graph. Also explain the importance of binding energy curve.
7. (i) How is the size of a nucleus found experimentally? Write the relation between the radius and mass number of a nucleus.

(ii) Prove that the density of a nucleus independent of its mass number.

ANSWERS :

1. This missing mass is known as the 'mass defect' and it accounts for the energy released. The mass defect (ΔM) can be calculated by subtracting the original atomic mass (M_A) from the sum of the mass of protons (m_p= 1.00728 amu) and neutrons (m_n= 1.00867 amu) present in the nucleus.
2. In this reaction total mass of reactant is=5.030151 amu and total mass of product is 5.011268 ,so mass defect is 0.018883 amu so total energy released will be 0.018883x931.5=17.5895245 Mev'
3. Since the nucleus as a mass number A = 240 and binding energy for nucleon is 7.6 MeV. Its total binding energy is E1 = 240 X 7.6 = 1824 MeV. As both fragments of mass number A = 120 as a binding energy for nucleon of 8.5 MeV, so total energy of fragments is E2 = 2 X 120 X 8.5 = 2040 MeV. Therefore energy released is = 2040 – 1824 =216 MeV.
4. The energy evolve during formation of nucleus due to mass defect is called binding energy. Mass defect=(Zm_p+(Z-A)m_n-m_N($_ZX^A$)) ,Binding energy =mass defectx931.5MeV

Larger the binding energy per nucleon, the greater the work that must be done to remove the nucleon from the nucleus, the more stable the nucleus.

5. Nitrogen has 7 proton and 7 neutron so total mass of proton and neutron =7X1.00727647+7X1.0087 =14.11183539 ,mass defect will be=14.11183539-14.00307 = 0.10876529,so

binding energy will be 0.010876529x931.5=101.314867635 MeV.

6. Correct graph and importance of curve
7. Description of closest approach, relation and proof.

LONG ANSWER QUESTIONS 3 MARKS

1. (i) Why is the binding energy per nucleon found to be constant for nuclei in the range of mass number (A) lying between 30 and 170? (ii) When a heavy nucleus with mass number A = 240 breaks into two nuclei, A = 120, energy is released in' the process. (iii) In β-decay, the experimental detection of neutrinos (or antineutrinos) is found to be extremely difficult.
2. (a) In a typical nuclear reaction, e.g.

$${}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{3}_{2}He + n + 3.27\ MeV$$

although number of nucleons is conserved, energy is released. How? Explain.
(b) Show that nuclear density in a given nucleus is independent of mass number A.

3. Draw a plot of potential energy of a pair of nucleons as a function of their separations. Mark the regions where the nuclear force is (i) attractive and (ii) repulsive. Write any two characteristic features of nuclear forces.
4. (i) What characteristic property of nuclear force explains the constancy of binding energy per nucleon (BE/A) in the range of mass number 'A' lying 30 < A < 170?
(ii) Show that the density of nucleus over a wide range of nuclei is constant- independent of mass number A.
5.. Using the curve for the binding energy per nucleon as a function of mass number A, state clearly how the release of energy in the processes of nuclear fission and nuclear fusion can be explained.

1. Answer: (i) Nuclear forces are short ranged. For a particular nucleon inside a sufficiently large nucleus will be under the influence of some of its neighbours which come within the range of the nuclear force. The property that a given nucleon influences only nucleons close to it is also referred to as saturation property of the nuclear force.
(ii) The binding energy per nucleon of the parent nucleus is less than those of the two daughter nuclei. It is this increased binding energy that gets released in this process.
(iii) Neutrinos are chargeless and massless particles, whose interaction with other particles is almost negligible. Hence, they can pass through very large quantity of matter without getting detected.

2. Answer: (a) In all types of nuclear reactions, the law of conservation of nucleons is followed. But during the reaction, the mass of the final product is found to be slightly less than the sum of the masses of the reactant components. This difference in mass of a nucleus and its constituents is called mass defect. So, as per mass energy relation $E = (\Delta M)c^2$, energy is released. In the given reaction the sum of the masses of two deutrons is more than the mass of helium and neutron. Energy equivalent of mass defect is released.

(b) Nuclear density $= \dfrac{\text{Mass of nucleus}}{\text{Volum}} = \dfrac{mA}{\frac{4}{3}\pi R^3}$

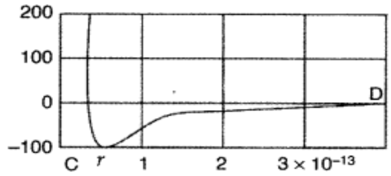
(m = mass of each nucleon)

As $R = R_0 A^{1/3}$ **where $R_0 = 1.2 \times 10^{-15}$ m.**

$\therefore$ Nuclear density $= \dfrac{3mA}{4\pi R_0^3 A} = \dfrac{3m}{4\pi R_0^3}$

i.e. independent of Mass Number A

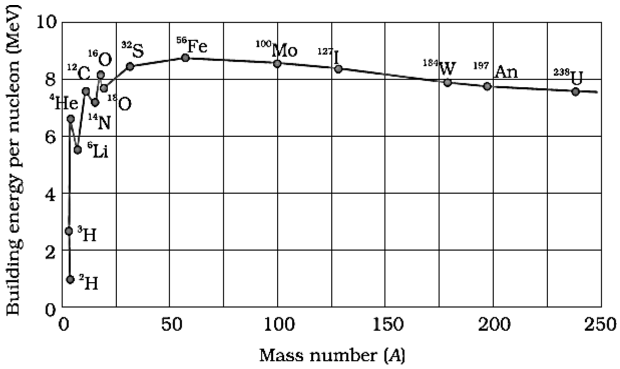
3. Answer: The graph indicates that the attractive force between the two nucleons is strongest at a separation r_0 = 1 fm. For a separation greater than the force is attractive and for separation less than r_0, the force is strongly repulsive.



Two characteristic features of nuclear forces :1. Strongest interaction 2. Short-range force 3. Charge independent character (any two)

4. Answer:(i) Saturation is the Short range nature of nuclear forces
(ii) Let A be the mass number and R be the radius of a nucleus If m is the average mass of a nucleon, then Mass of nucleus = mA
Volume of nucleus = $4/3\ \pi\ R^3$
$=4/3\ \pi\ (R_0A^{1/3})^3 = 4/3\ \pi\ R_0^3A$
Therefore nuclear density = mass of nucleus / volume of nucleus
$mA/(4/3\ \pi\ R_0^3A) = 3m/(4\pi\ R_0^3)$
clearly , nuclear density is independent of mass number A of the size of nucleus.

5. Answer: 1. Nuclear fission : Binding energy per nucleon is smaller for heavier nuclei than the middle ones i.e. heavier nuclei are less stable. When a heavier nucleus splits into the lighter nuclei, the B.E./nucleon changes (increases) from about 7.6 MeV to 8.4 MeV. Greater binding energy of the product nuclei results in the liberation of energy. This is what happens in nuclear fission which is the basis of the atom bomb.

