

**KENDRIYA VIDYALAYA SANGATHAN**  
**CHENNAI REGION**



तत् त्वं पूषन् अपावृणु  
केन्द्रीय विद्यालय संगठन

**CLASS – XII**

**PHYSICS**

**SESSION 2022-23**

**PREPARATION PLANNER & PACKAGE**  
**FOR HIGH ACHIEVERS**

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## CONTENT DEVELOPMENT TEAM

S.No	Name of the Chapter	Name of the Teacher	Name of the KV
1	Unit - 1 Electrostatics (Chapters 1 & 2)	MRS. R SUGUNA	CHENNAI AFS AVADI
2	Unit - II Current Electricity (Chapter-3) & Preparation of Questions Paper for 35 marks from Unit 1 & 2	MRS. GEETHA RAMESH	CHENNAI ANNANAGAR
3	Unit - III Magnetic Effects of Current and Magnetism (Chapters 4&5)	MR.T.MURALI	CHENNAI DGQA
4	Unit - IV Electromagnetic Induction and Alternating (Chapters 6 & 7)	MRS.RADHA MUKUNDAN	CHENNAI MINAMBAKKAM
5	Unit - V Electromagnetic Waves (Chapter-8) & Preparation of Questions Paper for 35 marks from Unit 3 & 4	MR.SANKARRAMAN	CHENNAI MINAMBAKKAM
6	Unit - VI Optics (Chapters 9&10)	MR .V SIVARAMAKRISHNAN	COIMBATORE
7	Unit - VII Dual Nature of Radiation and Matter (Chapter- 11) & Preparation of Questions Paper for 35 marks from Unit 5 & 6	MR. K. RENGANATHAN	TRICHY NO.1
8	Unit - VIII Atoms and Nuclei (Chapter 12 & 13)	MR. C. MURUGAVEL	PONDICHERRY NO.1 Shift 1
9	Unit - IX Electronic Devices (Chapter 14) & Preparation of Questions Paper for 35 marks from Unit 7, 8 & 9	MR SATYA SURYANARAYANA SURMPUDI	PORT BLAIR NO.2

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## CONTENT & PLAN

DAY	NAME OF THE UNIT	TASKS	PAGE NO.	Completed or Not
DAY -1	Unit - 1 Electrostatics (Chapters 1 & 2)	<ul style="list-style-type: none"> <li>• Preparation of Lessons</li> <li>• Revision –Formula chart &amp; Quick revision notes</li> <li>• Numericals for \revisions</li> </ul>	3 – 4 5 -9	
DAY -2		<ul style="list-style-type: none"> <li>• Numericals for practice</li> <li>• Solving-Case study questions</li> <li>• Solving-Assignment-1</li> <li>• Solving- Assignment-2</li> </ul>	9 – 14 14 – 17 17 – 21 21 - 23	
DAY -3	Unit - II Current Electricity (Chapter-3)	<ul style="list-style-type: none"> <li>• Preparation of Lessons</li> <li>• Revision –Formula chart &amp; Quick revision notes</li> <li>• Numericals for revisions</li> <li>• Numericals for practice</li> <li>• Solving-Case study questions</li> <li>• Solving-Assignment-1</li> <li>• Solving- Assignment-2</li> </ul>	24 25 – 29 30 – 36 37 – 42 43 – 51 51 - 60	
DAY -4	Full Revisions Revision Test - Unit 1 &2 (35 marks)		60 -69	
DAY -5	Unit - III Magnetic Effects of Current and Magnetism (Chapters 4&5)	<ul style="list-style-type: none"> <li>• Preparation of Lessons</li> <li>• Revision –Formula chart &amp; Quick revision notes</li> </ul>	70 - 72	
DAY -6		<ul style="list-style-type: none"> <li>• Numericals for revisions</li> <li>• Numericals for practice</li> <li>• Solving-Case study questions</li> <li>• Solving-Assignment-1</li> <li>• Solving- Assignment-2</li> </ul>	73 – 75 76 - 77 78 – 80 81 - 83	
DAY -7	Unit - IV Electromagnetic Induction and Alternating (Chapters 6 & 7)	<ul style="list-style-type: none"> <li>• Preparation of Lessons</li> <li>• Revision –Formula chart &amp; Quick revision notes</li> <li>• Numericals for revisions</li> <li>• Numericals for practice</li> <li>• Solving-Case study questions</li> <li>• Solving-Assignment-1</li> <li>• Solving- Assignment-2</li> </ul>	84 – 87 87 – 92 93 – 95 96 – 97 98 – 106 106 - 111	
DAY -8	Full Revisions Revision Test - Unit 3 &4 (35 marks)		112 - 120	

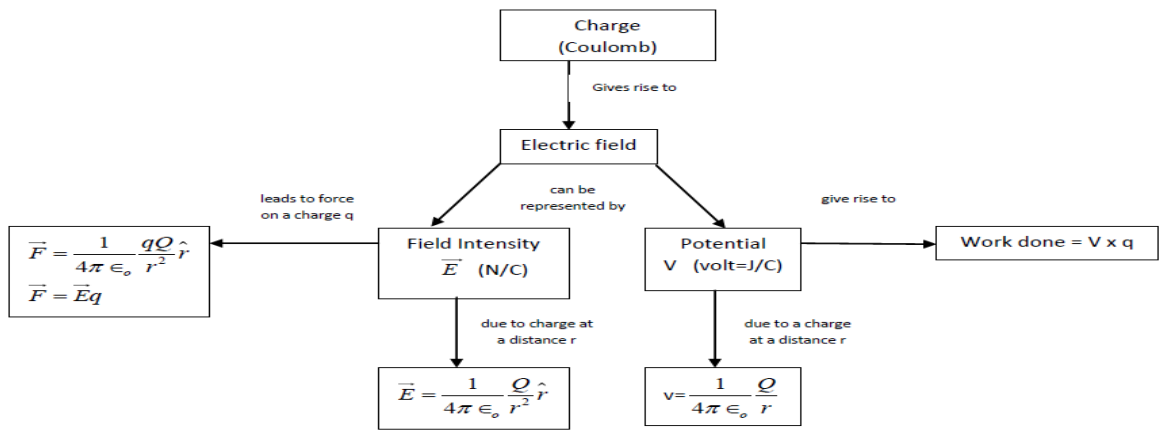
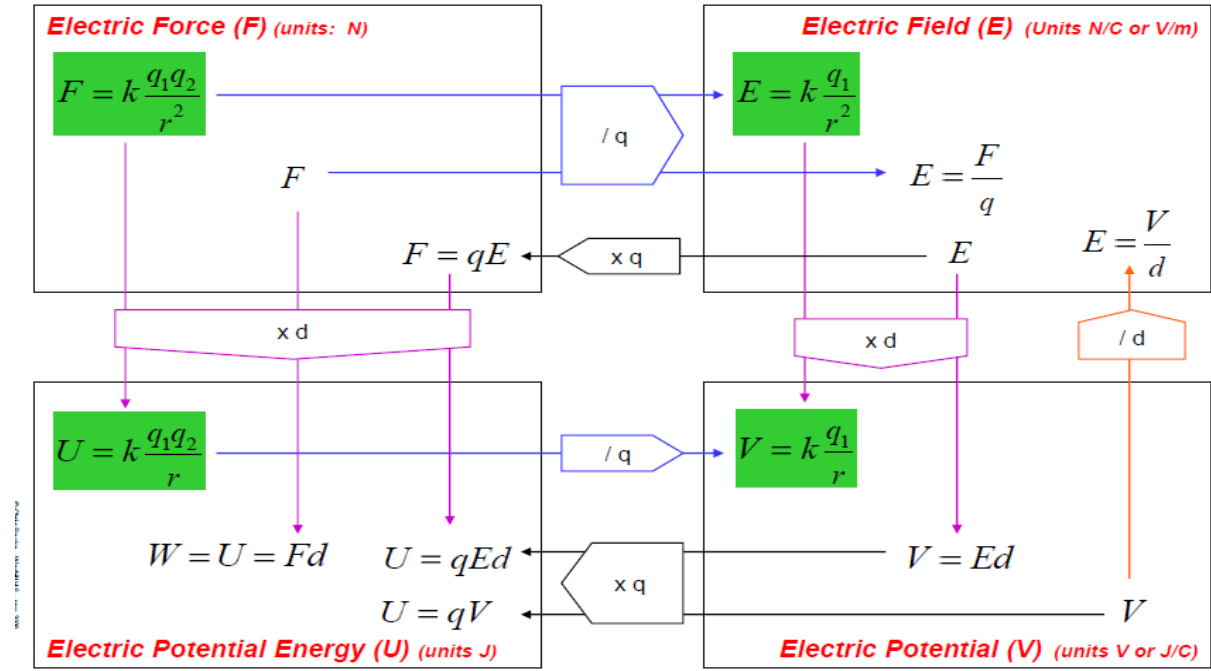
<b>DAY -9</b>	Unit - V Electromagnetic Waves (Chapter-8) Unit - VI Optics (Chapters 9)	<ul style="list-style-type: none"> <li>• Preparation of Lessons</li> <li>• Revision –Formula chart &amp; Quick revision notes</li> <li>• Numericals for revisions</li> <li>• Numericals for practice</li> <li>• Solving-Case study questions</li> <li>• Solving-Assignment-1</li> <li>• Solving- Assignment-2</li> </ul>	<p style="text-align: center;">121</p> <p>122 - 124</p> <p>124 –125</p> <p>126 – 129</p> <p>130 - 138</p>	
<b>DAY -10</b>	Unit - VI Optics Continued to (Chapters10)	<ul style="list-style-type: none"> <li>• Preparation of Lessons</li> <li>• Revision –Formula chart &amp; Quick revision notes</li> <li>• Numericals for revisions</li> <li>• Numericals for practice</li> <li>• Solving-Case study questions</li> <li>• Solving-Assignment-1</li> <li>• Solving- Assignment-2</li> </ul>	<p>139 – 140</p> <p>141 – 144</p> <p>145 – 146</p> <p>146 – 147</p> <p>148 – 151</p> <p>152 - 154</p>	
<b>DAY -11</b>	<b>Full Revisions</b>			
	Revision Test - Unit 5 & 6 (35 marks)		174 - 179	
<b>DAY -12</b>	Unit - VII Dual Nature of Radiation and Matter (Chapter- 11)	<ul style="list-style-type: none"> <li>• Preparation of Lessons</li> <li>• Revision –Formula chart &amp; Quick revision notes</li> <li>• Numericals for revisions</li> <li>• Numericals for practice</li> <li>• Solving-Case study questions</li> <li>• Solving-Assignment-1</li> <li>• Solving- Assignment-2</li> </ul>	<p style="text-align: center;">155</p> <p>156 – 158</p> <p>159 – 161</p> <p>162 – 164</p> <p>165 – 167</p> <p>168 - 173</p>	
<b>DAY -13</b>	Unit - VIII Atoms and Nuclei (Chapter 12 & 13)	<ul style="list-style-type: none"> <li>• Preparation of Lessons</li> <li>• Revision –Formula chart &amp; Quick revision notes</li> <li>• Numericals for revisions</li> <li>• Numericals for practice</li> <li>• Solving-Case study questions</li> <li>• Solving-Assignment-1</li> <li>• Solving- Assignment-2</li> </ul>	<p>180 – 181</p> <p>182 – 185</p> <p>186 – 187</p> <p>188 – 189</p> <p>190 – 193</p> <p>194 - 195</p>	
<b>DAY -14</b>	Unit - IX Electronic Devices (Chapter 14)	<ul style="list-style-type: none"> <li>• Preparation of Lessons</li> <li>• Revision –Formula chart &amp; Quick revision notes</li> <li>• Numericals for revisions</li> <li>• Numericals for practice</li> <li>• Solving-Case study questions</li> <li>• Solving-Assignment-1</li> <li>• Solving- Assignment-2</li> </ul>	<p style="text-align: center;">196</p> <p>197 – 200</p> <p>201 – 203</p> <p>204 – 205</p> <p>206 – 208</p> <p>209 - 214</p>	
<b>DAY -15</b>	<b>Full Revisions</b>			
	Revision Test - Unit 7,8 & 9 (35marks)		215 - 221	

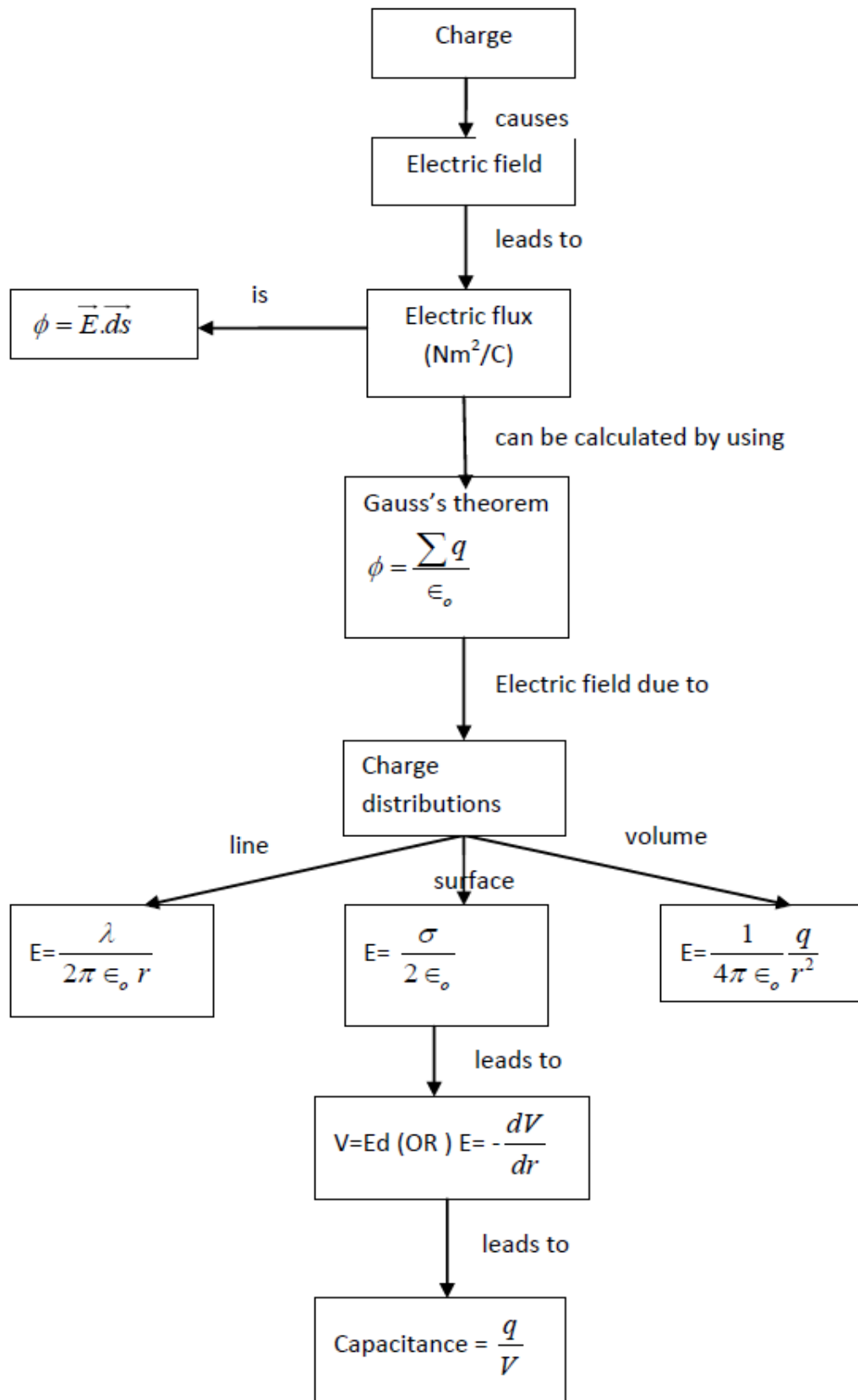
# Unit - 1 Electrostatics (Chapters 1&2)

## FORMULA CHART

### Electrostatics Concept Map

/ q to get "per charge"  
 x q to get "for an amount of charge"  
 / d to get "per distance"  
 x d (where d = r) to get "over distance"



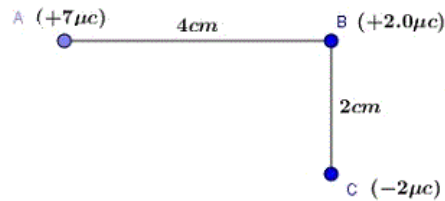


## NUMERICALS FOR PRACTICE WITH SOLUTIONS

S.no      QUESTION

HINT

- 1      What is the net force and its direction that the charges at the vertices A and C of the right triangle ABC exert on the charge in vertex B?

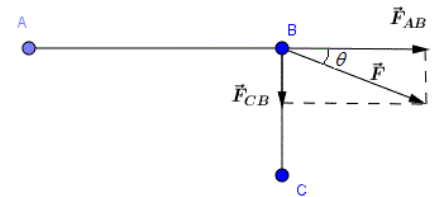


$$|F| = \sqrt{(|F_{AB}|^2 + |F_{CB}|^2)} =$$

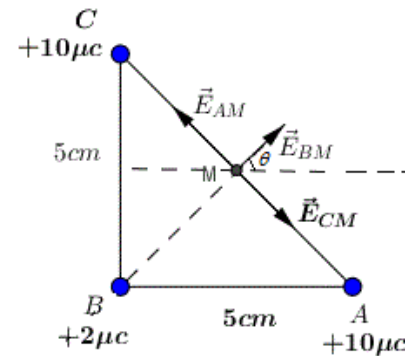
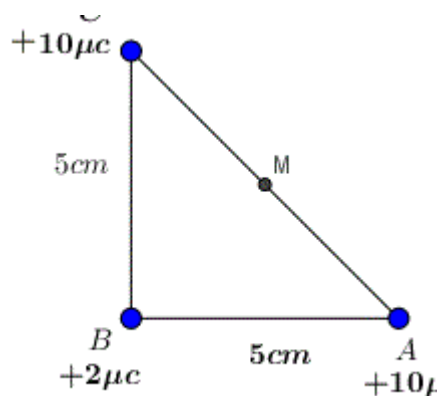
$$k \times 10^{-8} \sqrt{(0.875^2 + 1^2)} =$$

$$9.00 \times 10^9 \times 10^{-8} \sqrt{(0.875^2 + 1^2)} = 1.20 \times 10^2 \text{ N}$$

$$\theta = \arctan(|F_{CB}| / |F_{AB}|) = \arctan(k \times 10^{-8} / 0.875 k \times 10^{-8}) = 48.8^\circ$$



- 2      Three charges are located at the vertices of a right isosceles triangle as shown below. What is the magnitude and direction of the resultant electric field at the midpoint M of AC?



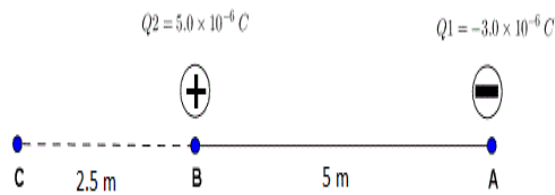
$$E = E_{BM} = 1.44 \times 10^7 \text{ N/C}$$

- 3      The distance AB between charges Q1 and Q2 shown below is 5.0 m. How much work must be done to move

If W is the work to be done to move Q2 from a position where



charge  $Q_2$  to a new location at point C so that the distance  $BC = 2.5 \text{ m}$ ?



its potential energy is  $E_{p1}$  and kinetic energy 0 (from rest) to another position where its potential energy is  $E_{p2}$  and kinetic energy 0 (to rest), then by the conservation of energy, we have.

$$E_{p1} + W = E_{p2}$$

which gives

$$W = E_{p2} - E_{p1}$$

$$W = k Q_1 Q_2 \left( \frac{1}{AB} - \frac{1}{AC} \right) \\ = 9 \times 10^{-3} \text{ J}$$

- 4 **A parallel plate capacitor having capacitance 12 pF is charged by a battery to a potential difference of 10 V between its plates. The charging battery is now disconnected and a porcelain slab of dielectric constant 6.5 is slipped between the plates. Find the work done by the capacitor on the slab.**

Initial Energy of the capacitor,  
 $U_i = (1/2) CV^2$

$$= (1/2) \times 12 \text{ pF} \times 10 \times 10 \\ = 600 \text{ pJ}$$

After the slab, the energy of the slab,  $U_f = (1/2) Q^2/C'$

$$Q = CV = (12 \text{ pF})(10 \text{ V}) = 120 \text{ pC}$$

$$C' = kC = 6.5 \times 120 \times 10^{-12} \text{ F}$$

$$\text{Therefore, } U_f = [(1/2) (120 \times 10^{-12})^2] / [6.5 \times 120 \times 10^{-12}]$$

$$U_f = 92 \text{ pJ}$$

$$W = U_i - U_f$$

- 5 **There is a uniform electrostatic field in a region. The potential at various points on a small sphere centred at P, in the region, is found to vary between the limits 589.0 V to 589.8 V. What is the potential at a point on the sphere whose radius vector makes an angle of  $60^\circ$  with the direction of the field?**

$$\Delta V = E \cdot d$$

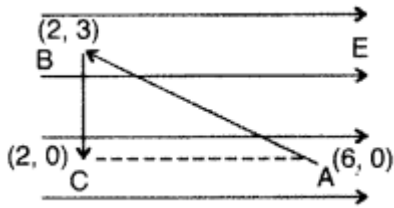
$$\Delta V = E d \cos \theta = 0.8 \times \cos 60^\circ$$

$$\Delta V = 0.4$$

Hence the new potential at the point on the sphere is

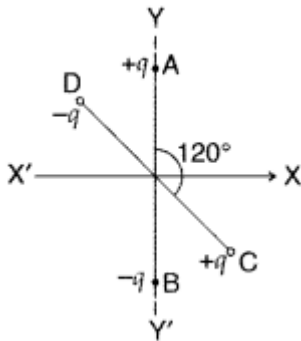
$$589.0 + 0.4 = 589.4$$

- 6 A test charge 'q' is moved without acceleration from A to C along the path from A to B and then from B to C in electric field E as shown in the figure.



- (i) Calculate the potential difference between A and C.  
(ii) At which point (of the two) is the electric potential more and why?

- 7 Two small identical electrical dipoles AB and CD, each of dipole moment 'p' are kept at an angle of  $120^\circ$  as shown in the figure. What X' is the resultant dipole moment of this combination? If this system is subjected to electric field (E  $\rightarrow$ ) directed along + X direction, what will be the magnitude and direction of the torque acting on this?



P.D does not depend upon the path along which the test charge q moves

$$\therefore E = \frac{-dV}{dr} = -\left(\frac{V_C - V_A}{d}\right) = \frac{V_A - V_C}{d}$$

$$\therefore d_{AC} = 4 \quad \text{So } V_A - V_C = E \times 4 = 4E$$

- (ii) At point C, electric potential will be more as potential decreases in the direction of electric field.

Answer:

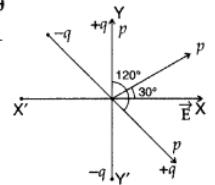
Resultant dipole moment of both dipoles is

$$= \sqrt{p^2 + p^2 + 2p^2 \cos \theta}$$

$$= \sqrt{2p^2 + 2p^2 \cos 120^\circ}$$

$$= \sqrt{2p^2 + 2p^2 \left(-\frac{1}{2}\right)}$$

$$= \sqrt{p^2} = p$$

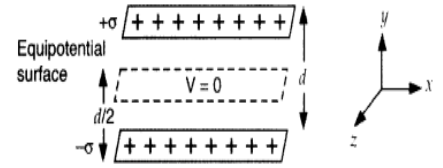


Resultant dipole moment (p) makes an angle of  $60^\circ$  with each dipole and  $30^\circ$  with x-axis as shown in the figure.

$$\text{Now } \tau = pE \sin 30^\circ = pE \left(\frac{1}{2}\right) \Rightarrow \tau = \frac{pE}{2}$$

- 8 Two uniformly large parallel thin plates having charge densities  $+\sigma$  and  $-\sigma$  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?

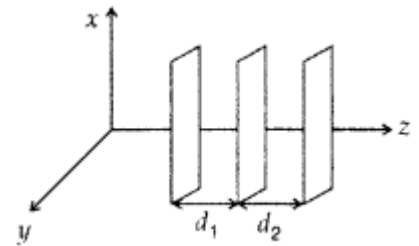
The equipotential surface is at a distance d/2 from either plate in X-Z plane. For a particle of charge (-q) at rest between the plates, then



- (i) weight  $mg$  acts, vertically downward
- (ii) electric force  $qE$  acts vertically upward

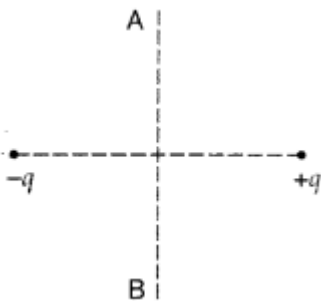
9 Draw 3 equipotential surfaces corresponding to a field that uniformly increases in magnitude but remains constant along Z-direction. How are these surfaces different from that of a constant electric field along Z-direction?

$d_2 < d_1$  for increasing field and  $d_2 = d_1$  for uniform field.

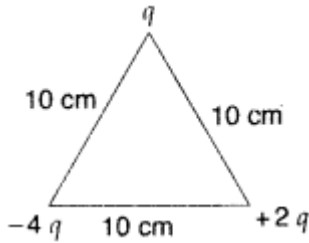


10 A charge 'q' is moved from a point A above a dipole of dipole moment 'p' to a point B below the dipole in equatorial plane without acceleration. Find the work done in the process. (All India 2016)

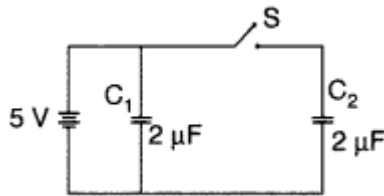
potential remains constant



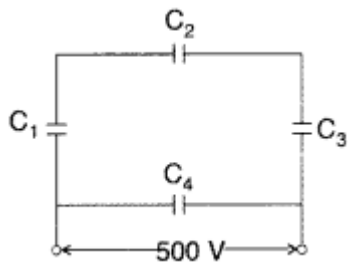
- 11 Calculate the work done to dissociate the system of three charges placed on the vertices of a triangle as shown.



- 12 Figure shows two identical capacitors  $C_1$  and  $C_2$ , each of  $2 \mu\text{F}$  capacitance, connected to a battery of  $5 \text{ V}$ . Initially switch 'S' is left open and dielectric slabs of dielectric constant  $K = 5$  are inserted to fill completely the space between the plates of the two capacitors. How will the charge and



- (ii) potential difference between the plates of the capacitors be affected after the slabs are inserted?
- 13 A network of four capacitors each of  $12 \mu\text{F}$  capacitance is connected to a  $500 \text{ V}$  supply as shown in the figure. Determine
- (a) equivalent capacitance of the network and
- (b) charge on each capacitor.



- 14 Two parallel plate capacitors of capacitances  $C_1$  and  $C_2$  such that  $C_1 = 3C_2$  are connected across a battery of  $V$  volts as shown in the figure. Initially the key (k) is kept dosed to fully charge the capacitors. The key is now

Find

$$\text{initial P.E} = U_i$$

$$\text{Final P.E} = U_f = 0$$

$$\text{W.D} = U_i - U_f$$

- (i) When switch S is open and dielectric is introduced, charge on each capacitor will be  $q_1 = C_1 V$ ,  $q_2 = C_2 V$   
 $q_1 = 5CV$   
 $= 5 \times 2 \times 5 = 50 \mu\text{C}$ ,  $q_2 = 50 \mu\text{C}$   
 Charge on each capacitor will become 5 times

- (ii) P.d. across  $C_1$  is still  $5 \text{ V}$  and across  $C_2$ ,  
 $q = (5C) V$

$$V' = \frac{V}{5} = \frac{5}{5} = 1 \text{ V}$$

Equivalent capacitance of the network,

$$C_{123} = \frac{12 \mu\text{F}}{3} = 4 \mu\text{F} (\because \text{being in series}) \dots (i)$$

$$C_{\text{eq}} = C_{123} + C_4 = (4 + 12) \mu\text{F} = 16 \mu\text{F} \dots [\text{From } (i)]$$

$$(b) (i) Q = CV, \quad Q_1 = C_4 V$$

$$\therefore Q_1 = 500 \times 12 \times 10^{-6}$$

$$= 6000 \times 10^{-6} = 6 \times 10^{-3} \text{ C}$$

$$\therefore \text{Charge on capacitor, } C_4 = 6 \times 10^{-3} \text{ C}$$

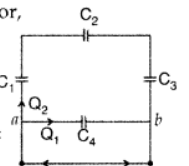
$$(ii) Q_2 = C_{123} V$$

$$= (4 \times 10^{-6}) \times 500$$

$$= 2 \times 10^{-3} \text{ C}$$

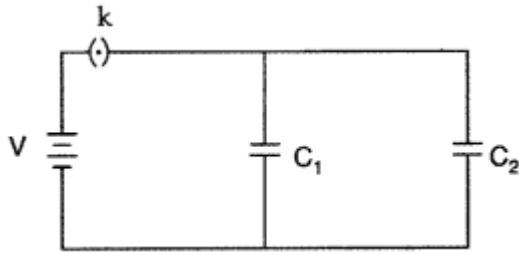
$$\therefore \text{Charge on each of the capacitors } C_1, C_2 \text{ and } C_3$$

$$= 2 \times 10^{-3} \text{ C}$$



Net capacitance before filling the gap with dielectric slab

thrown open and a dielectric slab of dielectric constant 'K' is inserted in the two capacitors to completely fill the gap between the plates,



Find the ratio of

- (i) the net capacitance and
- (ii) the energies stored in the combination, before and after the introduction of the dielectric slab.

$$C_{\text{initial}} = C_1 + C_2 = 3C_2 + C_2 = 4C_2$$

Net capacitance after filling the gap with dielectric slab of dielectric constant 'K'

$$C_{\text{final}} = KC_1 + KC_2 = 3KC_2 + KC_2 = 4KC_2$$

∴ Ratio of net capacitance,

$$\frac{C_{\text{initial}}}{C_{\text{final}}} = \frac{4C_2}{4KC_2} = \frac{1}{K}$$

Energy stored in the combination before introduction of dielectric slab,

$$U_{\text{initial}} = \frac{Q^2}{3C_2}$$

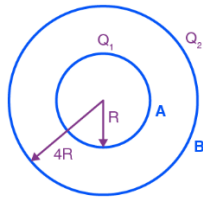
Energy stored in the combination after introduction of dielectric slab,

$$U_{\text{final}} = \frac{Q^2}{3KC_2}$$

∴ Ratio of energy stored

$$\frac{U_{\text{initial}}}{U_{\text{final}}} = \frac{Q^2}{3C_2} / \frac{Q^2}{3KC_2} = \frac{K}{1} = K$$

- 15 **Concentric metallic hollow spheres of radii R and 4R hold charges Q<sub>1</sub> and Q<sub>2</sub> respectively. Given that the surface charge density of the concentric spheres are equal, Find potential difference V(R) – V(4R) .**



$$V_A = kQ_1/R + kQ_2/R$$

Potential on the surface of the outer sphere (at B)

$$V_B = kQ_1/4R + kQ_2/4R$$

Potential difference,

$$\Delta = V_A - V_B = 3/4(kQ_1/R) =$$

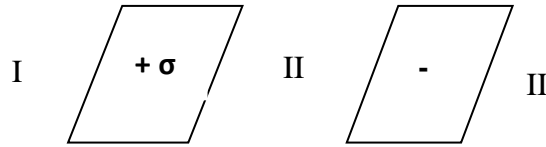
$$[3/16\pi\epsilon_0] (Q_1/R)$$

## NUMERICALS FOR PRACTICE

S.No	Question	Answer
1	What is the direction and magnitude of the electric field at the midpoint of an electric dipole made of $\pm Q$ , length 2a?	$E = \frac{2kQ}{a^2}$ Direction against $\vec{p}$

$$E_I = E_{III} = 0, E_{II} = \sigma/\epsilon_0$$

2



Write the expression for the electric field in the regions I, II, III shown in the above figure.

- 3 Show diagrammatically the stable and unstable equilibrium of an electric dipole placed in a uniform electric field

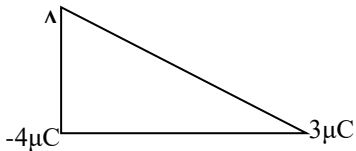
$$\rightarrow \vec{p} \rightarrow \vec{E} \text{ stable}$$

$$\leftarrow \vec{p} \rightarrow \vec{E} \text{ Unstable}$$

- 4 Two electric charges  $3\mu\text{C}$ ,  $-4\mu\text{C}$  are placed at the two corners of an isosceles right angled triangle of side 1 m as shown in the figure. What is the direction and magnitude of electric field at A due to the two charges?

$$E = 45 \times 10^3 \text{ NC}^{-1}$$

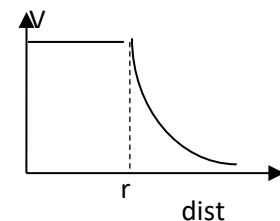
$$\theta = 36.9^\circ \text{ from line AB}$$



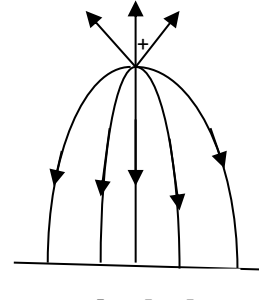
- 5 A charge  $+Q$  fixed on the Y axis at a distance of 1m from the origin and another charge  $+2Q$  is fixed on the X axis at a distance of  $\sqrt{2}$  m from the origin. A third charge  $-Q$  is placed at the origin. What is the angle at which it moves?

Force due to both the changes are equal  $= KQ^2$  &  $\perp$  to each other so the resultant force will make  $45^\circ$  with X-axis.

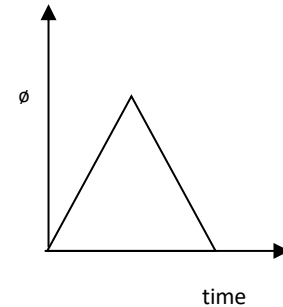
- 6 Draw the graph showing the variation of electric potential with distance from the centre of a uniformly charged shell.



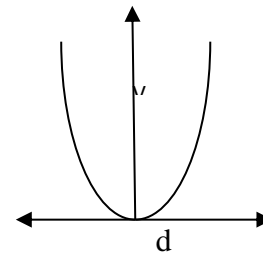
- 7 Sketch the electric field lines, when a positive charge is kept in the vicinity of an uncharged conducting plate



- 8 A uniformly charged rod with linear charge density  $\lambda$  of length  $L$  is inserted into a hollow cubical structure of side 'L' with constant velocity and moves out from the opposite face. Draw the graph between flux and time.



- 9 Draw a graph showing the variation of potential with distance from the positive charge to negative charge of a dipole, by choosing the mid-point of the dipole as the origin.



- 10 Three charges  $+Q$ ,  $q$ ,  $+Q$  are placed respectively, at distance  $0$ ,  $d/2$  and  $d$  from the origin, on the  $x$ -axis. If the net force experienced by  $+Q$  placed at  $x = 0$  is zero, then value of  $q$  is

$$\begin{aligned} \frac{Qq}{d^2} + \frac{Qq}{(d/2)^2} &= 0 \\ Q + 4q &= 0 \\ \text{or } q &= -Q/4 \end{aligned}$$

- 11 An electric field of  $1000 \text{ V/m}$  is applied to an electric dipole at an angle of  $45^\circ$ . The value of the electric dipole moment is  $10^{-29} \text{ Cm}$ . What is the potential energy of the electric dipole?

$$E = 1000 \text{ V/m}, p = 10^{-29} \text{ cm}, \theta = 45^\circ$$

Potential energy stored in the dipole,

$$\begin{aligned} U &= -p \cdot E \cos \theta = \\ &= -10^{-29} \times 1000 \times \cos 45^\circ \\ U &= -12 \times 10^{-26} \end{aligned}$$

$$U = -0.707 \times 10^{-26} \text{ J} = -7 \times 10^{-27} \text{ J}$$

- 12 The bob of a simple pendulum has a mass of 2 g and a charge of 5.0 C. It is at rest in a uniform horizontal electric field of intensity  $2000 \text{ V m}^{-1}$ . At equilibrium, the angle that the pendulum makes with the vertical is (take  $g = 10 \text{ m s}^{-2}$ )

At equilibrium,

$$T \cos \theta = mg \text{ ---(1)}$$

$$T \sin \theta = qE \text{ ---(2)}$$

Dividing (2) by (1)

$$\tan \theta = qE/mg$$

$$\theta = \tan^{-1}((5 \times 10^{-6} \times 2 \times 10^3) / (2 \times 10^{-3} \times 10)) = \tan^{-1}(0.5)$$

- 13 A capacitor with a capacitance  $5 \mu\text{F}$  is charged to  $5 \mu\text{C}$ . If the plates are pulled apart to reduce the capacitance to  $2 \mu\text{F}$ , how much work is done?

$$\text{Work done} = U_f - U_i = (1/2)q^2/C_f - (1/2)q^2/C_i$$

$$\text{Work done} = q^2/2[1/C_f - 1/C_i]$$

$$\text{Work done} =$$

$$[(5 \times 10^{-6})^2/2][(1/(2 \times 10^{-6})) - (1/(5 \times 10^{-6}))]$$

$$\text{Work done} = 3.75 \times 10^{-6} \text{ J}$$

- 14 A parallel plate capacitor of capacitance  $90 \text{ pF}$  is connected to a battery of emf  $20 \text{ V}$ . If a dielectric material of dielectric constant  $K = 5/3$  is inserted between the plates, find the magnitude of the induced charge?

Induced charge on dielectric,

$$Q_{\text{ind}} = Q(1 - 1/K)$$

$$\text{Final charge on capacitor, } Q = K C_0 V$$

$$Q = (5/3) \times 90 \times$$

$$10^{-12} \times 20 = 3 \times 10^{-9} \text{ C} = 3 \text{ nC}$$

$$Q_{\text{ind}} = 3(1 - 3/5) =$$

$$3 \times 2/5 = 1.2 \text{ nC}$$

- 15 How will connect seven capacitors of  $2 \mu\text{f}$  to obtain an effective capacitance of  $10/11 \mu\text{f}$ .
- 16 Two identical metal plates are given positive charges  $Q_1$  and  $Q_2$ , where  $Q_1 > Q_2$ . Find the potential difference between them,

5 in parallel and 2 in series

$$V = Q/C$$

Total charge =



if they are now brought together to form a parallel plate capacitor with capacitance C.

$$Q_1 - Q_2$$

$$V = Q_1 - Q_2 / C$$

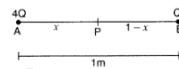
- 17 Why is electrostatic potential constant throughout the volume of the conductor and has the same value (as inside) on its surface?

Electric field inside the conductor = 0

$$E = -\frac{dV}{dr} \Rightarrow \frac{dV}{dr} = 0 \therefore V = \text{constant}$$

- 18 Two point charges  $4Q, Q$  are separated by  $1\text{m}$  in air. At what point on the line joining the charges is the electric field intensity zero?

(i) Given:  $r = 1\text{m}, q_1 = 4Q, q_2 = Q$



$$E_{\text{res}} = E_{\text{res}}$$

$$\frac{K(4Q)}{x^2} = \frac{KQ}{(1-x)^2} \Rightarrow \frac{4}{x^2} = \frac{1}{(1-x)^2}$$

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

$$\Rightarrow 3x = 2 \therefore x = \frac{2}{3}\text{m}$$

Also calculate the electrostatic potential energy of the system of charges, taking the value of charge,  $Q = 2 \times 10^{-7}\text{C}$

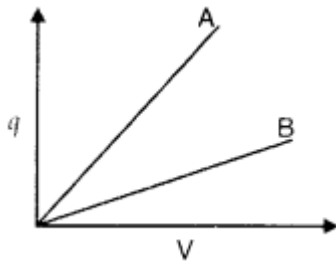
(ii) Electrostatic potential energy of the system is

$$U = K \frac{q_1 q_2}{r} = \frac{9 \times 10^9 \times 4Q \times Q}{1}$$

$$= 36 \times 10^9 \times (2 \times 10^{-7})^2 = 1.44 \times 10^{-3}\text{J}$$

- 19 The given graph shows variation of charge 'q' versus potential difference 'V' for two capacitors  $C_1$  and  $C_2$ . Both the capacitors have same plate separation but plate area of  $C_2$  is greater than that of  $C_1$ . Which line (A or B) corresponds to  $C_1$  and why?

Line B corresponds to  $C_1$   
Reason: Since slope (qv) of 'B' is less than that of 'A'



- 20 Net capacitance of three identical capacitors in series is  $1\text{pF}$ . What will be their net capacitance if connected in parallel? Find the ratio of energy stored in the two configurations if they are both connected to the same source.

Let C be the capacitance of a capacitor

$$\text{Given: } C_1 = C_2 = C_3 = C$$

When connected in series:

*When connected in series:*

$$C_s = \frac{C}{3} = 1 \mu\text{F} \quad \therefore C$$

*When connected in parallel:*

$$C_p = C + C + C = 3 + 3 + 3 = 9 \mu\text{F}$$

Energy stored in capacitor

$$E = \frac{1}{2} CV^2$$

$$\therefore \frac{E_s}{E_p} = \frac{\frac{1}{2} C_s V^2}{\frac{1}{2} C_p V^2} = \frac{C_s}{C_p} = \frac{1}{9} = 1 : 9$$

## **CASE STUDY QUESTIONS**

(I) Concept of field lines was introduced by Michael Faraday as an aid in visualizing electric and magnetic fields. Electric line of force is an imaginary straight or curved path along which a unit positive charge tends to move in an electric field. Properties of lines of forces observed by the scientist such as: Lines of force start from positive charge and terminate at negative charge, Lines of force never intersect, the tangent to a line of force at any point gives the direction of the electric field  $E$  at that point, the number of lines per unit area, through a plane at right angles to the lines, is proportional to the magnitude of  $E$ . This means that, where the lines of force are close together,  $E$  is large and where they are far apart,  $E$  is small. Each unit positive charge gives rise to  $1/\epsilon_0$  lines of force in free space. Hence number of lines of force originating from a point charge  $q$  is  $N = q/\epsilon_0$  in free space.