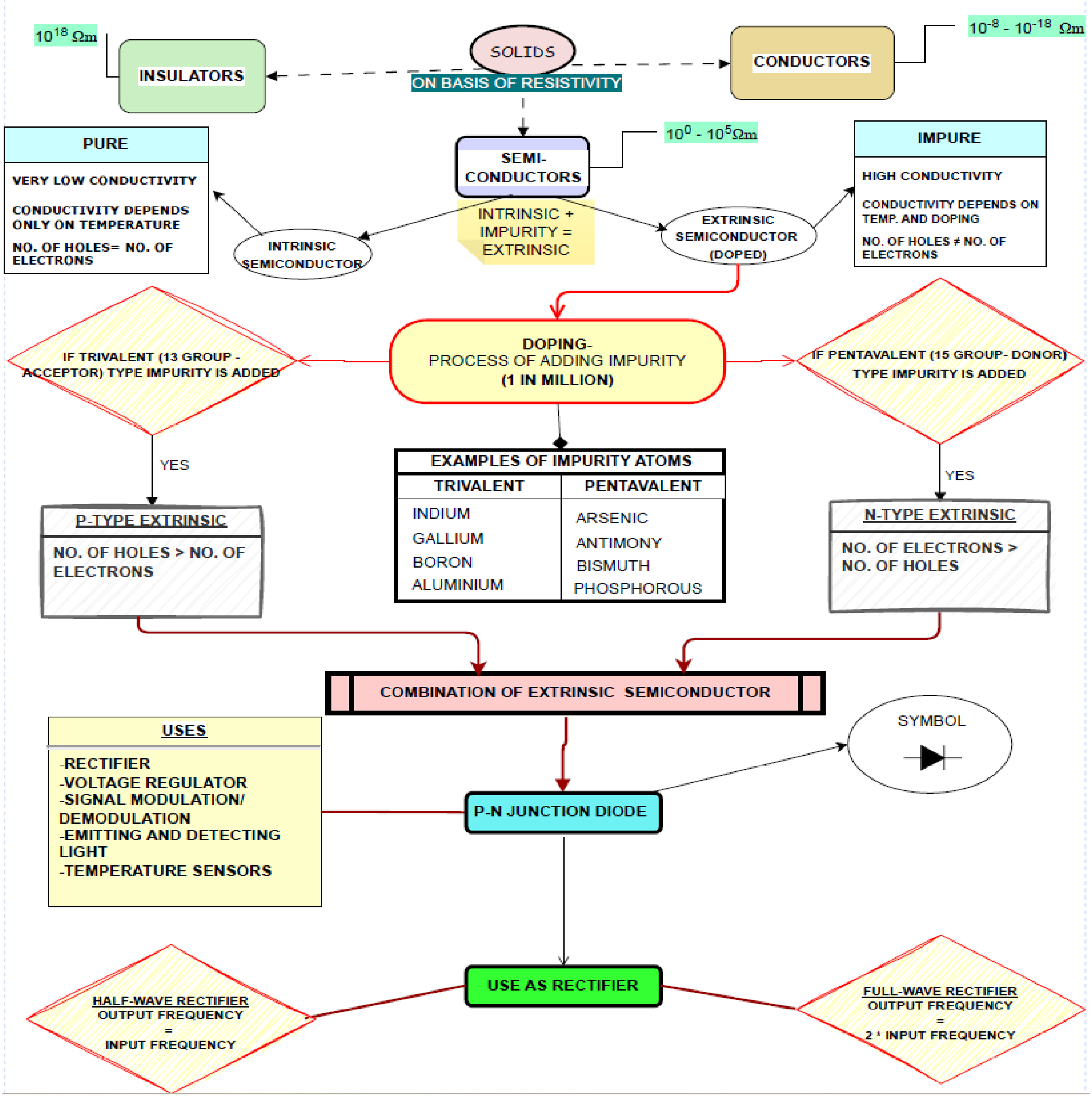


2. Nuclear fusion : The binding energy per nucleon is small for light nuclei, i.e., they are less stable. So when two light nuclei combine to form a heavier nucleus, the higher binding energy per nucleon of the latter results in the release of energy.

CHAPTER–14: SEMICONDUCTOR ELECTRONICS

Syllabus:- 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.

Mindmap



GIST OF CHAPTER

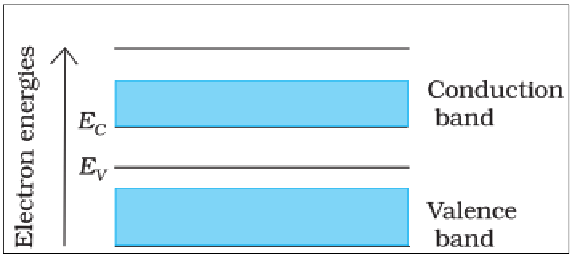
Semiconductor Electronics were discovered as a part of experiments in the **1930s**. This led to the realization that certain solid-state semiconductors and their junctions **had the capacity to control the number and direction of flow of charge carriers** through them.

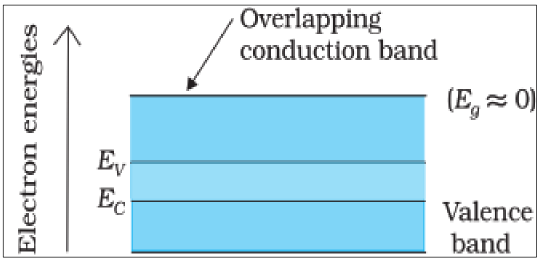
A semiconductor is a type of material whose resistivity is between a conductor (silver, copper, etc.) and insulator (glass, diamond) which is

$$\rho = 10^0 - 10^5 \quad \Omega - m$$

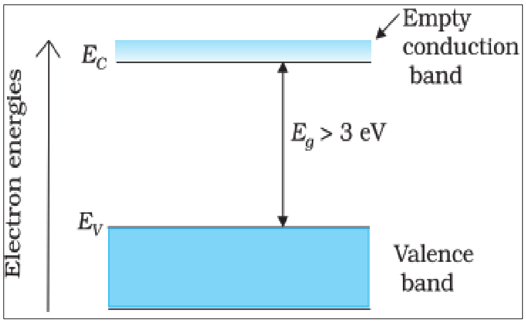
Insulators, conductors and semiconductors can be differentiated based on their energy bands.

- **Metals:-** In metals, the valence and conduction **band lie very close to each other** and **sometimes even overlap** which allows free movement of electrons.