1. Choose correct statement regarding electric lines of force:

- (a) Emerges from (-ve) charge and meet at (+ve) charge.
- (b) Electric field in a region is strong when the electric lines of force at that region is closely spaced.
- (c) Just as it is shown for a point system in the same way it represents for a solid sphere.
- (d) has a physical nature.

2. Two electric field lines due to a point charge:

- (a) Never intersect
- (b) May intersect near the charge
- (c) Always intersect at 2 points
- (d) None of these

3. The tangent at any point on the electric field line gives:

- (a) The direction of magnetic field at that point
- (b) The direction of electric field at that point
- (c) The direction of acceleration due to gravity
- (d) All of the above

4. A metallic sphere is placed in a uniform electric field. The lines of force follow the paths as shown in figure. Identify the correct path of lines of force.

- (a) I
- (b) ii
- (c) iii
- (d) iv

5. If the direction of the electric field line due to two unlike point charges is from left to right then:

- (a) Positive charge is at left and negative charge is at right
- (b) Negative charge is at left and positive charge is at right
- (c) Both charges are at left
- (d) Both charges are at right

**(II)** The parallel plate capacitor consists of two parallel metal plates X and Y each of area A, separated by a distance d, having a surface charge density  $\sigma$  as shown in figure. The medium between the plates is air. A charge +q is given to the plate X. It induces a charge -q on the upper surface of earthed plate Y. When the plates are very close to each other, the field is confined to the region between them. The electric lines of force starting from plate X and ending at the plate Y are parallel to each other and perpendicular to the plates. The capacitance is directly proportional to the area (A) of the plates and inversely proportional to their distance of separation (d). The capacitance (C) of the parallel plate capacitor is given by  $C = \epsilon_0 A/d$ . If the region between the two plates is filled with dielectric like mica or oil. Its capacitance increased by  $\epsilon_r$  times of the medium.

1. The potential difference between the two plates of a parallel plate capacitor, if Q is magnitude of charge on each plate of area A separated by a distance d is

- (a)  $Qd/(\epsilon_0 A)$
- (b)  $d\epsilon_0/AQ$
- (c)  $Ad/(\epsilon_0 Q)$
- (d)  $QA/d\epsilon_0$

2. A capacitor is charged by a battery and the charging battery is disconnected and a dielectric slab is inserted in it. Then for the capacitor

- (a) Charge remains constant
- (b) Charge increases
- (c) Potential difference remains constant
- (d) Potential difference increases

3. A parallel plate capacitor has a capacitance of  $10\ \mu\text{F}$ . If the distance between two plates is doubled then the new capacitance will be

- (a)  $20\ \mu\text{F}$
- (b)  $15\ \mu\text{F}$
- (c)  $10\ \mu\text{F}$
- (d)  $5\ \mu\text{F}$

4. Capacitance of a parallel plate capacitor does not depend on:

- (a) Area of the plates
- (b) Type of metal used for plates
- (c) Separating distance between the plates
- (d) Dielectric constant of the medium between the plates

5. A parallel plate air capacitor with no dielectric between the plates is connected to a constant voltage source. What happens to the capacitance if a dielectric of dielectric constant  $k = 2$  is inserted between the plates?

- (a) Capacitance decreases
- (b) Capacitance increases by two times
- (c) Capacitance remains unchanged
- (d) Insufficient data

**III** Electric field strength is proportional to the density of lines of force i.e., electric field strength at a point is proportional to the number of lines of force cutting a unit area element placed normal to the field at that point. As illustrated in given figure, the electric field at P is stronger than at Q.

1) Electric lines of force about a positive point charge are

- (a) radially outwards
- (b) circular clockwise
- (c) radially inwards
- (d) parallel straight lines

2) Which of the following is false for electric lines of force?

- (a) They always start from positive charge and terminate on negative charges.

- (b) They are always perpendicular to the surface of a charged conductor.
- (c) They always form closed loops.
- (d) They are parallel and equally spaced in a region of uniform electric field

## **ASSIGNMENT -I (MCQ )**

Q.NO.	QUESTIONS	ANS WER
1	<p><b>Three charges +Q, q, +Q are placed respectively, at distance 0, d/2 and d from the origin, on the x-axis. If the net force experienced by +Q placed at x = 0 is zero, then value of q is</b></p> <p>(a) +Q/4 (b) -Q/2 (c) +Q/2 (d) -Q/4</p>	(d)
2	<p><b>An electric field of 1000 V/m is applied to an electric dipole at an angle of 45°. The value of the electric dipole moment is 10<sup>-29</sup> Cm. What is the potential energy of the electric dipole?</b></p> <p>(a) -10 × 10<sup>-29</sup> J (b) -7 × 10<sup>-27</sup> J (c) -20 × 10<sup>-18</sup> J (d) -9 × 10<sup>-20</sup> J</p>	(b)
3	<p><b>Voltage rating of a parallel plate capacitor is 500 V. Its dielectric can withstand a maximum electric field of 106 V m<sup>-1</sup>. The plate area is 10<sup>-4</sup> m<sup>2</sup>. What is the dielectric constant if the capacitance is 15 pF? (given ε<sub>0</sub> = 8.86 × 10<sup>-12</sup> C<sup>2</sup> N<sup>-1</sup> m<sup>-2</sup>)</b></p> <p>(a) 3.8 (b) 8.5 (c) 6.2 (d) 4.5</p>	(b)
4	<p><b>The bob of a simple pendulum has a mass of 2 g and a charge of 5.0 C. It is at rest in a uniform horizontal electric field of intensity 2000 V m<sup>-1</sup>. At equilibrium, the angle that the pendulum makes with the vertical is (take g = 10 m s<sup>-2</sup>)</b></p> <p>(a) tan<sup>-1</sup> (0.2)</p>	(b)

- (b)  $\tan^{-1}(0.5)$   
 (c)  $\tan^{-1}(2.0)$   
 (d)  $\tan^{-1}(5.0)$
- 5 **A parallel plate capacitor has  $1 \mu\text{F}$  capacitance. One of its two plates is given  $+2 \mu\text{C}$  charge and the other plate,  $+4 \mu\text{C}$  charge. The potential difference developed across the capacitor is** (d)
- (a) 3 V  
 (b) 2 V  
 (c) 5 V  
 (d) 1 V
- 6 **Two identical conducting spheres A and B, carry equal charge. They are separated by a distance much larger than their diameters, and the force between them is F. A third identical conducting sphere, C, is uncharged. Sphere C is first touched to A, then to B, and then removed. As a result, the force between A and B would be equal to** (a)
- (a)  $3F/8$   
 (b)  $F/2$   
 (c)  $3F/4$   
 (d) F
- 7 **Two capacitors  $C_1$  and  $C_2$  are charged to 120 V and 200 V, respectively. It is found that by connecting them together the potential on each one can be made zero. Then** (c)
- (a)  $9C_1 = 4C_2$   
 (b)  $5C_1 = 3C_2$   
 (c)  $3C_1 = 5C_2$   
 (d)  $3C_1 + 5C_2 = 0$
- 8 **An electric dipole is placed at an angle of  $30^\circ$  to a non-uniform electric field. The dipole will experience** (d)
- (a) a torque only  
 (b) a translational force only in the direction of the field  
 (c) a translational force only in a direction normal to the direction of the field  
 (d) a torque as well as a translational force
- 9 **The magnitude of electric field intensity E is such that, an electron placed in it would experience an electrical force equal to its weight is given by** (b)
- (a)  $mge$

- (b)  $mg/e$   
 (c)  $e/mg$   
 (d)  $e^2g/m^2$
- 10 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 square is zero is: (a)
- (a)  $Q = -q$   
 (b)  $Q = -1/q$   
 (c)  $Q = q$   
 (d)  $Q = 1/q$
- 11 What is the flux through the cube of side 'a' if a point charge of  $q$  is at one corner? (b)
- (a)  $2q/\epsilon_0$   
 (b)  $q/8 \epsilon_0$   
 (c)  $q/ \epsilon_0$   
 (d)  $q 6a^2/ \epsilon_0$
- 12 The electric potential  $V$  at any point  $(x,y,z)$ , all in metres in space is given by  $V = 4x^2$  volt. (d)  
 The electric field at the point  $(1,0,2)$  in volt/metre, is
- (a) 8 along positive X -axis  
 (b) 16 along negative X -axis  
 (c) 16 along positive X - axis  
 (d) 8 along negative X - axis
- 13 The presence of an uncharged conductor near a charged one increases the (b)
- (a) the potential of the charged conductor  
 (b) the capacity of the charged conductor  
 (c) charge of the charged conductor  
 (d) No effect
- 14 What is the value of capacitance that must be connected in parallel with 50 pF condenser to make an equivalent capacitance of 150 pF? (b)
- (a) 200pF  
 (b) 100pF  
 (c) 50pF  
 (d) 150pF
- 15 The relation between electric polarization and susceptibility indicates that electric polarization is (d)
- (a) proportional to square root of susceptibility.  
 (b) proportional to susceptibility.  
 (c) inversely proportional to susceptibility.  
 (d) independent of susceptibility.
- 16 If a third equal and similar charge is placed between two equal and similar charges, then this third charge will ©
- (a) move out of the field of influence of the two charges

- (b) not be in equilibrium
- (c) Will be in stable equilibrium
- (d) be in unstable equilibrium

- 17 The electric potential at a point in free space due to a charge  $Q$  coulomb is  $Q \times 10^{11}$  V. The electric field at that point is (a)
- (a)  $4\pi\epsilon_0 Q \times 10^{22}$  V/m
  - (b)  $12\pi\epsilon_0 Q \times 10^{20}$  V/m
  - (c)  $4\pi\epsilon_0 Q \times 10^{20}$  V/m
  - (d)  $12\pi\epsilon_0 Q \times 10^{22}$  V/m

**Directions:** These questions consist of two statements, each printed as an Assertion and Reason. While answering these questions, you are required to choose any one of the following five responses.

- 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.
- 18 Assertion: If a point charge  $q$  is placed in front of an infinite grounded conducting plane surface, the point charge will experience a force. (a)  
Reason : This force is due to the induced charge on the conducting surface which is at zero potential.
- 19 Assertion : A metallic shield in the form of a hollow shell, can be built to block an electric field. (c)  
Reason : In a hollow spherical shell, the electric field inside is not zero at every point.
- 20 Assertion : Work done in moving a charge between any two points in an electric field is dependent of the path followed by the charge, between them (d)  
Reason : Electrostatic forces are non conservative in nature.
- 21 Assertion : Force between two charges decreases when air separating the charges is replaced by water. (a)  
Reason : Medium intervening between the charges has dielectric constant  $K > 1$ .
- 22 Assertion : The whole charge of a body can be transferred to another body (c)  
Reason : Charge cannot be transferred partially
- 23 Assertion : The number of electric lines of force emanating from  $1\mu\text{C}$  charge in vacuum is  $1.13 \times 10^6$  (a)  
Reason : This follows from Gauss's theorem in electrostatics
- 24 Assertion : In a series combination of capacitors, charge on each capacitor is same. (c)  
Reason : In such a combination, charge cannot move only along one route,
- 25 Assertion : When the battery across the plates of the charged condenser is off and dielectric slab is introduced between its plates, the energy stored in the capacitor (a)

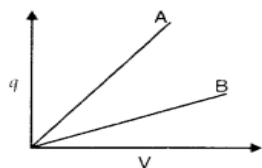


decreases.

Reason : The charge stored in capacitor Q remains constant and its capacity increases.

## **ASSIGNMENT- 2 (Descriptive questions)**

Q.No	Question	Mark
1	How does the electric flux, electric field enclosing a given charge vary when the area enclosed by the charge is doubled?	1
2	Name the physical quantities whose SI units are $Vm$ , $Vm^{-1}$ . Which of these are vectors?	1
3	How much work is done in moving a $500 \mu C$ charge between two points separated by a distance of $2cm$ on an equipotential surface?	1
4	Two capacitors of $0.1 \mu F$ and $0.2 \mu F$ are raised to the same potential of $50V$ . Calculate the ratio of the energy stored in each.	1
5	Consider three charged bodies P, Q and R. If P and Q repel each other and P attracts R, what will be the nature of the force between Q and R?	1
6	What is the work done in moving a test charge $q$ through a distance of $1 cm$ along the equatorial axis of an electric dipole?	1
7	Two capacitors of capacitances $6\mu F$ and $12 \mu F$ are connected in series with a battery. The voltage across $6\mu F$ capacitor is $2 V$ . Compute the total battery voltage.	1
8	A hollow metal sphere of radius $5 cm$ is charged such that the potential on its surface is $10 V$ . What is the potential at the centre of the sphere?	1
9	Two equal balls having equal positive charge ' $q$ ' coulombs are suspended by two insulating strings of equal length. What would be the effect on the force when a plastic sheet is inserted between the two ?	1
10	The given graph shows variation of charge ' $q$ ' versus potential difference ' $V$ ' for two capacitors $C_1$ and $C_2$ . Both the capacitors have same plate separation but plate area of $C_2$ is greater than that of $C_1$ . Which line (A or B) corresponds to $C_1$ and why?	2



- 11 two identical metallic spheres A and B of exactly equal masses are taken. Sphere A is given positive charge of  $Q$  coulomb and B is given an equal negative charge. So initially before the charge is given  $M_A=M_B=M$

- 12 Electric field inside a dielectric decreases when it is placed in an external field.  
Give reason to support this statement. 2
- 13 An electric dipole of moment  $p$  is aligned parallel to the external electric field.  
How much work has to be done in rotating the dipole through (a)  $90^\circ$  (b)  $180^\circ$  2
- 14 Derive the expression for the electric field intensity due to an infinitely long  
straight charged wire. 2
- 15 Derive the expression for the electric field intensity due to a thin infinite plane  
sheet of charge, 3
- 16 When two charged capacitors having different capacities and different potentials 3  
are joined together, show that there is always some loss of energy.

### MARKING KEY

Q.no	Marks
1	$\phi = \text{constant}$ 1/2 <b>E is halved</b> 1/2 (1) mark
2	Electric flux $\phi$ -scalar 1/2 Electric field intensity E-Vector 1/2 (1) mark
3	Zero (1) mark
4	$U_1/U_2 =$ $1/2C_1V^2/1/2C_2V^2 - 1/2$ $= 2 - 1/2$ (1) mark
5	Q attracts R---(1) mark
6	Since potential for equatorial axis $V = 0$ 1/2 $\therefore W = qV = 0$ -- 1/2 (1) mark
7	Charge on both capacitors are same $6 \times 2 = 12 \times V_2$ ---1/2 $V_2 = 1V,$ battery voltage = $3V$ 1/2 (1) mark
8	Inside the sphere $E = 0$ ----1/2 $V = \text{constant} = 10V$ —1/2 (1) mark

- 9 force would be reduced by a factor 'K' (equal to the value of dielectric constant of plastic sheet)—1/2

$$F_K = \frac{F_{Air}}{K} \quad \text{---1/2}$$

(1) mark

- 10 line B corresponds to  $C_1$ --1  
slope (q/v) of 'B' is less than that of 'A' ---1  
(2) marks

- 11 The process of giving positive charge involves removal of electrons and that of negative charge involves addition of electrons.---1  
Hence the mass of the positively charged sphere will be less than that of negatively charged sphere  $M_A < M_B$ —1  
(2) marks

- 12 An electric field  $E_P$  is induced inside the dielectric in a direction opposite to the direction of external electric field  $E_0$ . Thus net field becomes  
 $E = E_0 - E$

(2)marks

- 13  $W = pE(\cos\theta_1 - \cos\theta_2)$   
(a)  $W = pE$ ---1  
(b)  $W = 2pE$  ---1  
(2) marks

- 14 Diagram---1/2  
Derivation  $E = \lambda/2\pi\epsilon_0 r$  ---1 1/2  
(2)marks

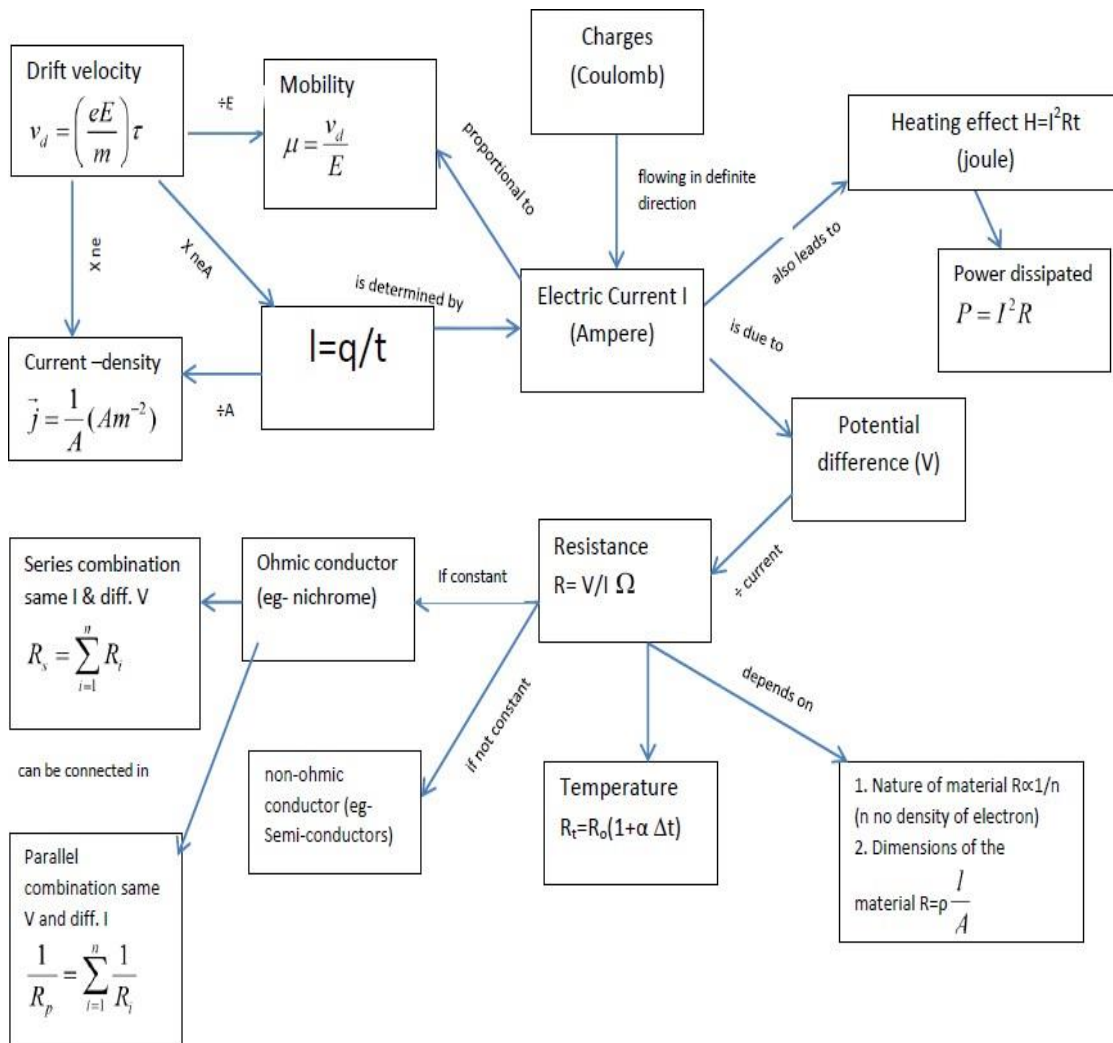
- 15 Diagram --1/2  
Derivation  $E = \sigma/2 \epsilon_0$  -2 1/2  
(3)marks

- 16 Derivation  
 $U_1 - U_2 = (V_1 - V_2)^2/2(C_1 + C_2)$   
(3) marks

# Unit - II

## Current Electricity (Chapter-3)

### FORMULA CHART

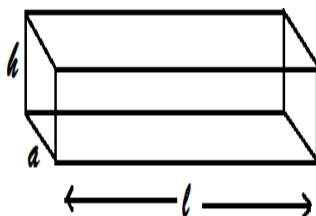


### NUMERICALS FOR PRACTISE WITH SOLUTIONS:

1: If current in the circuit is given by  $I=3t^2+2t-1$  then find charge in the circuit in first two second.

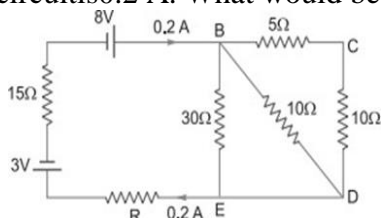
2: Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area  $1 \times 10^{-7} \text{ m}^2$  carrying a current of 1.5 A. Assume that each copper atom contributes roughly one conduction electron. The density of copper is  $9.0 \times 10^3 \text{ kg/m}^3$ , and its atomic mass is 63.5 u.

3: Find the resistance offered by the conductor shown in diagram when current flow (i) along length  $l$  (ii) along the side  $a$  (iii) along height  $h$ .

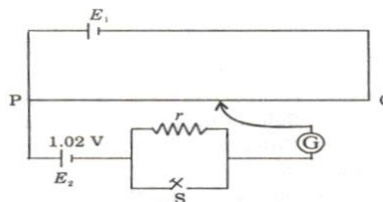


4. Nichrome and copper wires of same length and same radius are connected in series. Current  $I$  is passed through them. Which wire gets heated up more? Justify your answer

5. Calculate the value of the resistance  $R$  in the circuit shown in the figure so that the current in the circuit is 0.2 A. What would be the potential difference between points B and E?