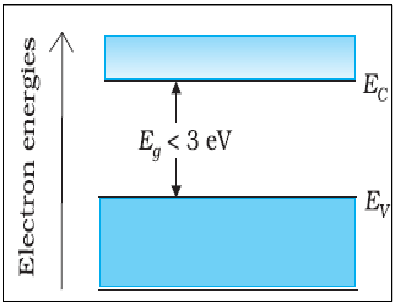


- **Insulators:-** In case of insulators, the conduction band and valence band is separated by a **large gap** which discourages movement of electrons.



- **Semiconductors:-** The **energy band gap is smaller in semiconductors** which encourages some electrons to enter the conduction band by crossing the gap.

  E_g-Si = 1.1 eV E_g-Ge = 0.74 eV



Types of Semiconductors

Semiconductors are classified into two types **based on the number of electrons and holes**.

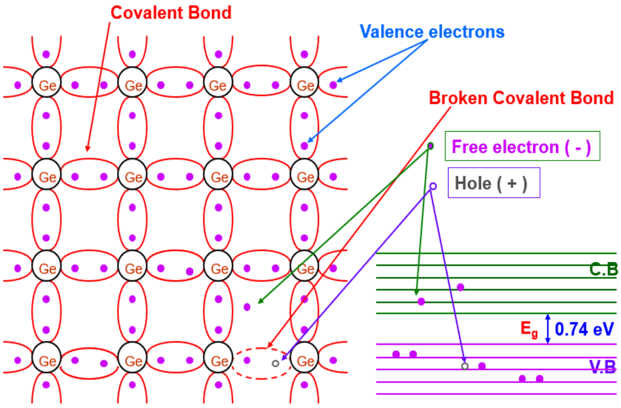
- **Intrinsic**
- **Extrinsic**

Intrinsic or Pure Semiconductor:

Intrinsic semiconductors **are free from impurities**. Examples: **Germanium and silicon**

- for **Pure Si (Z=14)** and for **Pure Ge (Z=32).** Both have 4 valence electrons.
- All 4 valence electrons are involved in covalent bond formation in Si or Ge crystal.
- It has an **equal number of holes and free electrons**.

  Thus, $n_e = n_h = n_i$



Here, **n_i = intrinsic carrier concentration, n_e = number of electrons, n_h = number of holes**

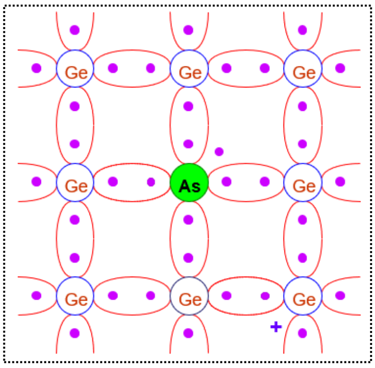
Extrinsic or impure Semiconductor:

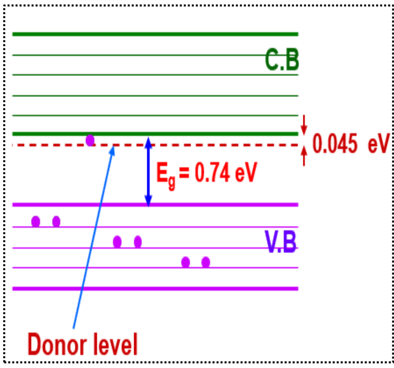
The electrical conductivity of **intrinsic (pure) semiconductor** is dependent **on its temperature.** However, **at room temperature**, its conductivity is very **poor**.

- The addition of certain impurities (very small amount-in part per million ppm) **can increase the conductivity** of the intrinsic (natural) semiconductors.
- The process of addition of impurity is called **doping** and the impurity atoms are called **dopants**.
- The impure semiconductor thus formed is called a **"doped" semiconductor** or **Extrinsic Semiconductor**.

An Extrinsic Semiconductor can be of two types based on the type of doping.

- ➢ **n-type semiconductor doped with Pentavalent impurity atom**. Examples include **Phosphorus (P), Antimony (Sb), Arsenic (As).**



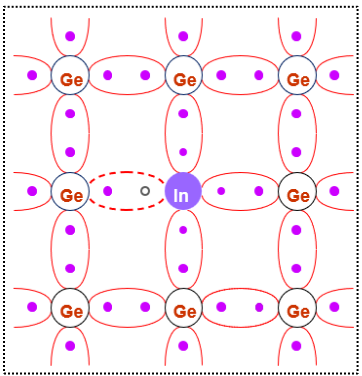


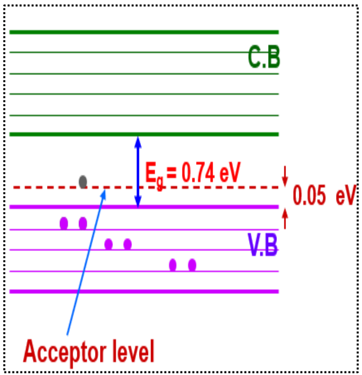
Here $n_e >> n_h$, that is the number of electrons is greater than the number of holes.

- ➢ **p-type semiconductor doped with Trivalent impurities atom.** Examples include **Boron (B), Aluminium (Al), Indium (In).**

Here $n_h >> n_e$, that is the number of holes is greater than the number of electrons.

The electron and hole concentration in a semiconductor *in thermal equilibrium* is given by $n_e \cdot n_h = n_i^2$



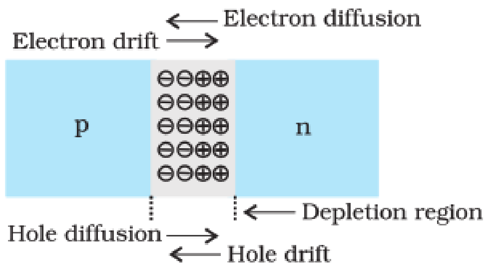


P-N Junction

By Considering a thin p-type silicon (p-Si) semiconductor wafer and adding precisely, a small quantity of pentavalent impurity, part of the p-Si wafer can be converted into n-Si. The wafer now contains p-region and n-region and a metallurgical junction between p-, and n-region.

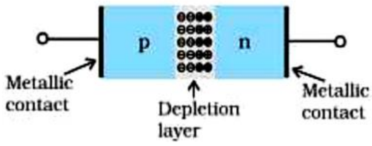
Two important processes occur during the formation of a p-n junction are **diffusion and drift**.

Initially, diffusion current is large and drift current is small. As the diffusion process continues, the space- charge regions on either side of the junction extend, thus increasing the electric field strength and hence drift current. This process continues until the diffusion current equals the drift current.

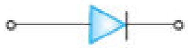


Semiconductor Diode

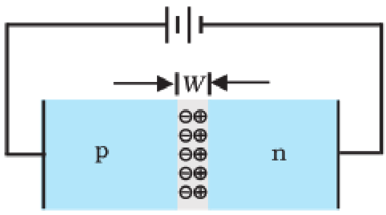
A semiconductor diode is basically a p-n junction with metallic contacts provided at the ends for the application of an external voltage. It is a two-terminal device.



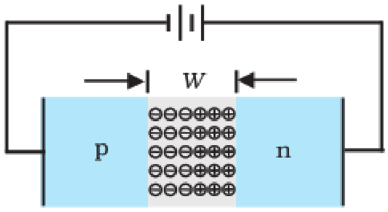
Symbol-



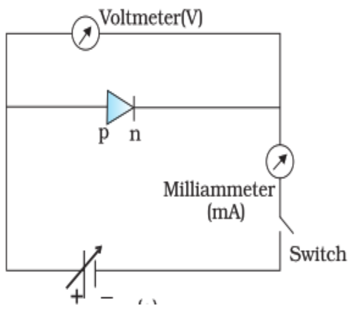
- When an external voltage *V* is applied across a semiconductor diode such that p-side is connected to the positive terminal of the battery and n-side to the negative terminal , it is said to be *forward biased*. In forward bias, it offers very low resistance.

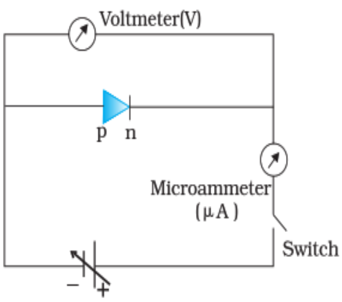


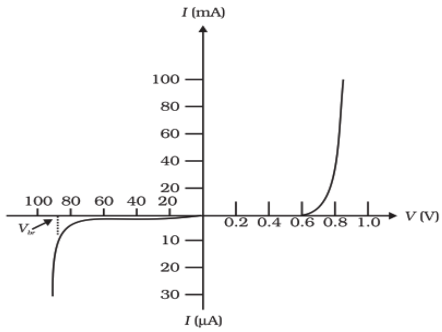
- When an external voltage (*V*) is applied across the diode such that n-side is positive and p-side is negative, it is said to be *reverse biased*. In reverse bias, it offers very high resistance.
- The ratio of forward biased to reverse biased resistance for p-n junction diode is 10^{-4}:1.



Characteristic curve study for p-n junction diode in forward and reverse bias:-







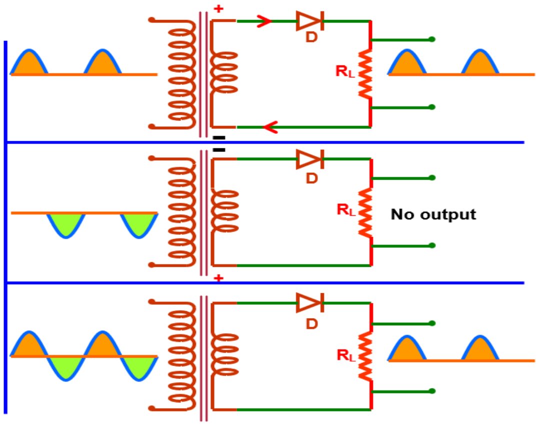
Application of Junction Diode as a Rectifier

An electrical device **that converts alternating current into direct current** with the help of a diode is called **a Rectifier**. There are two types of rectifiers:

1. **Half-Wave Rectifier** 2. **Full-Wave Rectifier**

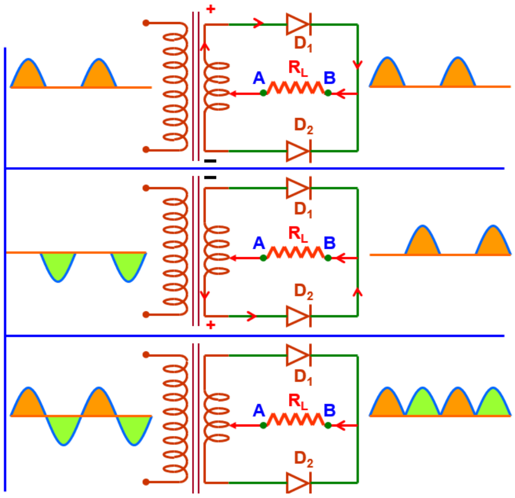
Half Wave Rectifier

A half-wave rectifier is defined as a type of rectifier **that only allows the one-half cycle of an AC voltage** and gives the pulsating DC voltage.
There is only one diode in the half-wave rectifier, which helps to rectify the AC voltage to DC voltage.
The average value of output direct current in a half wave rectifier is I_0/π.



Full Wave Rectifier

Full-wave rectifiers have **two diodes** where the **first diode will conduct in the positive half cycle** and **other diode will conduct in the negative half cycle**. It **will give full pulsating DC.**
The average value of output direct current in a full wave rectifier is $2I_0/\pi$
The sinusoidal wave is complete and with the help of the capacitor or inductor we can filter and convert pulsating DC into constant DC.



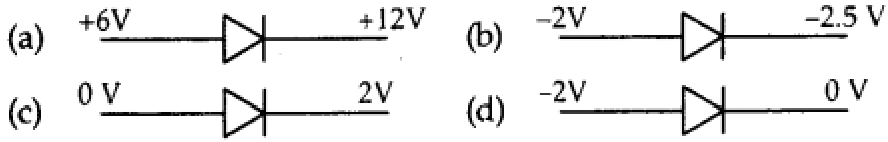
Application of Full Wave Rectifier and Half Wave Rectifier

The use of a half-wave rectifier can help us achieve the desired dc voltage by using step-
down or step-up transformers. Moreover, to power up the motor and LED that works on DC voltage, full wave rectifiers are used.

MULTIPLE CHOICE QUESTIONS

1. Carbon, silicon and Germanium have four valence electrons each. At room temperature which one of the following statements is most appropriate ?
   (a) The number of free electrons for conduction is significant only in Si and Ge but small in C.
   (b) The number of free conduction electrons is significant in C but small in Si and Ge.
   (c) The number of free conduction electrons is negligibly small in all the three.
   (d) The number of free electrons for conduction is significant in all the three.
2. In the energy band diagram of a semiconductor, if more charge carriers are seen near valence band. It would be
   (a) an intrinsic semiconductor (b) a metal may be n-type or p-type semiconductor
   (c) an n-type semiconductor (d) a p-type semiconductor
3. The peak voltage in the output of a half wave diode rectifier fed with a sinusoidal signal without filter is 10 V. The d.c. component of the output voltage is
   (a) $10/\sqrt{2}$ V (b) $10/\pi$ V (c) 10 V (d) $20/\pi$ V

4. In which case is the junction diode forward biased.



5. Assuming that the junction diode is ideal, and resistor has resistance of 200 Ω. The current in the arrangement shown here will be:

(a) 2 mA (b) 30 mA (c) 20 mA (d) 10 mA

6. Which of following statements is not true?

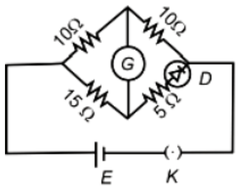
(a) Resistance of an intrinsic semiconductor decreases with increase in temperature.