6 State Kirchhoff's rules. Use these rules to write the expressions for the currents  $I_1$ ,  $I_2$  and  $I_3$  in the circuit diagram shown.



7 Calculate (i) potential gradient (ii) emf of the cell  $E_1$  (iii) when switch  $S$  is closed, will null point move towards P or Q. Give reason for your answer.

8 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  $R$ .

9 A cell of unknown emf  $E$  and internal resistance  $r$ , two unknown resistances  $R_1$  and  $R_2$  ( $R_2 > R_1$ ) and a perfect ammeter are given. The current in the circuit is measured in five different situations: (i) Without any external resistance in the circuit, (ii) With resistance  $R_1$  only, (iii) With resistance  $R_2$  only, (iv) With both  $R_1$  and  $R_2$  used in series combination and (v) With  $R_1$  and  $R_2$  used in parallel combination. The current obtained in the five cases are 0.42A, 0.6A, 1.05A, 1.4A, and 4.2A, but not necessarily in that order. Identify the currents in the five cases listed above and calculate  $E$ ,  $r$ ,  $R_1$  and  $R_2$ .

10. A set of n-identical resistors, each of resistance R ohm when connected in series have an effective resistance of Xohm and when the resistors are connected in parallel the effective resistance is Y ohm. Find the relation between R, XandY?

**ANSWERS TO THE NUMERICALS**

Q NO SOLUTIONS

1  $I = dq/dt$  or  $dq = Idt$

$$dq = (3t^2 + 2t - 1)dt$$

$$q = \int_0^2 (3t^2 + 2t - 1) dt = 10 C$$

2 (a) The drift speed V is given by  $V = (I / neA)$ ,  $e = 1.6 \times 10^{-19} C$ ,

$$A = 1.0 \times 10^{-7} m^2, \quad I = 1.5 A.$$

The density of conduction electrons, n is equal to the number of atoms per cubic metre (conduction electron per Cu atom)

A cubic assuming onemetre of copper has a mass of  $9.0 \times 10^3 kg$ .

Since  $6.023 \times 10^{23}$  copper atoms have a mass of 63.5

$$= 8.5 \times 10^{28} m^{-3}$$

$$V_d = 1.1 \times 10^{-3} ms^{-1}$$

3	<p><b>(i)</b> When current flows along the side l</p> $R = \rho l / ah$ <p><b>(ii)</b> When current flows along the side h</p> $R = \rho h / al$ <p><b>(iii)</b> When current flows along the side a</p> <p><b>(iv)</b> <math>R = \rho a / hl</math></p>
---	--

4 Nichrome wire gets heated up more.

Heat dissipated in a wire is given by

$$H = I^2 R t$$

$$H = I^2 \frac{\rho l}{A} \left( \because R = \frac{\rho l}{A} \right)$$

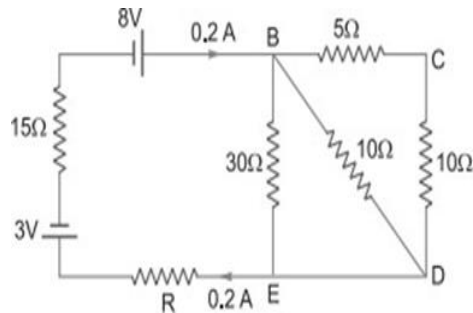
Here, radius is same, hence area ( $A$ ) is same. Also, current ( $I$ ) and length ( $l$ ) are same.

$$\therefore H \propto \rho$$

But  $\rho_{\text{nichrome}} > \rho_{\text{copper}}$

$$\therefore H_{\text{nichrome}} > H_{\text{copper}}$$

5



Here,  $R_{BCD} = 5\Omega + 10\Omega = 15\Omega$

Effective resistance between  $B$  and  $E$

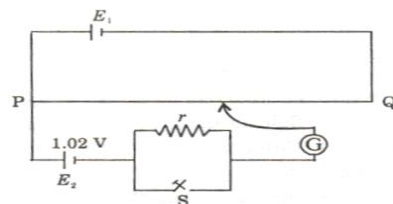
$$\frac{1}{R_{BE}} = \frac{1}{30} + \frac{1}{10} + \frac{1}{15} \Rightarrow R_{BE} = 5\Omega$$

Applying Kirchhoff's Law

$$5 \times 0.2 + R \times 0.2 + 15 \times 0.2 = 8 - 3 \Rightarrow R = 5\Omega$$

Hence,  $V_{BE} = IR_{BE} = 0.2 \times 5 = 1 \text{ volt}$

6



$E_2=1.02V$ ,  $PQ=1m$ . When switch S open, null position is obtained at a distance of 51 cm from P. problem

Kirchhoff's Rules:

(i) The algebraic sum of currents meeting at any junction is zero, *i.e.*,

$$\sum I = 0$$

(ii) The algebraic sum of potential differences across circuit elements of a closed circuit is zero, *i.e.*,  $\sum V = 0$

From Kirchhoff's first law

$$I_3 = I_1 + I_2 \quad \dots(i)$$

Applying Kirchhoff's second law to mesh *ABDCA*

$$-2 - 4I_1 + 3I_2 + 1 = 0$$

$$\Rightarrow 4I_1 - 3I_2 = -1 \quad \dots(ii)$$

Applying Kirchhoff's second law to mesh *ABFEA*

$$-2 - 4I_1 - 2I_3 + 4 = 0$$

$$\Rightarrow 4I_1 + 2I_3 = 2 \text{ or } 2I_1 + I_3 = 1$$

Using (i) we get

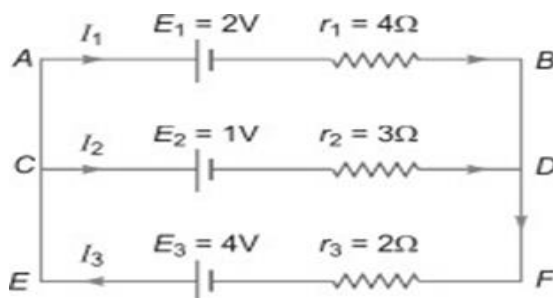
$$\Rightarrow 2I_1 + (I_1 + I_2) = 1$$

$$\text{or } 3I_1 + I_2 = 1 \quad \dots(iii)$$

Solving (ii) and (iii), we get

$$I_1 = \frac{2}{13} \text{ A}, I_2 = 1 - 3I_1 = \frac{7}{13} \text{ A}$$

$$\text{so, } I_3 = I_1 + I_2 = \frac{9}{13} \text{ A}$$



7 (i) Potential gradient  $k = = 0.02V/cm$

(ii) emf of the cell  $E1 = k = 2V$



(iii) When switch S is closed, null point is not affected because no current drawn from cell E1 at the null point.

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

$$V = IR = \frac{E}{r + R} R = \frac{E}{1 + \frac{r}{R}}$$

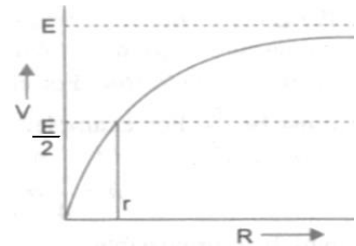
The terminal p.d.



On increasing R, V increases.

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

When  $R \rightarrow \infty$ ,  $V = E$ .



9

$$(i) I_1 = \frac{E}{r}, (ii) I_2 = \frac{E}{r + R_1}, (iii) I_3 = \frac{E}{r + R_2}, (iv) I_4 = \frac{E}{r + R_1 + R_2},$$

$$(v) I_5 = \frac{E}{r + \frac{R_1 R_2}{R_1 + R_2}}$$

This is clear that  $I_1 > I_5 > I_2 > I_3 > I_4$ .

Hence  $I_1 = 4.2A, I_5 = 1.4A, I_2 = 1.05A, I_3 = 0.6A, I_4 = 0.42A$ .

Putting these values in (i) to (v) and on solving,  $E = 4.2V, R_1 = 3\Omega, R_2 = 6\Omega, r = 1\Omega$

10 n – resistors connected in series  $X = nR$  —1)

n – Resistors connected in parallel  $Y =$  —2)

Multiply eq.(1)&(2)

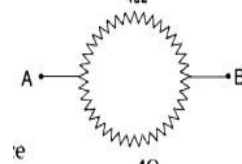
$$XY = \cancel{R} \times \frac{R}{\cancel{R}}$$

$$R^2 = \boxed{R = \sqrt{XY}}$$

### NUMERICALS FOR PRACTICE :

Q.1 Two conducting wires X and Y of same diameter but different materials are joined in series across a battery. If the number density of electrons in X is twice that in Y, find the ratio of drift velocity of electrons in the two wires.

Q 2 A wire of resistance  $8R$  is bent in the form of a circle. What is the effective resistance between the ends of the diameter?

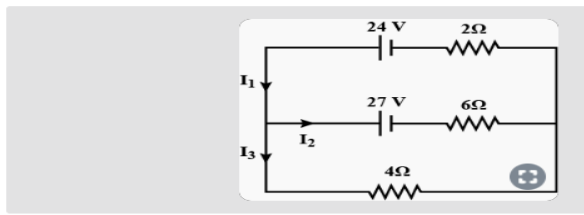


Q 3 A battery of emf  $10\text{ V}$  and internal resistance  $3\Omega$  is connected to a resistor. If the current in the circuit is  $0.5\text{ A}$ , find

- (i) the resistance of the resistor;
- (ii) the terminal voltage of the battery.

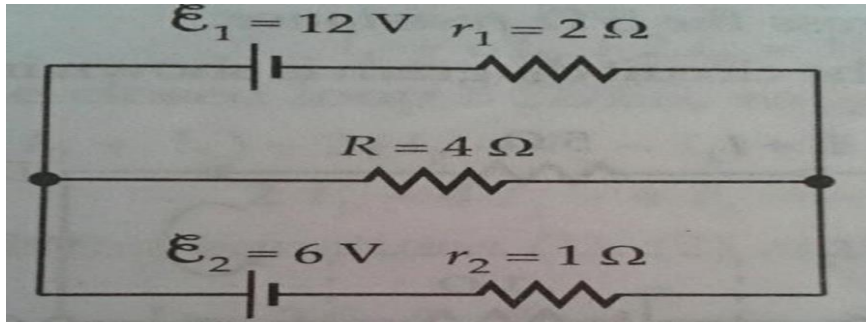
Q 4 Find the values of  $I_1, I_2$  &  $I_3$  in the given network.

In the circuit shown, the value of currents  $I_1, I_2$  and  $I_3$  are.

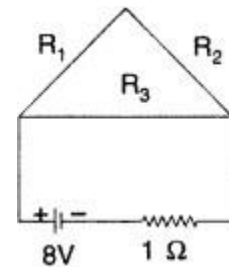


Q 5 Two cells of emfs  $1.5\text{ V}$  and  $2.0\text{ V}$  having internal resistance  $0.2\Omega$  and  $0.3\Omega$  respectively are connected in parallel. Calculate the emf and internal resistance of the equivalent cell.

Q 6 Find the Potential Difference ( P.D.) across each cell and the rate of energy dissipation in resistor  $R$  in the given network.



Q 7 . A uniform wire of resistance  $12\ \Omega$  is cut into three pieces so that the ratio of the resistances  $R_1 : R_2 : R_3 = 1 : 2 : 3$  and the three pieces are connected to form a triangle



across which a cell of emf  $8\text{V}$  and internal resistance  $1\ \Omega$  is connected as shown.

Calculate the current through each part of the circuit

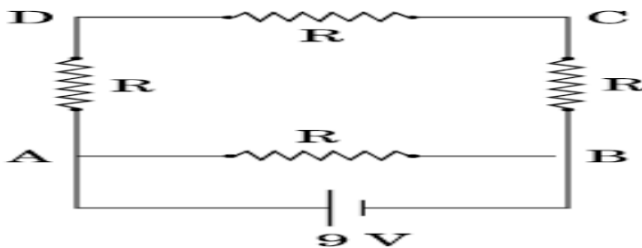
Q 8 Two wires, one of copper and the other of manganin, have same resistance and equal thickness. Which wire is longer? Justify your answer

Q.9 Nichrome and copper wires of same length and same radius are connected in series. Current  $I$  is passed through them. Which wire gets heated up more? Justify your answer

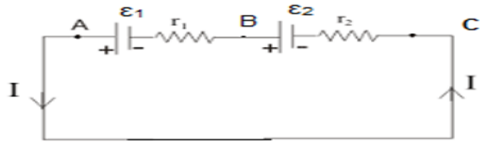
Q 10 Plot a graph showing variation of voltage  $V$  vs the current drawn from the cell. How can one get information from this plot about the emf of the cell and its internal resistance?

Q 11 A  $16\ \Omega$  resistance wire is bent to form a square. A source of emf  $9\text{ V}$  is connected across one of its sides as shown. Calculate the current drawn from the source. Find the potential difference between the ends  $C$  and  $D$ .

If now the wire is stretched uniformly to double the length and once again the same cell is connected in the same way, across one side of the square formed, what will now be the potential difference across one of its diagonals.



Q 12 : Consider two cells which is connected in series. The positive terminal of one cell is connected to negative terminal of the next cell. Here one terminal of two cells are free and the other terminal of two cells are joined together.  $\epsilon_1$  and  $\epsilon_2$  are the emfs of the cells and  $r_1$  and  $r_2$  are the internal resistance of the cells respectively. Let  $I$  be the current flowing through the cells



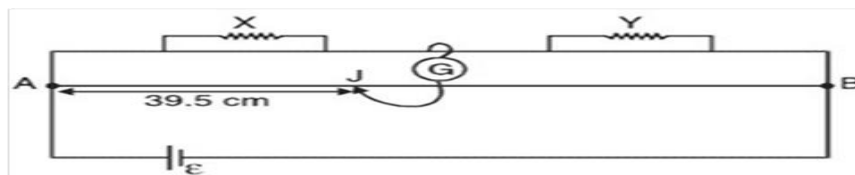
Q 13 you given three constantan wires P, Q and R of length and area of cross-section

$(L, A), (2L, \frac{A}{2})$  and  $(\frac{L}{2}, 2A)$  respectively. Which has highest resistance?

Q 14 Calculate the equivalent resistance between points A and B in the figure given below



Q 15 In a meter bridge, the balance point is found to be 39.5 cm from end A. The known resistance Y is . Determine unknown resistance



### HINT FOR NUMERICALS

PROBLE  
M NO

SOLUTION

- In series current is same,  
So,  $I_x = I_y = I = neAv_d$   
For same diameter, cross-sectional area is same  
 $A_x = A_y = A$   
 $\therefore I_x = I_y \Rightarrow n_x e A v_x = n_y e A v_y$   
Given  $n_x = 2n_y \Rightarrow \frac{v_x}{v_y} = \frac{n_y}{n_x} = \frac{n_y}{2n_y} = \frac{1}{2}$

2.

$$R_{\text{eff}} = \frac{4R \times 4R}{4R + 4R} = \frac{16R^2}{8R} = 2R$$

- Answer: Resistance of the resistor is  $17\Omega$  and the terminal voltage is  $8.5V$

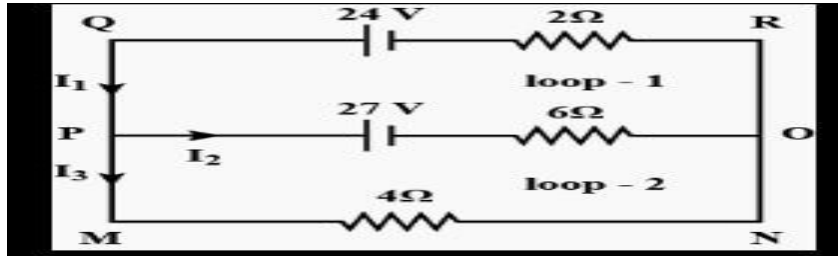
$$(i) \text{ Since } I = \frac{V}{r+R} \quad \therefore \frac{10}{r+R} = 0.5$$

$$\text{or } \frac{10}{3+R} = 0.5 \quad \text{or } \frac{100}{5} = 3+R$$

$$\therefore R = 20 - 3 = 17\Omega$$

$$(ii) \text{ Since } V = IR \quad \therefore V = \frac{5}{10} \times 17 = \frac{85}{10} = 8.5V$$

4.



Applying Kirchoff's voltage law,  
In loop. I

$$= -27 - 6I_2 - 2I_1 + 24 = 0$$

$$\Rightarrow 6I_2 + 2I_1 = -3 \quad \dots(1)$$

In loop- II

$$-27 - 6I_2 + 4I_3 = 0$$

$$6I_2 - 4I_3 = -27 \quad \dots(2)$$

Junction 'p'

$$I_1 = I_2 + I_3 \quad \dots(3)$$

Solving equation (1), (2) and (3) we get,

$$I_1 = 3A, I_2 = -3/2A, I_3 = 9/2A$$

5.  $E_1 = 1.5 V, E_2 = 2.0 V,$

$r_1 = 0.2 \Omega, r_2 = 0.3 \Omega$   
 $E = ?, r = ?$  (when two cells are connected in parallel)

$$E = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$

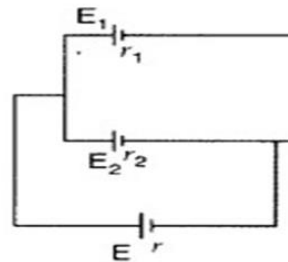
$$= \frac{1.5 \times 0.3 + 2 \times 0.2}{0.2 + 0.3} V$$

$$= \frac{0.45 + 0.40}{0.5} V = 1.7 V$$

$$r = \frac{r_1 r_2}{r_1 + r_2}$$

$$= \frac{0.2 \times 0.3}{0.2 + 0.3} \Omega = \frac{0.06}{0.5} \Omega$$

$$= 0.12 \Omega$$



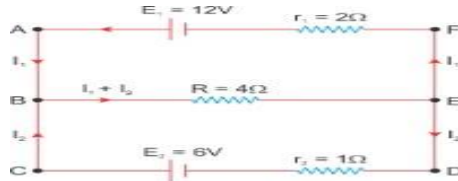
6.

Solving 1 and 2 we get  
 $I_1 = 18/7$  A and  $I_2 = -6/7$  A

$$\text{Potential difference across cell 1} = V_1 = E_1 - I_1 r_1 = 12 - \frac{18}{7} \times 2 = \frac{48}{7} \text{ V}$$

$$\text{Potential difference across cell 2} = V_2 = E_2 - I_2 r_2 = 6 - \frac{-6}{7} = \frac{48}{7} \text{ V}$$

$$\begin{aligned} \text{Rate of energy dissipation in R} = \text{power consumed} &= (I_1 + I_2)^2 \times R = \left(\frac{18}{7} - \frac{6}{7}\right)^2 \times 4 = \\ &= \frac{576}{7} \text{ watt} \end{aligned}$$



Applying Kirchoff's Voltage Law (KVL) at loop ABCDEFA

$$\begin{aligned} E_1 - E_2 + I_2 r_2 - I_1 r_1 &= 0 \\ 12 - 6 + I_2 r_2 - I_1 r_1 &= 0 \\ \Rightarrow 6 + I_2 - 2I_1 &= 0 \\ \Rightarrow 2I_1 - I_2 &= 6 \dots (1) \end{aligned}$$

Applying KVL at loop ABEFA

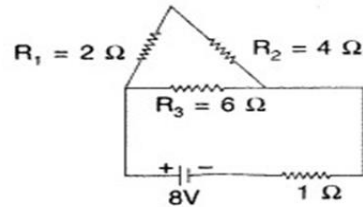
$$\begin{aligned} E_1 - (I_1 + I_2)R - I_1 r_1 &= 0 \\ 12 - (I_1 + I_2)R - I_1 r_1 &= 0 \\ \Rightarrow 12 - 4(I_1 + I_2) - 2I_1 &= 0 \\ \Rightarrow 12 - 4I_2 - 6I_1 &= 0 \\ \Rightarrow 4I_2 + 6I_1 &= 12 \dots (2) \end{aligned}$$

7.

$R_1$  and  $R_2$  are in series,  $R_{12} = 2\Omega + 4\Omega = 6\Omega$   
 $R_{12}$  and  $R_3$  are in parallel

$$R_{123} = 3\Omega$$

$$\left[ \because \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \right]$$



$$I = \frac{E}{R+r} = \frac{8}{3+1} = \frac{8}{4} = 2\text{A} \quad [ \because E = 8 ]$$

Current through arms AC = current through ABC.

(Since the resistance of arm AC = resistance of arm ABC) = 1A

8.

Copper Reason: Let  $l_1$  and  $l_2$  be lengths of copper and manganin wires having same resistance  $R$  and thickness i.e., area of cross-section ( $A$ ).

Resistance of copper wire,  $R = \frac{\rho_1 l_1}{A}$

Resistance of manganin wire  $R = \frac{\rho_2 l_2}{A}$

$\Rightarrow \rho_1 l_1 = \rho_2 l_2$  (As  $\rho l = \text{constant}$ )

Since  $\rho_1 \ll \rho_2$

So,  $l_1 \gg l_2$

i.e., copper wire would be longer.