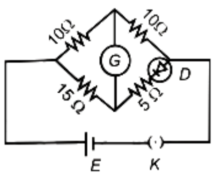
(b) Doping pure Si with trivalent impurities gives p-type semiconductor.

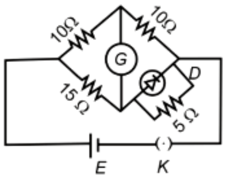
(c) The majority carriers in n-type semiconductor are holes.

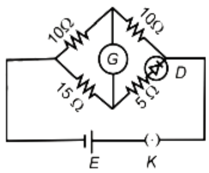
(d) A p-n junction can act as semiconductor diode.

7. Choose the correct circuit which can achieve the bridge balance (forward resistance of diode is 10 ohm)

(a) 

(b) 

(c) 

(d) 

8. A student wants to identify diode from a mixed collection of diodes, resistors, inductors, switch, thyristors, bulb etc using a multimeter. choose the correct statement out of the following about the diode :

(a) It is two terminal device which conducts current in both directions.

(b) It is two terminal device which conducts current in one direction only.

(c) It does not conduct current gives an initial deflection which decays to zero.

(d) It is three terminal device which conducts current in the direction only between central terminal and either of the remaining two terminals.

ANSWERS:

1. (a) Si and Ge are semiconductors, but C is an insulator. In Si and Ge at room temperature, the energy band gap is low due to which electrons in the covalent bonds gains kinetic energy and break the bond and move to conduction band. As a result, hole is created in valence band. So, the number of free electrons is significant in Si and Ge

2. (d)

3. (d) , $V_{d.c.} = V_{avg} = V_o \times 2/\pi = 20 / \pi$ V

4. (b) -2V > -2.5V

5. (d) 10 mA, ideal diode has zero resistance when forward biased.

6. (c) The majority carriers in n-type semiconductor are holes.

7. (a) In balanced bridge, Galvanometer will show zero result. Condition- P/Q = R/S

8. (b)

ASSERTION- REASON BASED QUESTIONS

For these Questions two statements are given one labelled Assertion (A) and other labelled Reason (R). Select the correct answer to these questions from the options as given below

A. If both Assertion and Reason are true and Reason is correct explanation of Assertion.

B. If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.

C. If Assertion is true but Reason is false.
D. If both Assertion and Reason are false.

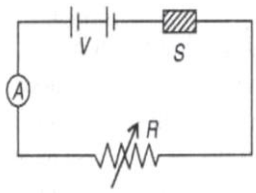
1. **Assertion (A):** As the temperature of a semiconductor increases, its resistance decreases.
Reason (R): The energy gap between conduction band and valence band is > 3eV in semiconductor.
2. **Assertion (A):** The resistivity of a semiconductor increases with temperature.
Reason (R): The atoms of a semiconductor vibrate with larger amplitude at higher temperature there by increasing it's resistivity.
3. **Assertion(A):** Semiconductors are used to build digital logic circuits.
Reason(R): They cannot easily switch between high and low voltage states.
4. **Assertion(A):** In digital electronics, we prefer Integrated circuits or diodes etc made up of Silicon over Germanium.
Reason(R): Silicon has better thermal stability.
5. **Assertion(A):** In an intrinsic semiconductor, the Fermi level lies midway between conduction and valence bands.
Reason(R): There are more electrons than holes in an intrinsic semiconductor.
6. **Assertion(A):** The band gap of Germanium is higher than that of silicon.
Reason(R): Germanium has higher resistivity than silicon.

ANSWERS

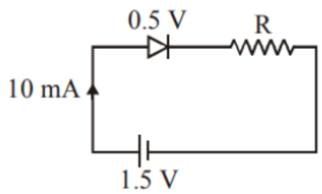
1. C, **Explanation:** As temperature rises, the electrons of valence band sufficient energy and jump to conduction band. Thus, the resistivity decreases. So assertion is true. In semiconductors the energy gap between conduction band and valence band is small.
2. D, **Explanation:** Resistivity of semiconductors decreases with temperature. So, assertion is false. Electrons from valence band jumps to conduction band with rise of temperature and hence the resistivity decreases. Hence, the reason is also false.
3. C**, Explanation:** Fast switching makes semiconductors ideal for logic.
4. A, **Explanation:** Silicon handles higher temperatures effectively.
5. C, **Explanation:** Reason is false; intrinsic semiconductors have equal electrons and holes.
6. D, **Explanation:** Both statements are false.

VERY-SHORT ANSWER QUESTIONS

1. In a p-n junction, width of depletion region is 300 nm and electric field of 7×10^5 V/m exists in it.
(i) Find the height of potential barrier.
(ii) What should be the minimum kinetic energy of a conduction electron which can diffuse from the n-side to the p-side?
Answer:- (i) $V=E.d=7\times10^5\times300\times10^{-9}=0.21V$
(ii) Kinetic energy =eV = 0.21 eV
2. The diagram shows a piece of pure **semiconductor 'S'** in series with **variable resistor R** and a source of constant voltage V. Would you increase or decrease the value of R to keep the reading of ammeter (A) constant when semiconductor 'S' is cooled ? Give one reason.



{Answer- Decrease the value of R
Reason : on cooling, conductivity of the semiconductor decreases}
3. When a diode is forward biased, it has a voltage drop of $\mathbf{0.5}V$. The safe limit of current through the diode is $\mathbf{10}mA$. If a battery of emf $\mathbf{1.5}V$ is used in the circuit, the value of minimum resistance to be connected in series with the diode so that the current does not exceed the safe limit will be?

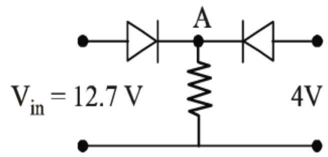


Answer- Applying Kirchhoff's voltage law

$1.5 - 0.5 - R \times 10 \times 10 - 3 = 0$

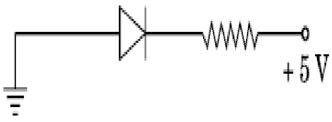
$\therefore R = 100\Omega$

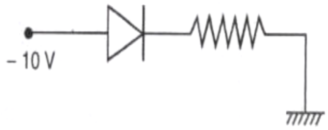
4. Both the diodes used in the circuit shown are assumed to be ideal and have negligible resistance when these are forward biased. Built in potential in each diode is **0.7 V**. For the input voltages shown in the figure, the voltage (in Volts) at point A is _______.