9. Nichrome wire gets heated up more.

Heat dissipated in a wire is given by

$$H = I^2 R t$$

$$H = I^2 \frac{\rho l}{A} t \quad (\because R = \frac{\rho l}{A})$$

Here, radius is same, hence area ( $A$ ) is same. Also, current ( $I$ ) and length ( $l$ ) are same.

$$\therefore H \propto \rho$$

But  $\rho_{\text{nichrome}} > \rho_{\text{copper}}$

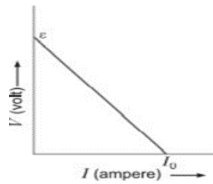
$$\therefore H_{\text{nichrome}} > H_{\text{copper}}$$

10.

$$V = \varepsilon - Ir \Rightarrow r = \frac{\varepsilon - V}{I}$$

$$\text{At } I = 0, V = \varepsilon$$

$$\text{When } V = 0, I = I_0, r = \frac{\varepsilon}{I_0}$$



The intercept on y-axis gives the emf of the cell. The slope of graph gives the internal resistance.

11. Net resistance of the circuit,  $R_{\text{eq}} = 3 \Omega$

$$\therefore \text{Current, } I = \frac{V}{R_{\text{eq}}} = \frac{9}{3} = 3 \text{ A}$$

P.D across CD,  $V_{\text{CD}} = I_{\text{CD}} \times R_{\text{CD}}$

$$= \left(3 \times \frac{1}{4} \text{ A}\right) \times 4 \Omega = 3 \text{ V}$$

When the wire is stretched to double its length, each resistance becomes four times, i.e.  $16 \Omega$  each.

$$\text{P.D across one of the diagonal, } V_{\text{AC}} \text{ or } V_{\text{BD}} = \left(\frac{9}{12} \times \frac{1}{4} \text{ A}\right) \times 32 \Omega = 6 \text{ V}$$

12. Cells connected in series

Consider the points A, B and C and let  $V(A)$ ,  $V(B)$  and  $V(C)$  be the potentials of these points respectively.  $V(A) - V(B)$  will be the potential difference between the positive and negative terminals for the first cell.

$$\text{So } V_{\text{AB}} = V(A) - V(B) = \varepsilon_1 - Ir_1.$$

$$V_{\text{BC}} = V(B) - V(C) = \varepsilon_2 - Ir_2.$$

Now the potential difference between the terminals A and C is

$$\begin{aligned} V_{AC} &= V(A) - V(C) = [V(A) - V(B)] + V(B) - V(C) \\ &= \varepsilon_1 - Ir_1 + \varepsilon_2 - Ir_2 \\ &= (\varepsilon_1 + \varepsilon_2) - I(r_1 + r_2). \end{aligned}$$

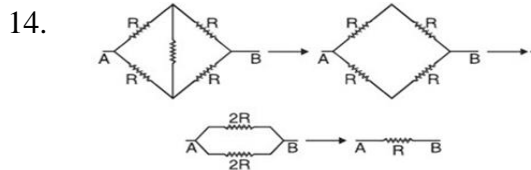
In case if we replace this combination of cells by a single cell between the points A and C with emf  $\varepsilon_{eq}$  and internal resistance  $r_{eq}$ ,  $V_{AC} = \varepsilon_{eq} - Ir_{eq}$ , and thus we found out that  $\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2$  and  $r_{eq} = r_1 + r_2$  from the previous equation.

It is clear that the equivalent emf of n number of cells in series combination is the sum of their individual emfs. The equivalent internal resistance of n cells in series combination is the sum of their individual internal resistance.

In series combination if the current leaves the cell from the negative electrode, the emf of the cell will be for example  $V_{BC} = -\varepsilon_2 - Ir_2$  and finally the equation for  $\varepsilon_{eq} = \varepsilon_1 - \varepsilon_2$ , ( $\varepsilon_1 > \varepsilon_2$ )

13. 
$$R_p = \rho \frac{L}{A}, R_q = \rho \frac{2L}{A} = \frac{L4\rho}{A}, R_R = \frac{\rho L}{4A}$$

**Q has the highest resistance.**



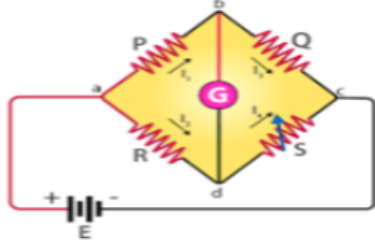
$$\therefore R_{eq} = R.$$

15. 8.16 OHM



## CASE BASED QUESTIONS

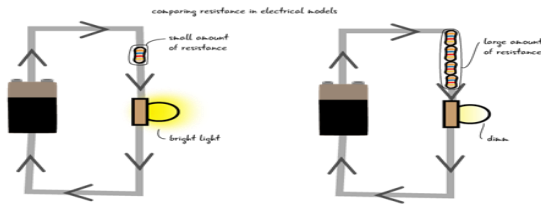
**Q 1** Read the source given below and answer any four out of the following questions: The Wheatstone bridge works on the principle of null deflection, i.e. the ratio of their resistances are equal and no current flows through the circuit. And The principle of working of Meter bridge is wheat stone bridge principle and it is used to find the resistance of an unknown conductor or to compare two unknown resistance.



- i. When a metal conductor connected to the left gap of a meter bridge is heated, the balancing point shifts
  - a. right
  - b. left
  - c. unchanged
  - d. none of these
- ii. Wheatstone bridge is a/an:
  - a. a.c. bridge
  - b. d.c. bridge
  - c. high voltage bridge
  - d. none of these
- iii. Wheatstone bridge is used to measure the d.c. the resistance of various types of wires for:
  - a. determining their effective resistance
  - b. computing the power dissipation
  - c. quality control of wire
  - d. none of these
- iv. By using the variations on a Wheatstone bridge we can:
  - a. measure quantities such as voltage, current, and power
  - b. measure high resistance values
  - c. measure quantities such as complex power
  - d. measure quantities such as capacitance, inductance and impedance
- v. For a Wheatstone bridge arrangement of four resistances –  $R_1$ ,  $R_2$ ,  $R_3$ ,  $R_4$  (Junction of  $R_1$  and  $R_2$  is connected to anode and Junction of  $R_3$  and  $R_4$  to the cathode of the cell). The null-point condition is given by
  - a.  $R_1R_3=R_2R_4$
  - b.  $(R_1 \times R_3) = (R_2 \times R_4)$
  - c.  $(R_1 + R_3) = (R_2 + R_4)$
  - d.  $(R_1 - R_3) = (R_2 - R_4)$

**2** Read the following source and answer any four out of the following questions: Resistance is a measure of the opposition to current flow in an electrical circuit. Resistance is measured in ohms.

Also Resistivity, the electrical resistance of a conductor of unit cross-sectional area, and unit length. A characteristic property of each material, resistivity is useful in comparing various materials on the basis of their ability to conduct electric currents.



**I. Resistivity is independent of:**

- A nature of material
- B temperature
- C dimensions of material
- D none of the above

**II As compare to short wires, long wires have resistance.**

- A more
- B less
- C same
- D zero

**III As compare to thin wires, thick wires have resistance.**

- A more
- B less
- C same
- D zero

**IV The resistance of a wire depends upon:**

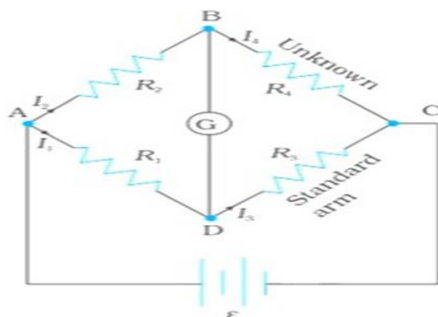
- A cross-sectional area
- B length of wire
- C wire's nature
- D all of the above

**V A copper wire having the same size as steel wire have:**

- A more resistance
- B less resistance
- C same resistance
- D none of the above

**3 Read the source given below and answer any four out of the following questions:**

The Wheatstone bridge works on the principle of null deflection, i.e. the ratio of their resistances are equal and no current flows through the circuit. Under normal conditions, the bridge is in the unbalanced condition where current flows through the galvanometer. The bridge is said to be in a balanced condition when no current flows through the galvanometer. This condition can be achieved by adjusting the known resistance and variable resistance.



I The Wheatstone bridge is an arrangement of four resistances –  $R_1$ ,  $R_2$ ,  $R_3$ ,  $R_4$ . The null-point condition is given by:

- a.  $\frac{R_1}{R_2} = \frac{R_3}{R_4}$
- b.  $R_1 + R_2 = R_3 + R_4$
- c.  $R_2 = \frac{R_3}{R_4 + R_1}$
- d.  $\frac{R_2}{R_1} = \frac{R_3}{R_4}$

II. The Wheatstone bridge is used for the precise measurement of \_\_\_\_\_.

- A high resistance
- B low resistance
- C low current
- D high current

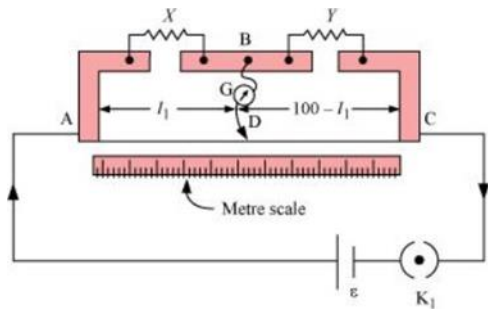
III Why are the connections between resistors in a Wheatstone or meter bridge made of thick copper strips?

- A Minimize the resistance
- B Maximize the resistance
- C Minimize current
- D None of these

IV . What happens if the galvanometer and cell are interchanged at the balance point of the bridge?

- a. Current flow
- b. Show deflection
- c. No deflection
- d. Low resistance

V In a metre bridge [Fig. below], the balance point is found to be at 39.5 cm from the end A, when the resistor Y is of  $12.5 \Omega$ . Determine the resistance of X.

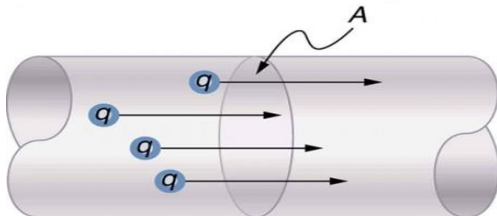


- 8.2  $\Omega$
- 8.4  $\Omega$
- 7.2  $\Omega$
- 8.6  $\Omega$

4. Read the source given below and answer any four out of the following questions:

The rate of flow of charge through any cross-section of a wire is called electric current flowing through it. Electric current ( $I$ ) =  $q/t$ . Its SI unit is ampere (A). The conventional direction of electric current is the direction of motion of positive charge. The current is the same for all cross-sections of a conductor of the non-uniform cross-section. Resistance is a measure of the opposition to current flow in an electrical circuit

Current = flow of charge



**I An example of non-ohmic resistance is:**

- A tungsten wire
- B carbon resistance
- C diode
- D copper wire

**II Current is:**

- A scalar quantity
- B vector quantity
- C both scalar and vector quantity
- D none of the above

**III In a current-carrying conductor, the net charge is:**

- A  $1.6 \times 10^{-19}$  coulomb
- B  $6.25 \times 10^{-18}$  coulomb
- C zero
- D infinite

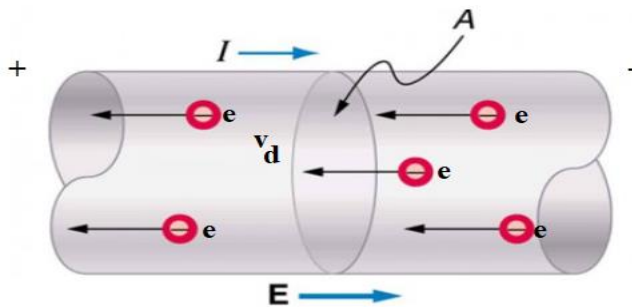
**IV The current which is assumed to be flowing in a circuit from the positive terminal to negative is called:**

- A direct current
- B pulsating current
- C conventional current
- D none of these

V A current passes through a wire of non-uniform cross-section. Which of the following quantities are independent of the cross-section?

- The charge crossing
- drift velocity
- current density
- free electron density

5. When a potential difference  $V$  is applied across the two ends of a conductor, the free electrons in the conductor experience a force and are accelerated towards the positive end of conductor. On their way, they suffer frequent collisions with the ions/atoms of the conductor and lose their gained kinetic energy and again get accelerated due to electric field and lose the gained kinetic energy in the next collision and so on. The average velocity with which the free electrons get drifted towards the positive end of the conductor under the effect of applied electric field is called drift velocity.



i) The motion of electrons between two successive collisions (with the atoms/ions) in the presence of electric field follows:

- (a) Straight line path
- (b) Circular path
- (c) Elliptical path
- (d) Curved path

ii) The drift velocity of the electrons depends on

- (a) Dimensions of the conductor
- (b) Number density of free electrons in the conductor
- (c) Both a and b
- (d) None of these.

iii) When potential difference across a given copper wire is increased, drift velocity of free electrons

- (a) Decreases
- b) Increases
- (c) Remain same
- (d) Get reduced to zero

**iv) Two wires of same material having radii in the ratio 1:2, carry currents in the ratio 4:1. The ratio of drift velocities of electrons in them is**

- (a) 2:1
- (b) 1:1
- (c) 1:4
- (d) 16:1

**v) If the temperature of a conductor increases, the drift velocity of free electrons**

- (a) Remains same
- (b) Increases
- (c) Decreases
- (d) May increase or decrease.

### **6. . Electromotive Force**

You can think of many different types of voltage sources. Batteries themselves come in many varieties. There are many types of mechanical/electrical generators, driven by many different energy sources, ranging from nuclear to wind. Solar cells create voltages directly from light, while thermoelectric devices create voltage from temperature differences. All such devices create a potential difference and can supply current if connected to a resistance. On the small scale, the potential difference creates an electric field that exerts force on charges, causing current. We thus use the name electromotive force, abbreviated emf. Emf is not a force at all; it is a special type of potential difference. Electromotive force is directly related to the source of potential difference, such as the particular combination of chemicals in a battery.

#### **1) Emf of a cell is**

- (a) the maximum potential difference between the terminals of a cell when no current is drawn from the cell.
- (b) the force required to push the electrons in the circuit.
- (c) the potential difference between the positive and negative terminal of a cell in a closed circuit.
- (d) less than terminal potential difference of the cell.

**2) A cell of internal resistance  $r$  is connected to an external resistance  $R$ . The current will be maximum in  $R$ , if**

- (a)  $R = r$
- (b)  $R < r$
- (c)  $R > r$
- (d)  $R = r/2$

**3) A cell of internal resistance  $r$  is connected across an external resistance  $nr$ . Then the ratio of the terminal voltage to the emf of the cell is**

- (a)  $1/(n)$
- (b)  $1/(n + 1)$
- (c)  $n/(n + 1)$
- (d)  $n/(n - 1)$

**4) To draw a maximum current from a combination of cells, how should the cells be grouped?**

- (a) Parallel
- (b) Series
- (c) Mixed grouping
- (d) Depends upon the relative values of internal and external resistances.

**5) A battery of 6V and internal resistance  $2\ \Omega$  is connected to a silver voltmeter. If the current of 1.5A flows through the circuit, the resistance of the voltmeter is**

- (a)  $4\ \Omega$
- (b)  $2\ \Omega$
- (c)  $6\ \Omega$
- (d)  $1\ \Omega$

## Solutions

	I	II	III	IV	V
1	a	b	c	d	a
2	c	a	b	d	A
3	a	b	a	C	A
4	c	a	c	c	D
5	d	d	b	d	C
6	a	a	c	d	b

## Assignment -1 on MCQ questions with answers

**1. Consider a current carrying wire current  $I$  in the shape of a circle. Note that as the current progresses along the wire, the direction of  $j$  (current density) changes in an exact manner, while die current/remains unaffected. The agent that is essentially responsible for is]**

- (a) source of emf.
- (b) electric field produced by charges accumulated on the surface of wire.
- (c) the charges just behind a given segment of wire which push them just the right way by repulsion.
- (d) the charges ahead.

**2. Which of the following is wrong? Resistivity of a conductor is**

- (a) independent of temperature.
- (b) inversely proportional to temperature.
- (c) independent of dimensions of conductor.
- (d) less than resistivity of a semiconductor.

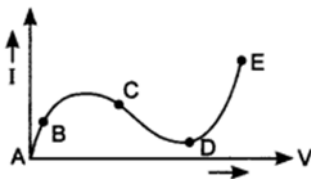
**3. Drift velocity  $v_d$  varies with the intensity of electric field as per the relation**

- (a)  $v_d \propto E$
- (b)  $v_d \propto 1/E$
- (c)  $v_d = \text{constant}$
- (d)  $v_d \propto E^2$

**4. When there is an electric current through a conducting wire along its length, then an electric field must exist**

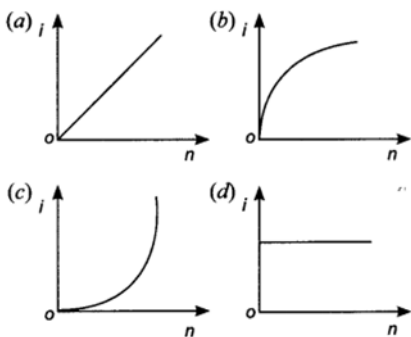
- (a) outside the wire but normal to it.
- (b) outside the wire but parallel to it.
- (c) inside the wire but parallel to it.
- (d) inside the wire but normal to it.

**5. From the graph between current I and voltage V shown below, identify the portion corresponding to negative resistance**



- (a) AB
- (b) BC
- (c) CD
- (d) DE

**6. A battery consists of a variable number  $n$  of identical cells having internal resistances connected in series. The terminals of battery are short circuited and the current  $i$  is measured. Which of the graph below shows the relationship between  $i$  and  $n$ ?**

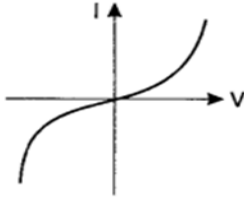


**7. A charge is moving across a junction, then**

- (a) momentum will be conserved.
- (b) momentum will not be conserved.
- (c) at some places momentum will be conserved and at some other places momentum will not be conserved.
- (d) none of these.

**8. The I-V characteristics shown in figure represents**





- (a) ohmic conductors
- (b) non-ohmic conductors
- (c) insulators
- (d) superconductors

**9. The resistivity of alloy manganin is**

- (a) Nearly independent of temperature
- (b) Increases rapidly with increase in temperature
- (c) Decreases with increase in temperature
- (d) Increases rapidly with decrease in temperature

**10. In the series combination of two or more than two resistances**

- (a) the current through each resistance is same.
- (b) the voltage through each resistance is same.
- (c) neither current nor voltage through each resistance is same.
- (d) both current and voltage through each resistance are same.

**11. Combine three resistors 5 Q, 4.5 Q and 3 Q in such a way that the total resistance of this combination is maximum**

- (a) 12.5 Q
- (b) 13.5 Q
- (c) 14.5 Q
- (d) 16.5 Q

12. If  $n$  cells each of emf  $e$  and internal resistance  $r$  are connected in parallel, then the total emf and internal resistance will be

- |                              |                     |
|------------------------------|---------------------|
| (a) $\epsilon, \frac{r}{n}$  | (b) $\epsilon, nr$  |
| (c) $n\epsilon, \frac{r}{n}$ | (d) $n\epsilon, nr$ |

**13. In a Wheatstone bridge if the battery and galvanometer are interchanged then the deflection in galvanometer will**

- (a) change in previous direction
- (b) not change
- (c) change in opposite direction
- (d) none of these.

**14. When a metal conductor connected to left gap of a meter bridge is heated, the balancing point**

- (a) shifts towards right

- (b) shifts towards left
- (c) remains unchanged
- (d) remains at zero

**15. Consider a current carrying wire (current  $I$ ) in the shape of a circle. Note that as the current progresses along the wire, the direction of  $j$  (current density) changes in an exact manner, while the current  $I$  remain unaffected. The agent that is essentially responsible for is**

- (a) source of emf.
- (b) electric field produced by charges accumulated on the surface of wire.
- (c) the charges just behind a given segment of wire which push them just the right way by repulsion.
- (d) the charges ahead.

**16. The drift velocity of the free electrons in a conducting wire carrying a current  $i$  is  $v$ . If in a wire of the same metal, but of double the radius, the current be  $2I$ , then the drift velocity of the electrons will be**

- (a)  $v/4$       (b)  $v/2$    (c)  $v$     (d)  $4v$

**17. Temperature dependence of resistivity  $\rho(T)$  of semiconductors insulators and metals is significantly based on the following factors.**

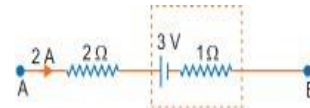
- (a) Number of charge carriers can change with temperature  $T$ .
- (b) Time interval between two successive collisions does not depend on  $T$ .
- (c) Length of material can be a function of  $T$ .
- (d) Mass of carriers is a function of  $T$ .

**18. Kirchoff's junction rule is a reflection of**

- (a) Conservation of current density vector.
- (b) Conservation of energy.
- (c) The fact that the momentum with which a charged particle approaches a junction is unchanged (as a vector) as the charged particle leaves the junction.
- (d) The fact that there is no accumulation of charged at a junction.

**19. Figure represents a part of a closed circuit. The potential difference between points A and B ( $V_A - V_B$ ) is**

- a.  $+9v$       b.  $-9v$
- c.  $+3v$       d.  $+6v$



**20. Two resistors of resistance  $R_1$  and  $R_2$  having  $R_1 > R_2$  are connected in parallel.**

**For equivalent resistance  $R$ , the correct statement is:**

- (a)  $R > R_1 + R_2$       (b)  $R_1 < R_1 < R_2$
- (c)  $R_2 < R_1 < (R_1 + R_2)$       (d)  $R < R_2 < R_1$

**21. The resistivity of iron is  $1 \times 10^{-7}$  ohm-meter. The resistance of the given wire of a particular thickness and length is 1 ohm. If the diameter and length of the wire both are doubled the resistivity will be (in ohm-meter)**

- (a)  $1 \times 10^{-7}$    (b)  $2 \times 10^{-7}$    (c)  $4 \times 10^{-7}$    (d)  $8 \times 10^{-7}$

**22. If charges move without collisions through the conductor , their kinetic energy would also change so that the total energy is**

- a. changed**
- b. unchanged**
- c. doubled**
- d. halved**

**23. Consider a current carrying wire (current I ) in the shape of a circle. Note that as the current progresses along the wire, the direction of j (current density) changes in an exact manner, while the current I remain unaffected. The agent that is essentially responsible for is**

- a. source of emf.**
- b. electric field produced by charges accumulated on the surface of wire.**
- c. the charges just behind a given segment of wire which push them just the right way by repulsion.**
- d. the charges ahead.**

**24 The current in a wire varies with time according to the equation  $I = 4 + 2t$  where I is in ampere and t is in seconds . The quantity of charge which passes through a cross section of the wire**

- a. 40 C**
- b. 48 C**
- c. 38 C**
- d. 43 C**

**25. Which of the following characteristics of electrons determines the current in a conductor?**

- a. drift velocity alone**
- b. thermal velocity alone**
- c. both drift velocity and thermal velocity**
- d. Neither drift velocity nor thermal velocity**

MCQ No

Answers

1. Explanation:

(b) Current density j changes due to electric field produced by charges accumulated on the surface of wire.

2. (a) Resistivity is property of material and inversely proportional to temperature for conductor,  $\rho = mne^2\tau$ .

3. Answer: a

Explanation:

(a) Drift velocity  $v_d = eE\tau$ , i.e.  $v_d \propto E$

4. Explanation:

(c) Electric field parallel to wire inside creates potential difference and electrostatic force on electrons

5. Answer: c

Explanation:

(c) For portion CD slope of the curve is negative i.e. resistance be negative.

6. Answer: d

Explanation: (d)  $I = nEnr = Er$ . current is independent of n.

7. d none of these.

8. b non-ohmic conductors

9. a Nearly independent of temperature

10. a the current through each resistance is same.

11. a 12.5 Q

12. A  $E_r r/n$

13. b not change

14. a shifts towards right

15. (b) electric field produced by charges accumulated on the surface of wire.

16. (b)  $v/2$

17. (a) Number of charge carriers can change with temperature T.

18. (d) the fact that there is no accumulation of charged at a junction.

19. (a)+9V

20. Answer d

$R < R_2 < R_1$

21. Answer a  $1 \times 10^{-7}$

22. Answer b unchanged
23. b. electric field produced by charges accumulated on the surface of wire.
24. Answer b. 48 C
25. Answer: a drift velocity alone

## **Solution for Assignment - 1**

### **Assertion and reasoning**

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.
- (e) If assertion is false but reason is true.

**Q 1 Assertion:** A current flow in a conductor only when there is a electric field within the conductor

**Reason:** The drift velocity of electrons in the presence of electric field decreases

**Q 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 circuit from the negative to the positive terminal.

**Q 3 Assertion:** The electric bulb glows immediately when the switch is on.

**Reason:** The drift velocity of electrons in a metallic wire is very high

**Q 4 Assertion:** Resistivity of a conductor increases with increase in temperature.

**Reason:** When temperature increases the random motion of free electrons increases and vibration of ions increases which decreases the relaxation time.

**Q 5 Assertion:** There is no current in the metals in the absence of electric field.

**Reason:** Motion of free electron are randomly.

**Q 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.

**Q 7 Assertion:** In meter bridge experiment, a high resistance is always connected in series with a galvanometer.

**Reason:** As resistance increases current through the circuit increases.

**Q 8 Assertion:** A person touching a high-power line gets stuck with the line.

**Reason:** The current carrying wires attract the man towards it.

**Q 9 Assertion:** Electric field outside the conducting wire which carries a constant current is zero.

**Reason:** Net charge on conducting wire is zero.

**Q 10 Assertion:** Potential difference across the terminals of a cell is always less than its emf.

**Reason:** Emf of a cell is the maximum potential difference across the terminals of a cell in an open circuit.

**Q 11 Assertion:** A potentiometer of longer length is used for accurate measurement.

**Reason:** The potential gradient for a potentiometer of longer length with a given source of e.m.f. becomes small

**Q 12 Assertion:** The e.m.f. of the driver cell in the potentiometer experiment should be greater than the e.m.f. of the cell to be determined.

**Reason:** The fall of potential across the potentiometer wire should not be less than the e.m.f. of the cell to be determined.

**Q 13 Assertion:** In meter bridge experiment, a high resistance is always connected in series with a galvanometer.

**Reason:** As resistance increases current through the circuit increases.

**Q 14 Assertion:** In a meter bridge experiment, null point for an unknown resistance is measured. Now, the unknown resistance is put inside an enclosure maintained at a higher temperature. The null point can be obtained at the same point as before by decreasing the value of the standard resistance.

**Reason:** Resistance of a metal increases with increase in temperature.

**Q 15 Assertion:** The e.m.f of the driver cell in the potentiometer experiment should be greater than the e.m.f of the cell to be determined.

**Reason:** The fall of potential across the potentiometer wire should not be less than the e.m.f of the cell to be determined.

**Q 16 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.

**Q 17 Assertion:** Electric field outside the conducting wire which carries a constant current is zero.

**Reason:** Net charge on conducting wire is zero.

**Q 18 Assertion:** The connecting wires are made of copper.

**Reason:** The electrical conductivity of copper is high.

**Q 19 Assertion:** A potentiometer of longer length is used for accurate measurement.

**Reason:** The potential gradient for a potentiometer of longer length with a given source of e.m.f. becomes small.

**Q 20Assertion:** The e.m.f. of the driver cell in the potentiometer experiment should be greater than the e.m.f. of the cell to be determined.

**Reason:** The fall of potential across the potentiometer wire should not be less than the e.m.f. of the cell to be determined.

### **Answers for assertion and reasoning**

<b>Q no</b>	<b>answers</b>
<b>1.</b>	<b>(c) drift velocity is directly proportional to electric field</b>
<b>2.</b>	<b>(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.</b>
<b>3.</b>	<b>Ans. (c)</b>
<b>4.</b>	<b>Ans.(a)</b>
<b>5.</b>	<b>(a) It is clear that electrons move in all directions haphazardly in metals. When an electric field is applied, each free electron acquires 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.</b>

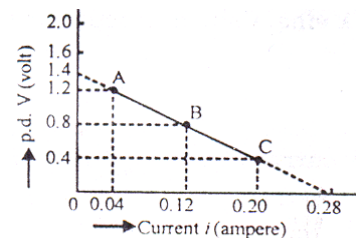
6. (c) The metallic body of the electrical appliances is connected to the third pin which is connected to the earth. This is a safety precaution and avoids eventual electric shock. By doing this the extra charge flowing through the metallic body is passed to earth and avoid shocks. There is nothing such as reducing of the heating of connecting wires by three pin connections.
7. (c) The resistance of the galvanometer is fixed. In meter bridge experiments, to protect the galvanometer from a high current, high resistance is connected to the galvanometer in order to protect it from damage.
8. d) Because there is no special attractive force that keeps a person stuck with a high-power line. The actual reason is that a current of the order of 0.05 A or even less is enough to bring disorder in our nervous system. As a result of it, the affected person may lose temporarily his ability to exercise his nervous control to get himself free from the high-power line
9. (a) When current flows through a conductor it always remains unchanged, hence no electric field is produced outside it.
10. (a)
11. Sensitivity is inversely proportional to potential gradient which directly proportional to length of wire
12. (a) If either the e.m.f. of the driver cell or potential difference across the whole potentiometer wire is lesser than the e.m.f. of the experimental cell, then balance point will not be obtained.
13. (c) The resistance of the galvanometer is fixed. In meter bridge experiments, to protect the galvanometer from a high current, high resistance is connected to the galvanometer.
14. (d) With increase in temperature, resistance of metal wire increases, but balance conduction will not change.
15. (a) If either e.m.f. of the driver cell or potential difference across the whole potentiometer wire is lesser than the e.m.f. of then experimental cell, then balance point will not be obtained.
16. Ans. (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.



17. **Ans. (a) When current flows through a conductor it always remains unchanged, hence no electric field is produced outside it.**
18. **(a) Due to high electrical conductivity of copper, it conducts the current without offering much resistance. The copper being diamagnetic material does not get magnetised due to current through it and hence does not disturb the current in the circuit.**
19. **(a) Sensitivity  $\propto 1/(\text{Potential gradient}) \propto \text{Length of wire}$**
20. **(a) If either the e.m.f. of the driver cell or potential difference across the whole potentiometer wire is lesser than the e.m.f. of the experimental cell, then balance point will not be obtained.**


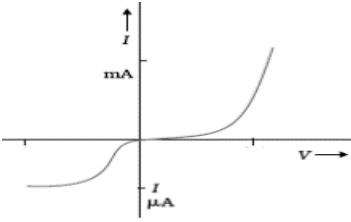
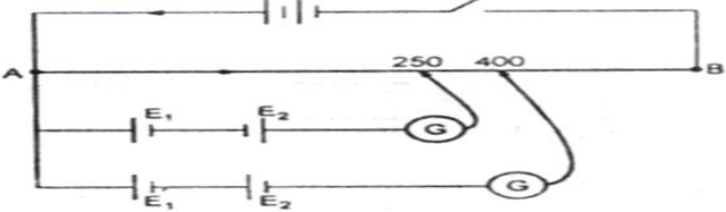
### Assignment -2 ( 2 marks questions)

1. Using data given in graph determine (i) emf (ii) internal resistance of the cell.  
(iii) For what current, does maximum power dissipation occur in the circuit?



2. Draw V-I graph for ohmic and non-ohmic materials. Give one example for each.
3. Two primary cells of emf  $E_1$  and  $E_2$  ( $E_1 > E_2$ ) are connected to the potentiometer wire as shown in the figure. If the balancing lengths for the cells are 250 cm and 400 cm. Find the ratio of  $E_1$  and  $E_2$
4. How does the resistivity of (i) a conductor and (ii) a semiconductor vary with temperature? Give reasons.
5. Explain How does the resistivity of a conductor depend upon (i) number density 'n' of free e's. (ii) Relaxation time ' $\tau$ '.
6. Out of the two bulbs marked 25W and 100W, which one has higher resistance.
7. Explain how electron mobility changes for a good conductor when (i) the temperature of the conductor is decreased at constant potential difference and (ii) applied potential difference is doubled at constant temperature.
8. A cylindrical metallic wire is stretched to increase its length by 5%. Calculate the percentage change in its resistance.
9. Explain how the average velocity of free electrons in a metal at constant temperature, in an electric field, remain constant even though the electrons are being constantly accelerated by this electric field?

10 .Two metallic wires of the same material have the same length but cross-sectional area is in the ratio of 1:2. They are connected (i) in series and (ii) in parallel. Compare the drift velocities of electrons in the two wires in both the cases.

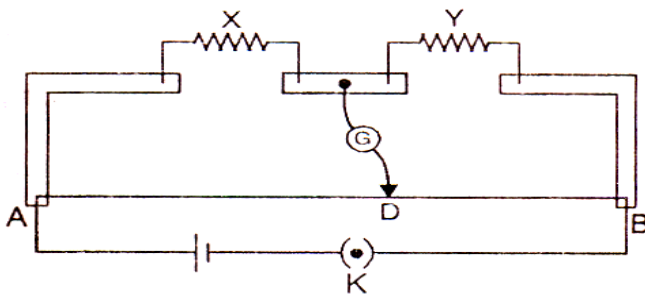
Q NO	ANSWERS
1.	<p>(i) Emf = 1.4V</p> <p>(ii) Internal resistance of the cell <math>r = \frac{E - V}{I} = 5\Omega</math></p> <p>(iii) For maximum power dissipation <math>I = \frac{E}{r + R}</math>  <math>= .14A</math></p>
2.	<p>: Ohmic materials –metallic conductors for small current.</p> <div style="display: flex; justify-content: space-around; align-items: center;">   </div>
3.	<div style="text-align: center;">  </div> <p>: <math>E_1 - E_2 = 250 \phi</math></p> <p><math>E_1 + E_2 = 400 \phi</math></p> <p><math>E_1 : E_2 = 13 : 3</math></p>
4.	<p>Ans: <math>\rho = \frac{m}{n e^2 \tau}</math> and <math>\rho \propto \frac{1}{\tau}</math></p> <p>(i) For a conductor, the density of free e's is almost independent of temperature but the frequency of collision of e's increases with increase in temperature. Therefore the relaxation time decreases. Hence the resistivity of a conductor increases with increase in temperature (conductivity decreases).</p>

	(ii) On increasing the temperature of a semiconductor, the density of free e's increases and the relaxation time decreases. But the increase in 'n' is large than the decrease in 'τ'. Hence the resistivity of a semiconductor decreases with increase in temperature (conductivity increases).
5.	$\rho = \rho \alpha$ and $\rho \propto \alpha$
6.	Ans: $R \propto \frac{l}{A}$ The bulb marked 25W has higher resistance than the bulb marked 100W.
7.	Mobility $\mu = \frac{v_d}{E} = \frac{e\tau}{m}$ (i) When the temperature of the conductor is decreased at constant potential difference, the relaxation time 'τ' of free e's decreases. Hence 'μ' decreases. (ii) Mobility is independent of applied potential difference.
8.	$Al = A'l' \Rightarrow A = \frac{105}{100} A'$ $R = \rho \frac{l}{A} \Rightarrow \frac{R_1}{R_2} = \frac{lA'}{l'A} \Rightarrow R_2 = (1.05)^2 R_1$ $\% \text{ Change} = \frac{R_2 - R_1}{R_1} \times 100 = 10.25\%$
9.	The electron keeps colliding with the positive metal ions and other electrons. The velocity gained by it between two successive collisions due to electric field is lost in next collision.
10.	(i) In series, current in both wires is same. Drift velocity $v_d = \frac{I}{neA}$ , (ii) In parallel, p.d. across the both wires is same. Drift velocity $v_{d1} = \frac{eV\tau}{m l_1}$ $\frac{v_{d1}}{v_{d2}} = \frac{l_1}{l_2} = \frac{1}{1}$

### Assignment -2 ( 3 marks questions)

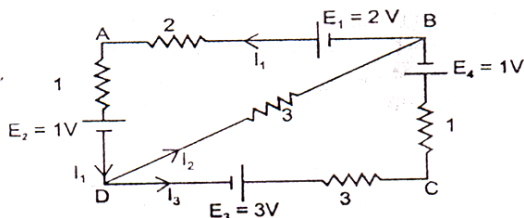
1. Define the term resistivity and write its SI unit. Derive the expression for the resistivity of a conductor in terms of number density of free electrons and relaxation time.

2. Define the terms resistivity and conductivity and state their S.I. units. Draw a graph showing the variation of resistivity with temperature for a typical semiconductor.
3. Define the temperature coefficient of resistivity. Write its S.I. unit. Plot a graph showing the variation of resistivity of nichrome / copper with temperature.
4. What is meant by drift velocity of free e<sup>-</sup>s. Derive ohm's law on the basis of the theory of electron drift.
5. Draw Circuit diagram for a meter bridge to determine the unknown resistance of a resistor. Obtain the balance condition for a meter bridge. Find the shift in the balance point for a meter bridge when two resistors in its two gaps, are interchanged.
6. Are the paths of e<sup>-</sup>s straight lines between successive collisions in the (i) absence of electric field (ii) presence of electric field. Establish a relation between drift velocity and current. Hence obtain the relation between current density and drift velocity.
7. In a meter bridge the balance point is found to be 39.5 cm from one end A, when the resistor Y is of 12.5 Ω . Determine the resistance of X.

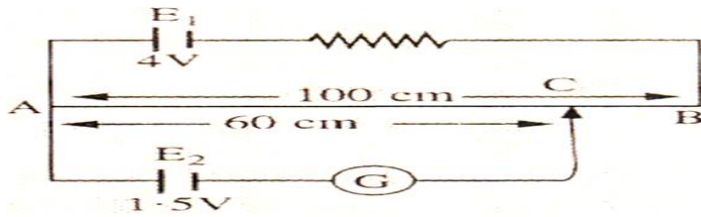


Why are the connections between resistors in a meter bridge made of thick copper strips? What happens if the galvanometer and cell are interchanged at the balance point of the bridge? Would the galvanometer show any current?

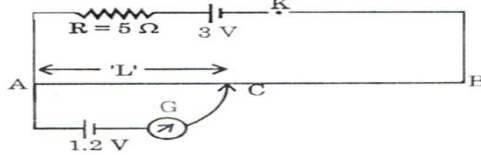
8.  $E_2 = 1.02V$ ,  $PQ = 1m$ . When switch S open, null position is obtained at a distance of 51 cm from P. Calculate (i) potential gradient (ii) emf of the cell  $E_1$  (iii) when switch S is closed, will null point move towards P or Q. Give reason for your answer
9. In the given network find the values of currents  $I_1$ ,  $I_2$  and  $I_3$ .



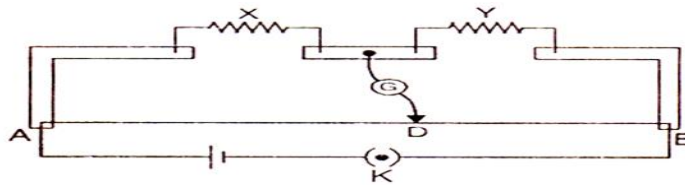
10. (i) Find the p.d. between the ends A and B.  
 (ii) Would the method work, if the battery  $E_1$  is replaced by a cell of emf of 1V.



11.  $AB=100\text{ cm}$ ,  $R_{AB}=10\Omega$ . Find the balancing length  $AC$ .



12. The given figure shows the experimental set up of a meter bridge. The null point is found to be 60cm away from the end A with X and Y in position as shown. When a resistance of  $15\Omega$  is connected in series with 'Y', the null point is found to shift by 10cm towards the end A of the wire. Find the position of null point if a resistance of  $30\Omega$  were connected in parallel with 'Y'.



13 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  $R$ .

Q No	Answers
1	<p><b>The resistivity of a material is equal to the resistance of the unit cube of that material. S.I. unit – ohm metre</b></p> $I = neAv_d \text{----- (1)}$ $V_d = \frac{eE}{m} \tau = \frac{eV}{ml} \tau \text{-----(2)}$ <p>Putting the value of <math>v_{d \text{ in (1), } I = \frac{ne^2 A \tau}{ml} V \Rightarrow R = \frac{V}{I} = \frac{m}{ne^2 \tau} \frac{l}{A} \text{----- (3)}</math></p> <p>Resistance <math>R = \rho \frac{l}{A} \text{----- (4), comparing (3) \&amp; (4), } \rho = \frac{m}{ne^2 \tau}</math></p>
2	<p><b>The reciprocal of resistivity of a material is called its conductivity. S.I. unit – mho/ metre</b></p>

3 The temperature coefficient of resistivity  $\alpha$  of a material is defined as the fractional increase in its resistivity per unit increase in temperature. S.I. unit – per kelvin.



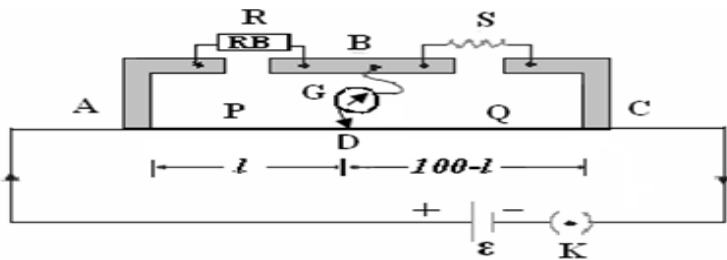
4 Drift velocity – The average velocity with which free electrons of a conductor get drifted in a direction opposite to the direction of applied electric field.  $v_d = \frac{eE}{m} \tau = \frac{eV}{ml} \tau$

$$\text{Current } I = neAv_d = \frac{ne^2 A \tau}{ml} V \Rightarrow \frac{V}{I} = \frac{m}{ne^2 \tau A}$$

At a constant temperature, RHS of above equation is constant for a given conductor.

$$\therefore \frac{V}{I} = \frac{m}{ne^2 \tau A} = \text{Constant } I \Rightarrow V \propto I$$

5 :  $S$  is an unknown resistance whose value to be determine. It is connected across one of the gaps. Across the other gap, a resistance box is connected. The four arms AB, BC, AD and DC [with resistances  $R$ ,  $S$ ,  $P$  and  $Q$ ] form a Wheatstone bridge with AC as the battery arm and BD the galvanometer arm.