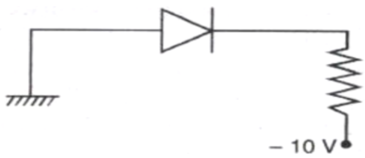


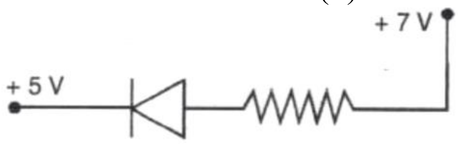
Answer- Right hand diode is reversed biased and left-hand diode is forward biased. Hence Voltage at 'A' $V_A = 12.7 - 0.7 =$ **12 volt**

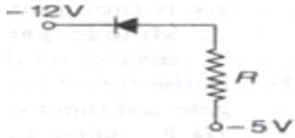
5. In the following circuit diagram, is the junction diode forward biased or reverse biased ?

(i) 

(ii) 

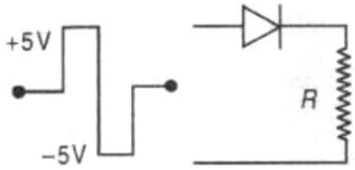
(iii) 

(iv) 

(v) 

{**Answer-** (i) reverse bias (ii) reverse bias (iii) Forward bias (iv) forward bias (v) forward bias

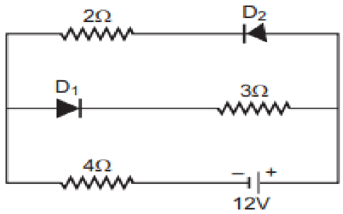
6. Draw and explain the output wave forms across the load resistor R, if the input waveform is as shown in the figure.



{**Answer:-**since the diode will be forward biased during the first half only,

so in 2nd half of input signal there will be no output. 

7. The circuit shown in the figure has two oppositely connected ideal diodes connected in parallel. Find the current flowing through each diode in the circuit.



{**Answer:-** through D1, I=0, through D2, $I = \frac{12}{2+4} = 2A$ }

SHORT-ANSWER QUESTIONS

1. Three samples are given to you. One is Copper, 2nd is Germanium, 3rd is Glass. Identify them as a conductor, an insulator or a semiconductor. Distinguish them on the basis of energy band diagrams.

{**Answer:-** 1st is a Conductor, 2nd is a semiconductor, 3rd is an insulator

(a). Conductors (Metals) :

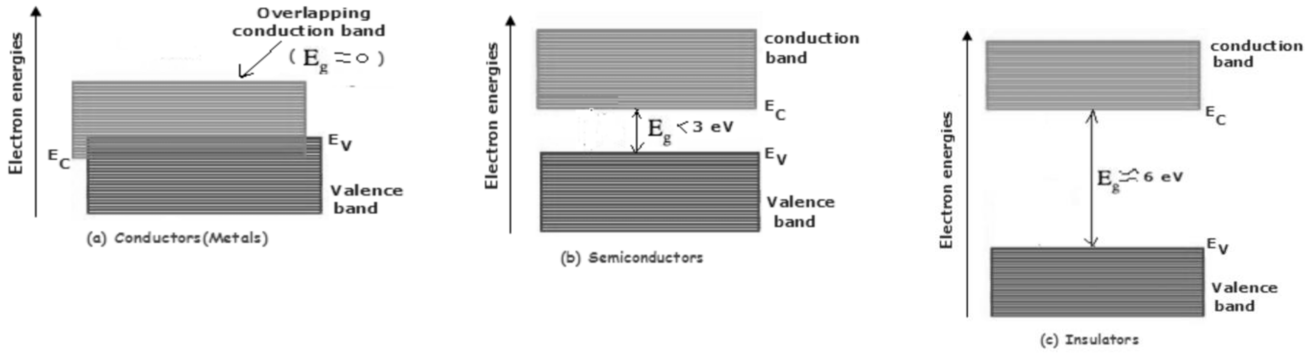
In conductors either conduction and valence band partly overlap each other or the conduction band is partially filled. Forbidden energy gap does not exist (This makes a large number of free electrons available for electrical conduction. So, the metals have high conductivity.

(b). Semiconductors :

In semiconductors, the conduction band is empty, and valance band is totally filled E_g is quite small (3 eV). At 0K, electrons are not able to cross this energy gap, and the semiconductor behaves as an insulator. But at room temperature, some electrons are able to jump to conduction band and semiconductor acquires small conductivity

(c). Insulators

In insulators, conduction band is empty and valance band is totally filled. E_g is very large (≈6 eV). It is not possible to give such large amount of energy to electrons by any means. Hence conduction band remains total empty, and the crystal remains as an insulator.



2. A pure sample of Ge with another Ge sample which is doped with an impurity of 13th or 15th group elements with impurity concentration 1 in million. Identify and compare the properties of both samples formed.

{Answer- One is intrinsic , 2nd one is extrinsic.

Intrinsic Semiconductor	**Extrinsic Semiconductor**
1. It is a pure semiconductor.	1. It is a semiconductor with added impurity.
2. $n_e = n_h$	2. $n_e \neq n_h$
3. Low conductivity at room temperature	3. High conductivity at room temperature
4. Its electrical conductivity depends on the temperature only.	4. Its electrical conductivity depends on temperature and the amount of doping.

3. A sample of Si doped with trivalent impurity and another Si sample which is doped with pentavalent impurity (each with impurity concentration 1 in million).

{Answer- First is p-type extrinsic semiconductor, 2nd one is n-type extrinsic semiconductor.

4. A student wants to produce **12 V** d.c. from **220 V, 50 Hz** a.c. signal. Firstly, he steps down the voltage from **220 V a.c.** to **12 V a.c.** using **a transformer** and to convert **12 V a.c.** to **12 V d.c.** he uses **a semiconductor device** which will produce an output frequency of 100Hz. Identify that semiconductor device. Explain its underlying working principle and working with help of a circuit diagram. Depict the input and output wave forms.

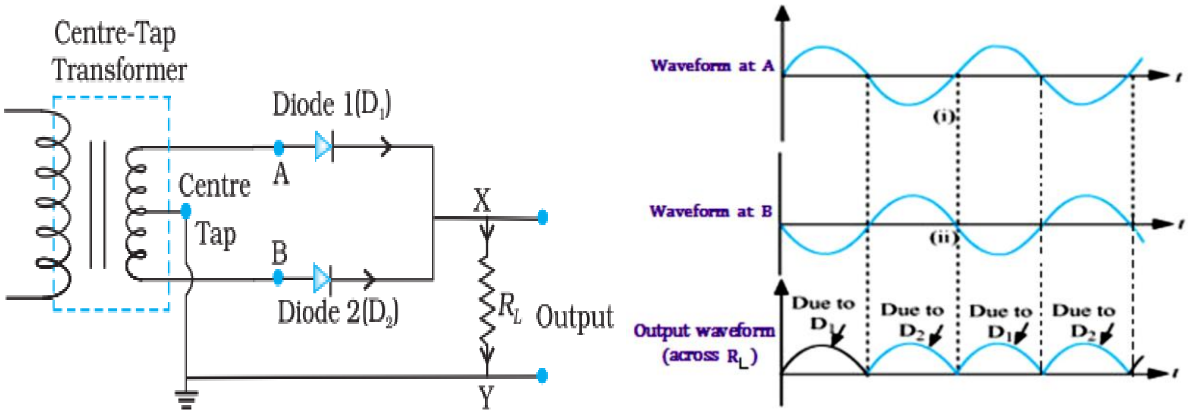
{Answer:- Device is Full wave rectifier.