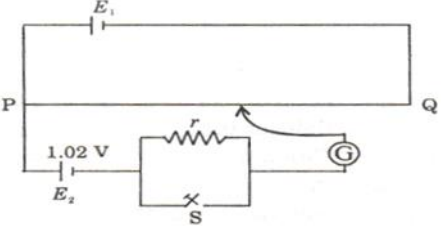
After taking out a suitable resistance  $R$  from resistance box, the jockey is moved along the wire  $AC$  till there is no deflection in galvanometer. This is the balanced condition of Wheatstone bridge. For balanced condition of Wheatstone bridge,  $\frac{P}{Q} = \frac{R}{S}$  -----(1)

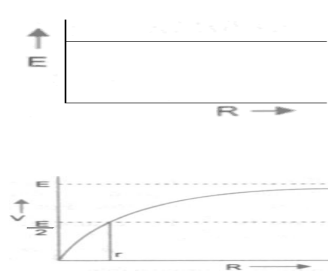
Let  $l$  be the balancing length. Then  $AD = l$  and  $DC = 100 - l$

$P$  = resistance of arm  $AD = r l$  and  $Q$  = resistance of arm  $DC = r (100 - l)$

$$\text{From eq. (1), } \frac{R}{S} = \frac{l}{100 - l}$$

**Let ' $l$ ' be the balancing length for a meter bridge from end 'A'. When two resistors in its two gaps, are interchanged, the balancing length becomes  $(100 - l)$ .**

6	<p>(i) In the absence of electric field, the paths of e's are straight lines between successive collisions. (ii) In the presence of electric field, every electron experiences a force in a direction opposite to the direction of electric field. Therefore, the paths of e's are curved.</p>
7	<p><math display="block">X = \frac{lY}{100-l} = 8.16 \Omega</math></p> <p><b>Thick copper stripes offer minimum resistance. Therefore the connections between resistors in a meter bridge are made of thick copper strips to minimize the resistances of connections which are not accounted in bridge formula.</b></p> <p><b>When the galvanometer and cell are interchanged at the balance point of the bridge, the condition for balanced bridge remains satisfied. The galvanometer will not show any current.</b></p>
8	<div style="display: flex; align-items: center;">  <div style="margin-left: 20px;"> <p><b>Potential gradient <math>k = \frac{E_2}{l_2} = 0.02V/cm</math></b></p> <p>(ii) emf of the cell <math>E_1 = k l_{PQ} = 2V</math></p> <p>(iii) When switch S is closed, null point is not affected because no current drawn from cell <math>E_1</math> at the null point.</p> </div> </div>
9	<p><b>: At junction D, <math>I_1 = I_2 + I_3</math> ----- (1)</b></p> <p><b>In loop DCBD, <math>-3 + 3I_3 + I_3 + 1 - 3I_2 = 0 \Rightarrow 4I_3 - 3I_2 = 2</math> ----- (2)</b></p> <p><b>In loop ADDBA, <math>I_1 + 1 + 3I_2 - 2 + 2I_1 = 0 \Rightarrow 3I_1 + 3I_2 = 1</math> ----- (3)</b></p> <p><b>On solving (1), (2) &amp; (3), <math>I_1 = 13/33</math> A, <math>I_2 = -2/33</math> A &amp; <math>I_3 = 5/11</math> A</b></p>
10	<p>(i) <math>\phi = \frac{E_2}{l_{AC}}</math> ; <math>V_{AB} = \phi l_{AB} = 2.5V</math> (ii) No, because <math>E_1 &lt; E_2</math>. Therefore the null point can not be obtained through the potentiometer wire.</p>
11	<p><b>: <math>I = \frac{E_1}{R_{AB} + R} = 0.2A</math> ; <math>\phi = \frac{IR_{AB}}{l_{AB}} = 2 \times 10^{-2} V/cm</math> ; <math>E_2 = \phi l_{AC} \Rightarrow l_{AC} = 60cm</math>.</b></p>
12	<p><b>Formula <math>\frac{X}{Y} = \frac{l}{100-l}</math> , <math>\frac{X}{Y} = \frac{60}{40} \Rightarrow 2X = 3Y</math> .....(1)</b></p> <p>When a resistance of <math>15\Omega</math> is connected in series with 'Y'</p>

	$\frac{X}{Y+15} = \frac{50}{50} \Rightarrow X = Y + 15 \dots\dots\dots(2)$ <p>On solving (1) &amp; (2), <math>X = 45 \Omega</math>,  <math>Y = 30\Omega</math></p> <p>When a resistance of <math>30\Omega</math> is connected in series with 'Y'</p> $\frac{X}{Y+30} = \frac{l}{100-l} \Rightarrow l = 75cm \text{ from end A.}$
13.	<p>(i) <b>The emf E of a cell is independent of external resistance I.</b></p> <p><b>(v) The terminal p.d. <math>V = IR = \frac{E}{r+R} R = \frac{E}{1+\frac{r}{R}}</math></b></p>  <p><b>On increasing R, V increases.</b></p> <p><b>When <math>R = 0</math>, <math>V \rightarrow 0</math>. When <math>R = r</math>, <math>V = \frac{E}{2}</math></b></p> <p><b>When <math>R \rightarrow \infty</math>, <math>V = E</math>.</b></p>

**Assignment -2 ( 5 marks questions)**

1. A cell of unknown emf E and internal resistance r, two unknown resistances R1 and R2 ( $R_2 > R_1$ ) and a perfect ammeter are given. The current in the circuit is measured in five different situations: (i) Without any external resistance in the circuit, (ii) With resistance R1 only, (iii) With resistance R2 only, (iv) With both R1 and R2 used in series combination and (v) With R1 and R2 used in parallel combination. The current obtained in the five cases are 0.42A, 0.6A, 1.05A, 1.4A, and 4.2A, but not necessarily in that order. Identify the currents in the five cases listed above and calculate E, r, R1 and R2.

2. (a) Describe the formula for the equivalent EMF and internal resistance for the parallel combination of two cells with EMF  $\epsilon_1$  and  $\epsilon_2$  and internal resistances r1 and r2 respectively. What is the corresponding formula for the series combination?

(b) Two cells of EMF 1V, 2V and internal resistances  $2\Omega$  and  $1\Omega$  respectively are connected in

(i) series, (ii) parallel. What should be the external resistance in the circuit so that the current through the resistance be the same in the two cases? In which case more heat is generated in cells?

3.. Deduce the condition for balance in a Wheatstone bridge. Using the principle of Wheatstone bridge, describe the method to determine the specific resistance of a wire in the laboratory. Draw the circuit diagram and write the formula used. Write any two precautions.

4. Describe the principle and construction of potentiometer. Explain how a potentiometer can be used to compare the emfs of two primary cells?



5. Draw Circuit diagram for a meter bridge to determine the unknown resistance of a resistor. Obtain the balance condition for a meter bridge. Find the shift in the balance point for a meter bridge when two resistors in its two gaps, are interchanged.

6.. Are the paths of e's straight lines between successive collisions in the (i) absence of electric field (ii) presence of electric field. Establish a relation between drift velocity and current. Hence obtain the relation between current density and drift velocity.

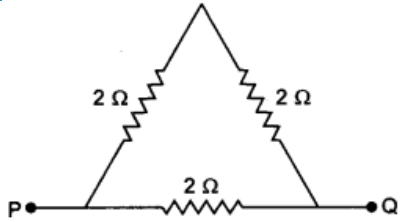
Q no	Ans
1.	$(i) I_1 = \frac{E}{r}, (ii) I_2 = \frac{E}{r + R_1}, (iii) I_3 = \frac{E}{r + R_2}, (iv) I_4 = \frac{E}{r + R_1 + R_2}, (v) I_5 = \frac{E}{r + \frac{R_1 R_2}{R_1 + R_2}}$ <p>This is clear that <math>I_1 &gt; I_5 &gt; I_2 &gt; I_3 &gt; I_4</math>.</p> <p>Hence <math>I_1 = 4.2A, I_5 = 1.4A, I_2 = 1.05A, I_3 = 0.6A, I_4 = 0.42A</math>.</p> <p>Putting these values in (i) to (v) and on solving,  <math>E = 4.2V, R_1 = 3\Omega, R_2 = 6\Omega, r = 1\Omega</math></p>
2.	<p>(a) Derive the formula <math>\varepsilon_{eq} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}</math> and <math>r_{eq} = \frac{r_1 r_2}{r_1 + r_2}</math></p> <p>(b) For series combination, <math>I_s = \frac{3}{3 + R}</math> and for parallel combination, <math>I_p = \frac{\frac{5}{2} + R}{3} = \frac{5}{3R + 2}</math></p> <p>given <math>I_s = I_p \Rightarrow R = \frac{9}{4} = 225 \Omega</math>.</p>
3.	<p>Ans: Derive the formula <math>\frac{P}{Q} = \frac{R}{S}</math></p>
4.	<p>[Ans: (a) Derive the formula <math>\frac{E_1}{E_2} = \frac{l_1}{l_2}</math></p>
5	<p>To derive the condition</p>
6..	<p>(i) in the absence of electric field, the paths of e's are straight lines between successive collisions. (ii) In the presence of electric field, every electron experiences a force in a direction opposite to the direction of electric field. Therefore, the paths of e's are curved.</p> <p>Derive the formula <math>I = AneV_d</math> and <math>j = neV_d</math>]</p>

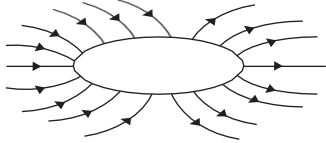
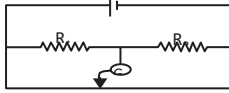
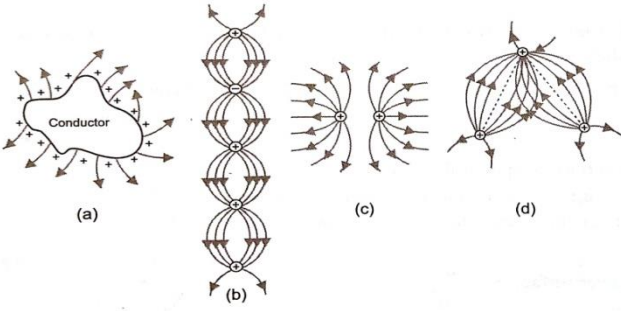
## REVISION QUESTION PAPER

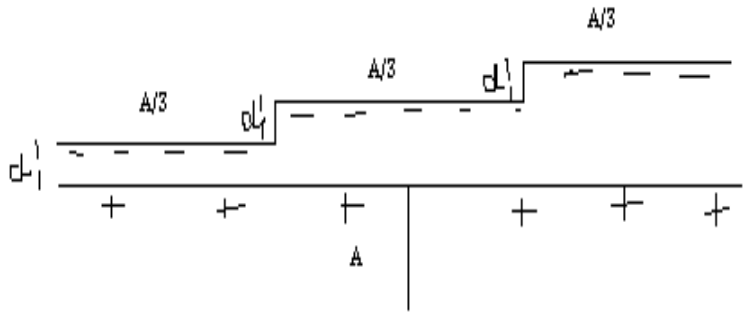
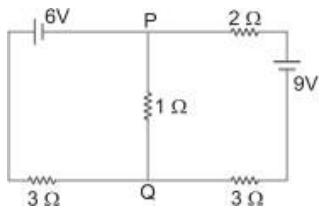

(CHAPTERS 1,2 AND 3) FOR 35 MARKS

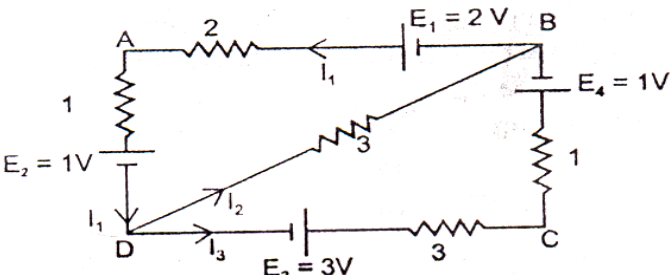
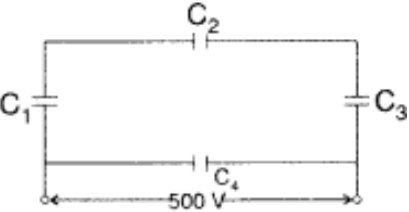
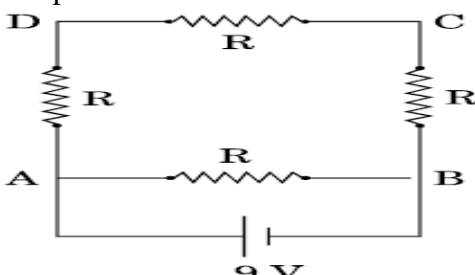
(i) There are 18 questions in all.

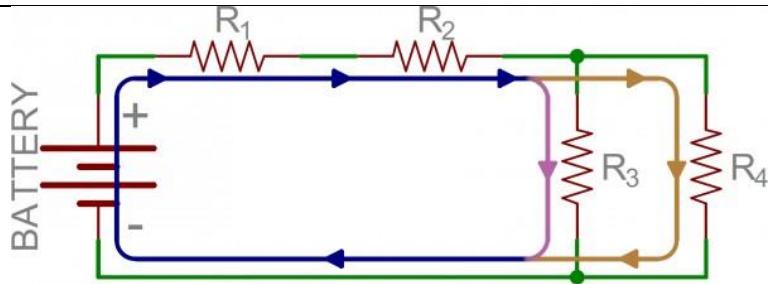
- (ii) This question paper has five sections: Section A , Section B, Section C-sections D and Section E
- (iii) All questions are compulsory
- (iv) Section A contains nine MCQ of 1 mark each, Section B contains four questions of two marks each, Section C contains three questions of three marks each, Section D contains one long answers question of 5 marks and Section E contains one case based questions of 4 mark
- (v) There is no overall choice. However an internal choice has been provided in section B, C, D and E. You have to attempt only one of the choice in such questions

SECTION A M C Q		
1.	Three charges each equal to $1 \mu C$ placed at the corners of an equilateral triangle . If force between any two charges is $F$ , then the net force on either will be (a) $\sqrt{3}F$ (b) $\sqrt{2} F$ (c) $3 F$ (d) $F$	1 MARK
2.	<u>A cylinder of radius <math>R</math> and length <math>L</math> is placed in a uniform electric field <math>E</math> parallel to the cylinder axis. The total flux for the surface of the cylinder is given by</u> (a) $2\pi R^2 E$ (b) $\pi r^2$ (c) $\frac{\pi R^2 - \pi R}{E}$ (d) Zero	1 MARK
3.	<u>A point charge <math>q</math> is placed at a distance <math>a/2</math> directly above the centre of a square of side <math>a</math>. The electric flux through the square is</u> (a) $q/\epsilon_0$ (b) $q/\pi\epsilon_0$ (c) $q/4\epsilon_0$ (d) $q/6\epsilon_0$	1 MARK
4.	<u>Three resistors each of <math>2 \text{ ohm}</math> are connected together in a triangular shape. The resistance between any two vertices will be</u>  (a) <u><math>4/3 \text{ ohm}</math></u> (b) <u><math>3/4 \text{ ohm}</math></u> (c) <u><math>3 \text{ ohm}</math></u> (d) <u><math>6 \text{ ohm}</math></u>	1 MARK
5.	<u>In an experiment on meter bridge, if the balancing length <math>AC</math> is <math>x</math>, what would be its value, when the radius of the meter bridge wire <math>AB</math> is doubled? Justify your answer.</u>	1 MARK
6.	A capacitor is connected to a cell of emf $E$ having some internal resistance $r$ . The potential difference across the : (a) Cell is $<E$	1 MARK

	(b) Cell is E (c) Capacitance is $>E$ (d) Capacitance is $<E$	
7.	Figure below shows a hollow conducting body placed in an electric field. Which of the quantities are zero inside the body?   (a) Electric field and potential (b) Electric field and charge density (c) Electric potential and charge density (d) Electric field, potential and charge density	1 MARK
8.	In a Wheatstone bridge in the battery and galvanometer are interchanged then the deflection in galvanometer will : (a) Change in previous direction (b) No change (c) Change in opposite direction (d) None of these	1 MARK
9.	In the meter bridge experiment shown in figure the balance length AC corresponding to null deflection of the galvanometer is $x$ , What should be the balancing length if the radius of the wire AB is doubled?   (a) $4x$ (b) $2x$ (c) $x$ (d) $x/2$	1 MARK
<b>SECTION B - TWO MARKS</b>		
10.	Which among the curves cannot possibly represent electrostatic field lines:   (a) (b) (c) (d)	2 MARKS

11.	<p>A capacitor is made of a flat plate of area <math>A</math> and second plate having a stair like structure as shown in figure below. If width of each stair is <math>A/3</math> and height is 'd', find capacitance of the arrangement.</p> 	2 MARKS
12.	<p>A cell of emf (<math>E</math>) and internal resistance (<math>r</math>) is connected across a variable external resistance (<math>R</math>). Plot graphs to show variation of (i) <math>E</math> with <math>R</math>, (ii) Terminal p.d. of the cell (<math>V</math>) with <math>R</math>.</p> <p style="text-align: center;">Or</p> <p>Find the magnitude and direction of current in <math>1\Omega</math> resistor in the given circuit</p> 	2 MARKS
13	<p>A point charge <math>q</math> is placed at <math>O</math> as shown in Fig. Is <math>V_A - V_B</math> positive, negative or zero if <math>q</math> is a (i) positive charge (ii) negative charge?</p> 	2 MARKS
14	<p>State the principle on which the working of a meter bridge is based. Under what conditions is the error in determining the unknown resistance minimized?</p> <p style="text-align: center;">OR</p> <p>A proton is moved in a uniform electric field of <math>1.7 \times 10^{-4} \text{N/C}</math> between two points <math>A</math> and <math>B</math> separated by a distance of <math>0.1 \text{ m}</math></p> <p>(i) What is the potential difference between the points?</p> <p>(j) How much work is done in the above process?</p>	2 MARKS
SECTION C - 3 MARKS		
15	<p><b>Two parallel plate capacitors <math>X</math> and <math>Y</math> have the same area of plates and same separation between them has air between the plates while <math>Y</math> contains a dielectric medium <math>K=4</math>.</b></p> <p>(i) Calculate the capacitance of each capacitor if equivalent capacitance of the combination is <math>4\mu\text{F}</math>.</p> <p>(ii) Calculate the potential difference between the plates of <math>X</math> and <math>Y</math>.</p> <p>(iii) Estimate the ratio of electrostatic energy stored in <math>X</math> and <math>Y</math>.</p> <p style="text-align: center;">OR</p>	3 MARKS

	<p>2. In the given network find the values of currents <math>I_1</math>, <math>I_2</math> and <math>I_3</math>.</p> 	
16	<p>Network of four capacitors each of <math>15 \mu\text{F}</math> capacitance is connected to a <math>500 \text{ V}</math> supply as shown in the figure.</p>  <p>Determine (a) <b>equivalent capacitance of the network</b> and (b) charge on each capacitor.</p>	3 MARKS
17	<p>A <math>16 \Omega</math> resistance wire is bent to form a square. A source of emf <math>9 \text{ V}</math> is connected across one of its sides as shown. Calculate the current drawn from the source. Find the potential difference between the ends C and D. If now the wire is stretched uniformly to double the length and once again the same cell is connected in the same way, across one side of the square formed, what will now be the potential difference across one of its diagonals</p> 	3 MARKS
SECTION D		
18	<p>Derive expression for potential at a point P which makes an angle with the axis of an electric dipole</p> <p style="text-align: center;">OR</p> <p>Four charges <math>+q</math>, <math>-q</math>, <math>+q</math> and <math>-q</math> are to be arranged respectively at the four corners of a square ABCD of side 'a'. (a) Find the work required to put together this arrangement. (b) A charge <math>q_0</math> is brought to the centre of the square, the four charges being held fixed. How much extra work is needed to do this?</p>	5 MARKS
SECTION E - COMPETANCY BASED QUESTION		
19	<p>Two components are in series, if the same current flows through them. Here's an example circuit with three series resistors.</p>	4 MARKS