Working Principle- a diode offers low resistance when forward biased and high resistance when reversed biased.

During the positive half cycle of a.c. input signal, diode D_1 gets forward biased and conducts while D_2 being reverse biased does not conducts. Hence, there is a current in R_L due to diode D_1 and we get an output voltage.

During the negative half cycle of ac input signal, diode D_1 gets reverse biased and does not conduct while D_2 being forward biased conducts. Hence, now there is a current in R_L due to diode D_2 and again we get an output voltage.

Thus, we get output voltage for complete cycle of a.c. input signal in the same direction.



5. Suppose a pure Si crystal has 5×10^{28} atoms m^{-3}. It is doped by 1ppm concentration of As. Calculate the number of electrons and holes. Given that $n_i = 1.5\times10^{16}$ m^{-3}. Is the doped crystal n-type or p-type?

{Answer:- Here $n_i = 1.5\times10^{16}$ m^{-3}

Doping concentration of As atoms = 1 ppm= 1 part per million

∴ Number density of pentavalent As atoms,

$N_D = \frac{5\times10^{28}}{10^6} = 5\times10^{22}$ atoms m^{-3}

Now, the thermally generated electrons are negligibly small as compared to those produced by doping, so

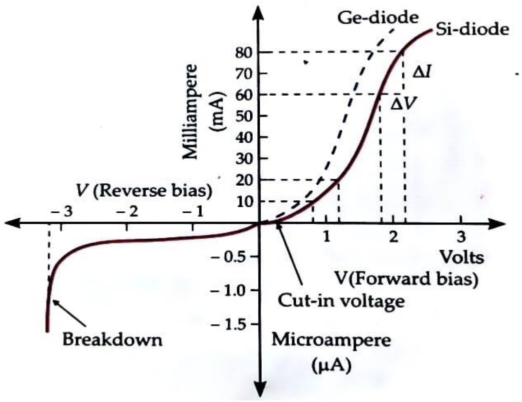
$n_e \approx N_D = 5\times10^{22}$ atoms m^{-3}

Also, $n_e n_h = n_i^2$

$\therefore n_h = \frac{n_i^2}{n_e} = \frac{1.5\times10^{16}\times1.5\times10^{16}}{5\times10^{22}} = 4.5\times10^{9}$ m^{-3}

Since the impurity is pentavalent, the doped crystal is n-type.

6. The V-I characteristic of a silicon diode is given in fig. below. Calculate the diode resistance in : (a) forward bias at V=+2 V and V=+1 V, and (b) reverse bias V= -1 V and -2 V.



Answer:- (a) the forward bias diode resistance is given by

$r_f = \frac{\Delta V}{\Delta I}$, where ΔV and ΔI are the small changes in voltage and current near the desired voltages.

$$r_f(at+2V) = \frac{(2.2-1.8)V}{(80-60)mA} = \frac{0.4\ V}{20\ \times10^{-3}\ A} = 20\ \Omega$$

$$r_f(at+1V) = \frac{(1.2-0.8)V}{(20-10)mA} = \frac{0.4\ V}{10\ \times10^{-3}\ A} = 40\ \Omega$$

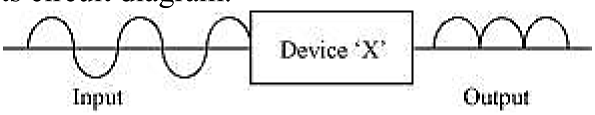
(b) in the reverse bias characteristic, the non-linearity in the V-I curve is small. The slopes of V-I curve at -1 V and -2 V are nearly equal.

$$r_r(at-2V) = \frac{-2\ V}{-0.25\ \mu A} = 8\ \times10^{6}\ \Omega$$

Also, $r_r(at-1V) = 8\ \times10^{6}\ \Omega$

LONG ANSWER QUESTIONS

1. **(a)** Explain the formation of depletion layer and potential barrier in a p–n junction.
(b) In the figure given below the input waveform is converted into the output waveform by a device 'X'. Name the device and draw its circuit diagram.



Answer:- (a) p-n junction : When a semiconductor crystal is so prepared that, it's one half is p-type and other is n-type, then the contact surface dividing the two halves, is called p-n junction.

Formation of p-n junction : potential barrier & depletion region

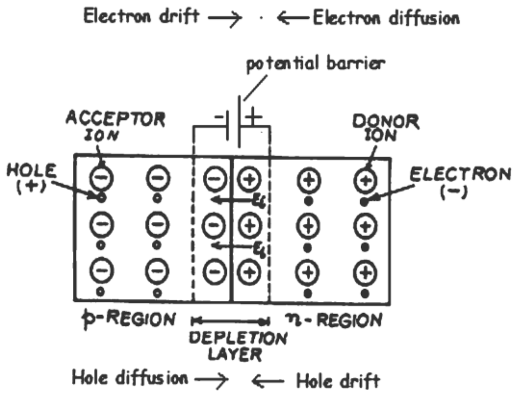
Diffusion and **drift** are the two important processes involved during the formation of a p-n junction.

Due to different concentration gradient of the charge carriers on two sides of the junction, electrons from n-side starts moving towards p-side and holes start moving from p-side to n-side.

Due to **diffusion**, positive space charge region is created on the n-side of the junction and negative space charge region is created on the p-side of the junction. Hence an electric field called Junction field is set up from n-side to p-side which forces the minority charge carriers to cross the junction. This process is called **Drift.**

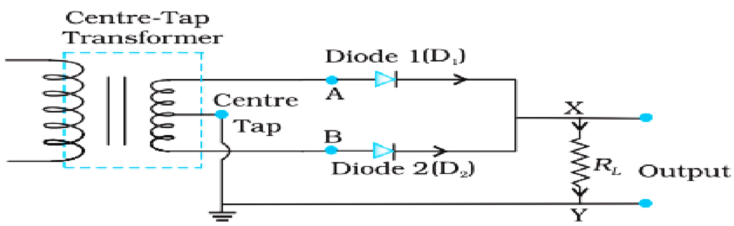
The potential difference developed across the p-n junction due to diffusion of majority charge carriers, which prevents the further movement of majority charge carriers through it, is called potential barrier. **For Si, V_B = 0.7 V** and **for Ge, V_B =0.3 V**

The small space charge region on either side of the p-n junction, which becomes depleted from mobile charge carriers is known as depletion region **(10^{-6} m)**



(b) The device is a full-wave rectifier.

The circuit diagram of a full-wave rectifier is represented as-

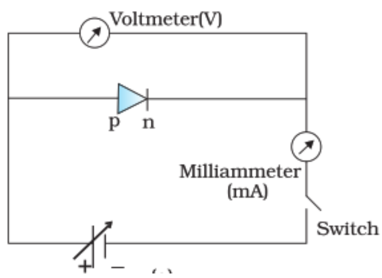


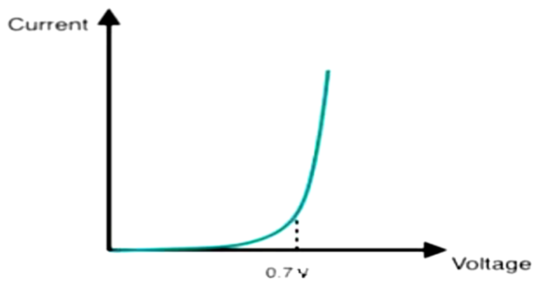
2. (a) A student connects p-side of a **p-n junction** diode with positive terminal of battery and n-side is connected with negative terminal of battery. Another student connects the diode in opposite way with battery. Identify the biasing in both the cases. Draw the circuit diagram of these biasings of a p-n junction.

(b) If the ratio of the concentration of electrons to that of holes in a semiconductor is 5/7 and the ratio of currents is 4/7. Find the ratio of their drift velocities.

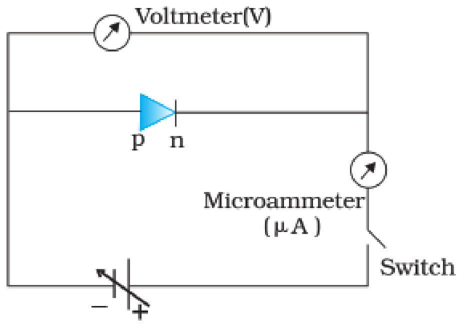
{Answer:- Case-1 Forward biasing :

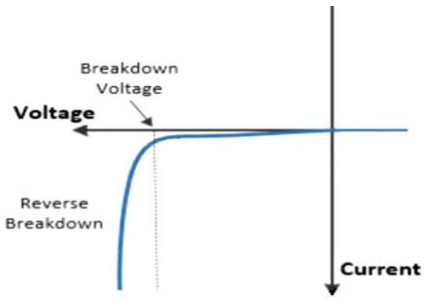
When the positive terminal of external battery is connected to p-side and negative terminal to the n-side, then the p-n junction is said to be forward biased





Case-2 Reverse biasing : When the positive terminal of external battery is connected to n-side and negative terminal to the p-side, then the p-n junction is said to be reverse biased





(b) Relation between drift velocity and current is

$I = nAeV_d$, $\frac{I_e}{I_h} = \frac{n_e AeV_e}{n_h AeV_h}$ or $\frac{7}{4} = \frac{7}{5} \times \frac{V_e}{V_h}$ or $\frac{V_e}{V_h} = \frac{5}{4}$

CASE STUDY-BASED QUESTIONS

1. Extrinsic semiconductors are made by doping pure or intrinsic semiconductors with suitable impurity. There are two type of dopants used in doping, Si or Ge, and using them p-type and n-type semiconductors can be obtained. A p-n junction is the basic building block of many semiconductor devices. Two important processes occur during the formation of a p-n junction: diffusion and drift. When such a junction is formed, a depletion layer is created consisting of immobile ion-cores.

This is responsible for a junction potential barrier. The width of a depletion layer and the height of potential barrier changes when a junction is forward-biased or reverse-biased. A semiconductor diode is basically a p-n junction with metallic contacts provided at the ends for application of an external voltage. Using diodes, alternating voltages can be rectified.

(i) Which of the following is a donor impurity atom for Ge ?

(A) Boron (B) Antimony (C) Aluminium (D) Indium

(ii) When a pentavalent atom occupies the position of an atom in the crystal lattice of Si, four of its electrons form covalent bonds with four silicon neighbors, while the fifth remains bound to the parent atom. The energy required to set this electron free is about :

(A) 0.5 eV (B) 0.1 eV (C) 0.05 eV (D) 0.01 eV

(iii) During formation of a p-n junction :

(A) a layer of negative charge on n-side and a layer of positive charge on p-side appear.
(B) a layer of positive charge on n-side and a layer of negative charge on p-side appear.
(C) the electrons on p-side of the junction move to n-side initially.
(D) initially diffusion current is small, and drift current is large.

(iv) (a) In reverse-biased p-n junction :

(A) the drift current is of the order of few mA.
(B) the applied voltage mostly drops across the depletion region.
(C) the depletion region width decreases.
(D) the current increases with increase in applied voltage.

OR

(b) The output frequency of a full-wave rectifier with 50 Hz as input frequency is :

(A) 25 Hz (B) 50 Hz (C) 100 Hz (D) 200 Hz

Answer:- i).B ii). C iii).B iv). (a) B **OR** (b) C

IMPORTANT LINKS

NAME OF THE CHAPTERS	WORKSHEET 1	WORKSHEET2
CHAPTER–1	Electric Charges and Fields-Worksheet-1	Electric Charges and Fields-Worksheet-2
CHAPTER–2:	Electrostatic Potential and Capacitance-Worksheet-1	Electrostatic Potential and Capacitance-Worksheet-2
CHAPTER–3:	Current Electricity -Worksheet-1	Current Electricity -Worksheet-2
CHAPTER–4:	Moving Charges and Magnetism-Worksheet	Chapter -4:Magnetic effects of current
CHAPTER–5:	Magnetic Material- Worksheet	(CHAPTER-5 Magnetism & Matter)
CHAPTER–6:	Electromagnetic Induction-Worksheet	Electromagnetic Induction
CHAPTER–7:	Alternating Current and Electromagnetic Waves-Worksheet	ALTERNATING CURRENT
CHAPTER–8:		ELECTROMAGNETIC WAVES
CHAPTER–9:	Ray Optics and Optical instruments-Worksheet	Ray Optics and Optical instruments-Worksheet 2
CHAPTER–10:	Wave -Optics-Worksheet	WAVE OPTICS-Worksheet 2
CHAPTER–11:	Dual Nature of Radiation and Matter-Worksheet-1	Dual Nature of Radiation and Matter-Worksheet-2
CHAPTER–12:	Atoms-Worksheet	Worksheet for Atoms
CHAPTER–13:	Nuclei-Worksheet	Worksheet for Nuclei
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