In parallel circuits the voltage across them remains same. 1. In series circuit the resistances has same

a) Voltages b) Current c) Capacitance d) Energy

2. In parallel circuit the resistances has same

a) Voltage b) current c) Inductance d) Power

3) In the above circuit

a) R1, R2 series and R3, R4 parallel

b) R1, R3 series and R2, R4 parallel

c) R2, R3 series and R1, R4 parallel

d) R2, R4 series and R3, R1 parallel

4) Power consumption is more for a given battery

a) Two equal resistances are kept in series

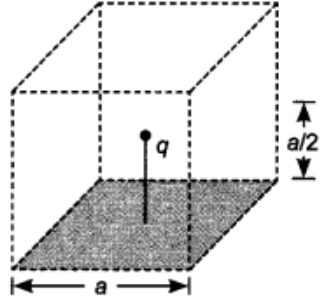
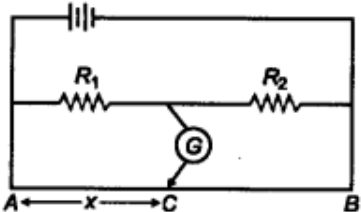
b) Two equal resistances are kept in parallel

c) Both are true

d) None of the above

### MARKING SCHEME

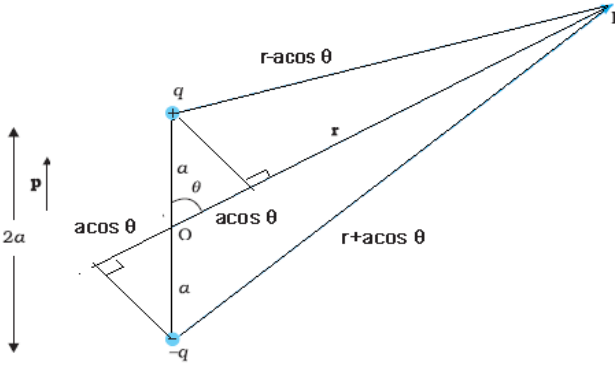
1.	(a) $\sqrt{3} F$	1 MARK
2.	<p><u>Answer: d</u> Explanation</p> <p>(d)</p> <p>Flux through surface A <math>\phi_A = E \times \pi R^2</math>  and through B <math>\phi_B = -E \times \pi R^2</math>  Flux through curved surface C  <math>\int \vec{E} \cdot \vec{ds} = \int E ds \cos 90^\circ = 0</math>  Total flux through cylinder  <math>= \phi_A + \phi_B + \phi_C = 0</math></p>	1 MARK
3.	<p><u>Answer: d</u> Explanation:</p> <p>(d) An imaginary cube can be made by considering charge q at the centre and given square is one of its face. So flux through the given square (i.e. one face)</p>	1 MARK

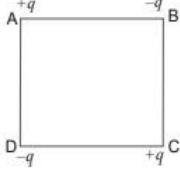
	$\phi = q/6\epsilon_0$ 		
4.	Answer: d Explanation: (d) $I = nEnr = Er$ . current is independent of n.		1 MARK
5.	<p><u>At the balance point, we have</u></p> $\frac{R_1}{R_2} = \frac{x}{100 - x}$  <p><u>As <math>R_1</math> and <math>R_2</math> remain the same, then x will also remain the same. It will not depend upon the diameter of the wire.</u></p>		1 MARK
6.	Option (b) Explanation In the given case, cell is in open circuit mode ( $I=0$ ). So voltage across the cell is equal to its emf		
7.	(b) Electric field and charge density Explanation : Electric field is always zero inside , If there is any excess charge on hollow conductor it always resides on outer surface of conductor . Therefore inside a hollow conductor there is no charge and hence charge density is zero		1 MARK
8.	(C) No change Explanation The deflection in galvanometer will not be changed due to interchange of battery and the galvanometer.		1 MARK
9.	Option c X Explanation Balancing length is independent of cross sectional area of the wire.		1 MARK
10.	<p>(a) Field lines are wrongly drawn because electric field lines must be normal to the surface of the conductor at each point.</p> <p>(b) Field lines are wrongly drawn because electric field lines cannot start from a negative charge.</p> <p>(c) Field lines are correctly drawn because they are originating from negative charge.</p> <p>(d) Field lines are wrongly drawn because electric field lines cannot intersect.</p>	$4 \times 1/2$	2 MARKS





	(b) At macroscopic level, the quantization of charge has no practical significance because the charge at macroscopic level is very large as compared to elementary charge (e) i.e., $1.6 \times 10^{-19} \text{C}$ . For example, a small charge of $1 \mu\text{C}$ has about 1013 electronic charges. In such cases the charge may be treated as continuous and not quantized.	1 MARK	
14.	1. Meter bridge is based on the principle of Wheatstone bridge 2. An error in determination of resistance, can be minimized by adjusting the balance point near the middle of the meter bridge.  OR Given $q = 1.6 \times 10^{-19} \text{C}$ , $E = 1.7 \times 10^{-4} \text{N/C}$ , $d = 0.1 \text{m}$ (i) $V = E \times d$ $1.7 \times 10^{-4} \times 0.1 = 1.7 \times 10^{-5} \text{volts}$ (ii) $W = V \times q$ $1.7 \times 10^{-4} \times 1.6 \times 10^{-19} = 2.72 \times 10^{-24} \text{Joules}$	1 MARK  1 MARK  1 MARK  1 MARK	2 MARKS   OR  2 MARKS
15.	(i) Capacitance of X, $C_X = \frac{\epsilon_0 A}{d}$ Capacitance of Y, $C_Y = \frac{\epsilon_r \epsilon_0 A}{d} = 4 \frac{\epsilon_0 A}{d}$ $\therefore \frac{C_Y}{C_X} = 4 \Rightarrow C_Y = 4C_X$ As X and Y are in series, so $C_{eq} = \frac{C_X C_Y}{C_X + C_Y} \Rightarrow 4 \mu\text{F} = \frac{C_X \cdot 4C_X}{C_X + 4C_X}$ $\Rightarrow C_X = 5 \mu\text{F}$ and $C_Y = 4C_X = 20 \mu\text{F}$ OR (ii) In series charge on each capacitor is same, so P.d. $V = \frac{Q}{C} \Rightarrow V \propto \frac{1}{C}$ $\therefore \frac{V_X}{V_Y} = \frac{C_Y}{C_X} = 4 \Rightarrow V_X = 4V_Y$ Also $V_X + V_Y = 15$ From (ii) and (iii), $4V_Y + V_Y = 15 \Rightarrow V_Y = 3 \text{V}$ $V_X = 15 - 3 = 12 \text{V}$ Thus potential difference across X, $V_X = 12 \text{V}$ , P.d. across Y, $V_Y = 3 \text{V}$ (iii) $\frac{\text{Energy stored in X}}{\text{Energy stored in Y}} = \frac{Q^2 / 2C_X}{Q^2 / 2C_Y} = \frac{C_Y}{C_X} = \frac{4}{1} \Rightarrow \frac{U_X}{U_Y} = \frac{4}{1}$ At junction D, $I_1 = I_2 + I_3$ ----- (1)	1 MARK  1 MARK  1 MARK  1 MARK  1 MARK  1 MARK	3 MARKS       3 MARKS

	<p>In loop DCBD, <math>-3 + 3I_3 + I_3 + 1 - 3I_2 = 0 \Rightarrow 4I_3 - 3I_2 = 2</math> -- (2) In loop ADDBA, <math>I_1 + 1 + 3I_2 - 2 + 2I_1 = 0 \Rightarrow 3I_1 + 3I_2 = 1</math> ---- (3) On solving (1), (2) &amp; (3), <math>I_1 = 13/33</math> A, <math>I_2 = -2/33</math> A &amp; <math>I_3 = 5/11</math> A</p>		
16.	<p>Now <math>C_5</math> and <math>C_4</math> are in parallel Equivalent capacitance of the network <math>C = C_5 + C_4 = 15 + 5 = 20 \mu\text{F}</math>  (b) Charge on capacitor, <math>C_4</math> is <math>q = C_4 V = (15 \times 10^{-6}) \times 500 = 7500 \mu\text{C} \dots *V = 500\text{V}</math>  Charge on each capacitor, <math>C_1</math>, <math>C_2</math> and <math>C_3</math> will be, <math>q = C_5 V = (5 \times 10^{-6}) \times 500 = 2500 \text{Mc}</math></p>	1 MARK 1 MARK 1 MARK	3 MARKS
17.	<p>Let AB be a dipole of dipole length <math>2l</math> formed by two point charges <math>-q</math> and <math>+q</math> kept at A and B respectively as in figure. Let P be a point at a distance <math>r</math> from the centre O of the dipole.</p>  <p>The electric potential due to dipole at the point P,  <math>V = (V_1 \text{ due to } -q) + (V_2 \text{ due to } +q)</math>  If the dipole is very short (<math>r \gg l</math>), then</p> $V = \frac{1}{4\pi\epsilon_0} \frac{p \cos \theta}{r^2}$ <p style="text-align: center;">OR</p>	1 MARK 2 MARKS	5 MARKS
		2 MARKS 1 MARK 1 MARK 1 MARK	5 MARKS

	<p>(a) Work done in bringing charge <math>+q</math> at point A  <math>W_A = 0</math>          Work done in bringing charge <math>-q</math> to the point B  <math>W_B = W_{AB} = -q \times \frac{1}{4\pi\epsilon_0} \frac{q}{a} = -\frac{1}{4\pi\epsilon_0} \frac{q^2}{a}</math>          Work done in bring the charge <math>+q</math> to the point C  <math>W_C = W_{AC} + W_{BC}</math>  <math>= q \times \frac{1}{4\pi\epsilon_0} \frac{q}{a\sqrt{2}} + q \times \left( -\frac{1}{4\pi\epsilon_0} \frac{q}{a} \right) = \frac{1}{4\pi\epsilon_0} \frac{q^2}{a\sqrt{2}} - \frac{1}{4\pi\epsilon_0} \frac{q^2}{a}</math>          Work done in bringing a charge <math>-q</math> to the point D  <math>W_D = W_{AD} + W_{BD} + W_{CD}</math>  <math>= -q \times \frac{1}{4\pi\epsilon_0} \frac{q}{a} + (-q) \left( \frac{1}{4\pi\epsilon_0} \frac{-q}{a\sqrt{2}} \right) + (-q) \times \frac{1}{4\pi\epsilon_0} \frac{q}{a}</math>          Total work done <math>W = W_A + W_B + W_C + W_D</math>  <math>= 2 \times \frac{1}{4\pi\epsilon_0} \frac{q^2}{a\sqrt{2}} - 4 \times \frac{1}{4\pi\epsilon_0} \frac{q^2}{a} = \frac{1}{4\pi\epsilon_0} \frac{q^2}{a} (\sqrt{2} - 4)</math></p> <p>(b) Work done in bringing a charge from infinity to a point is given by  <math>W = q_0 V_p</math> (<math>V_p</math> = Electric potential at the point)          Electric potential at the centre of the square is  <math>V_C = \frac{1}{4\pi\epsilon_0} \left( \frac{+q}{s} \right) + \frac{1}{4\pi\epsilon_0} \left( \frac{-q}{s} \right) + \frac{1}{4\pi\epsilon_0} \left( \frac{+q}{s} \right) + \frac{1}{4\pi\epsilon_0} \left( \frac{-q}{s} \right) = 0</math>          and electric potential at infinity is always zero.          Hence, work done <math>W = 0</math>.</p>	 <p style="text-align: center;">1 MARK</p>	
18.	1-b 2-a 3-a 4-b	1 MARK 1 MARK 1 MARK 1 MARK	4 MARKS

## Unit - III Magnetic Effects of Current and Magnetism (Chapters 4&5)

### FORMULA CHART

S.NO	FORMULAE	SYMBOLS
1.	<b>Biot – Savart Law:</b> $dB = \frac{\mu_0 I dl \sin \theta}{4\pi r^2}$	<b>dB</b> = magnetic field at a point at distance 'r' due to a current element. <b><math>\mu_0</math></b> = permeability of free space <b>I dl</b> = current element <b><math>\theta</math></b> = angle between current element I dl and position vector r

2.	<b>Magnetic Field at the Centre of a Circular Loop</b> (or) Magnetic Field at the Centre: $B = \frac{\mu_0 n I}{2a}$	$a$ = radius of the current carrying circular loop $n$ = number of turns in a circular coil
3.	<b>Magnetic Field at a Point on the Axis of Circular Loop:</b> $B = \frac{\mu_0 2 I A}{4\pi (x^2 + a^2)^{3/2}}$	$x$ = distance between the observation point and the centre of the loop. $a$ = radius of the circular loop
4.	<b>Ampere's Law:</b> $\oint B \cdot dl = \mu_0 I$	
5.	<b>Magnetic Field Due to a Current Carrying Straight Conductor:</b> $B = \frac{\mu_0 I}{2\pi r}$	
6.	<b>Magnetic Field Due to a Current Carrying Solenoid:</b> $B = \mu_0 n I$	$n$ -number of turns per unit length
7.	<b>Motion of a Charged Particle Inside an Electric Field:</b> $y = \frac{1}{2} \left( \frac{qE}{mv^2} \right) x^2$	$q$ = charge moving with a uniform velocity $v$ = potential difference across the plates $E = v/b$ = electric field $x$ = displacement along $x$ - axis
8.	<b>Magnetic Lorentz Force:</b> $F = B q v \sin \theta$	$F$ = Force acting on a charged particle in magnetic field $v$ = velocity of charged particle $q$ = charge of the particle
9.	<b>Lorentz Force :</b> $F = F_e + F_m$ $F = qE + q (v \times B)$	$F_e$ = Force on a charged particle due to electric field $F_m$ = Force on a charged particle due to magnetic field
10.	<b>Force On a Current Carrying Conductor:</b> $F = B I L \sin \theta$	$L$ = Length of a current carrying conductor.
11.	<b>Force between Two Infinitely Long Current Carrying Parallel Conductors:</b> $F = \frac{\mu_0}{4\pi} \cdot \frac{2 I_1 I_2}{r}$	$I_1, I_2$ = Current Passing Through The Conductors. $r$ = Distance between the two parallel conductors
12.	<b>Torque acting on a Current Carrying Loop:</b> $\tau = B I A \sin \theta$	$\Theta$ = the angle made by normal to the plane of the coil with the direction of magnetic field $A$ = Area of the current carrying loop

13.	<b>Moving Coil Galvanometer (or) American type Galvanometer:</b> $I = G \frac{\phi}{\sin \theta}$	$G = \frac{k}{nBA}$ Galvanometer constant $\Phi$ = Steady angular deflection
14.	<b>Resistance Of the Ammeter:</b> $R_A = \frac{R_g \cdot S}{R_g + S}$	$R_g$ = Resistance of Galvanometer $S$ = Shunt Resistance
15.	<b>Resistance Of the Voltmeter:</b> $R_V = R - R_g$	
16.	<b>Magnetic Dipole Moment:</b> $M = m(2a)$	$2a$ = Magnetic Length
17.	<b>Current loop as a Magnetic Dipole:</b> Magnetic dipole $M = nIA$	I-current A-Area n-number of turns
18.	<b>Magnetic Field (Axial Line of a magnet):</b> $B = \frac{\mu_0 \cdot 2Mr}{4\pi (r^2 - a^2)^2}$	
19.	<b>Magnetic Field (Equatorial Line of a magnet):</b> $B = \frac{\mu_0 \cdot M}{4\pi (r^2 - a^2)^{3/2}}$	
20.	<b>Torque:</b> $T = MB \sin \theta$	
21.	<b>Pot Energy:</b> $U = mB (\cos \theta_2 - \cos \theta_1)$	
22.	<b>Magnetic Intensity:</b> $H = \frac{B_0}{\mu_0}$	$B_0$ = Magnetic Field In Vacuum
23.	<b>Intensity Of Magnetisation:</b> $I = \frac{M}{V}$	$M$ = magnetic dipole moment acquired by the specimen $V$ = volume of the specimen
24.	<b>Magnetic Flux:</b> $\Phi = B \cdot A$	S.I Unit = wb (Weber)
25.	<b>Magnetic Induction:</b> $B = B_0 + \mu_0 I$	S.I Unit = T (Tesla)
26.	<b>Magnetic Susceptibility</b> $\chi_m = \frac{I}{H}$	$H$ = Magnetic Intensity
27.	<b>Magnetic Permeability:</b> $\mu = \frac{B}{H}$	$B$ = Magnetic induction $H$ = Magnetic Intensity

<b>28.</b>	<b>Radius of The Circular Path Of Charged particle moving perpendicular to the mag. Field</b> $r = \frac{mv}{Bq}$	<b>m-mass v-velocity</b> <b>B- mag field strength</b> <b>q-charge</b>
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### NUMERICALS WITH SOLUTION

Q1) A magnetic dipole is acted upon by two magnetic fields which are inclined to each other at an angle of  $75^\circ$ . One of the fields has a magnitude of 15mT. The dipole attains stable equilibrium at an angle of  $30^\circ$  with this field. Find the magnitude of other magnetic field?(3)

Q2) A sample of cast iron exhibits a magnetic field  $B=0.5T$ , when the intensity of magnetizing field (H) is 10A/m.

- (i) Find the permeability of iron (3)
- (ii) What would be the field in air for this value of H?

Q3) A long, straight wire of radius 'a' carries a current distributed uniformly over its cross section. What is the ratio of the magnetic fields due to the wire at distance  $a/3$  and  $2a$ , respectively, from the axis of wire?(5)

Q4) A circular coil of 200 turns and radius 10 cm is placed in a uniform magnetic field of 0.5 T, normal to the plane of the coil. If the current in the coil is 3.0 A, calculate the

- (a) total torque on the coil
- (b) total force on the coil
- (c) average force on each electron in the coil, due to the magnetic field. (3)

Q5) Calculate the strength of the magnetic field at a distance of 20 cm from a pole of strength 40 Am in air. Find the induction at the same point. (3)

Q6) A magnet of moment of  $4 \text{ Am}^2$  is suspended in a uniform magnetic field of induction  $5 \times 10^{-4}T$  with its axis at right angles. When the magnet is released from its position, calculate kinetic energy that it gains in passing to the stable equilibrium position? (3)

Q7) A galvanometer having a resistance of  $20\Omega$  and 30 divisions on both sides has figure of merit 0.005 ampere/division. What is the resistance that should be connected in series such that it can be used as voltmeter upto 15 volt? (3)

Q8) In an experiment electrons are accelerated, from rest, by applying a voltage of 500V. Calculate the radius of the path if a magnetic field 100mT is then applied.

(Charge of the electron =  $1.6 \times 10^{-19} \text{C}$ , Mass of the electron =  $9.1 \times 10^{-31} \text{kg}$ ) (3)

Q9) An  $\alpha$  particle is moving along a circle of radius  $R$  with a constant angular velocity  $\omega$ . Point  $A$  lies in the same plane at a distance  $2R$  from the centre. Point  $A$  records magnetic field produced by  $\alpha$  particle. If the minimum time interval between two successive times at which  $A$  records zero magnetic field is " $t$ ", what is the angular speed  $\omega$ , in terms of  $t$ ? (5)

Q10) The dipole moment of a circular loop carrying current  $I$  is ' $m$ ' and the magnetic field at the centre of the loop is  $B_1$ . When the dipole moment is doubled by keeping the current constant, the magnetic field at the centre of the loop is  $B_2$ . Find the ratio of  $B_1/B_2$ ? (3)

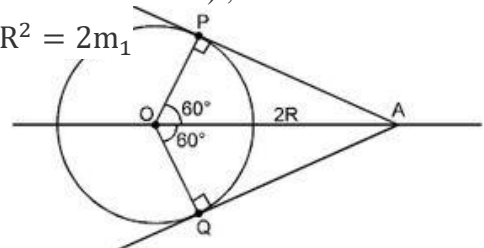
SOLUTIONS:





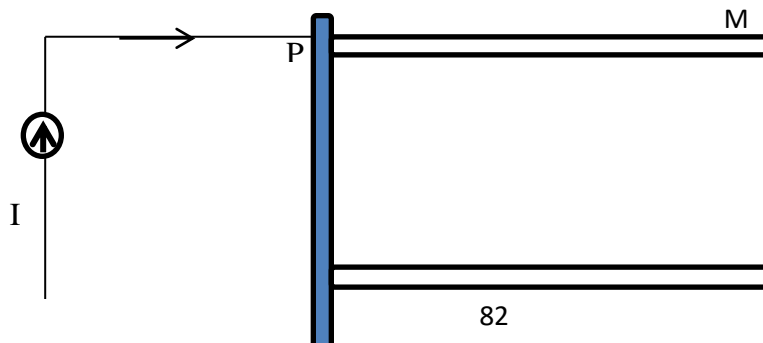
	$F = Be \frac{1}{neA}$ $= \frac{0.5 \times 3}{10^{29} \times 10^{-5}}$ $= 1.5 \times 10^{-24} \text{N}$	(1)
5)	$H = \frac{1}{4\pi r^2} m$ <p style="text-align: right;">Given that, <math>m = 40 \text{ Am}</math></p> $r = 20 \text{cm} = 20 \times 10^{-2} \text{m}$ $\therefore H = \frac{1}{4\pi} \times \frac{40}{(20 \times 10^{-2})^2}$ $= 79.57 \text{ Am}^{-1}$ <p>Now, magnetic induction at the same point:</p> $B = \mu_0 H = 4\pi \times 10^{-7} \times 79.57 = 10^{-4} \text{Wb / m}^2$	(1) (1) (1)
6)	<p>magnetic moment, <math>M = 4 \text{ Am}^2</math></p> <p>Magnetic field, <math>B = 5 \times 10^{-4} \text{T}</math></p> <p>Potential energy of dipole placed in uniform field, <math>U_2 = -mB \dots(i)</math></p> <p>From energy conservation principle:</p> $\Delta K + \Delta U = 0 \dots\dots\dots(ii)$ $K_2 - K_1 = U_1 - U_2$ $K_1 = 0, U_1 = 0$ $U_2 = -mB \text{ (from equation (i))}$ $= -4 \times 5 \times 10^{-4} \text{J}$ <p>From equation (ii)</p> $K_2 - 0 = 0 + 20 \times 10^{-4}$ $K_2 = 2 \times 10^{-3} \text{J}$	(0.5) (0.5) (1) (1)
7)	$R_g = 20 \Omega$ $N_L = N_R = N = 30$ <p>Figure of merit <math>= \frac{1}{\phi} = 0.005 \text{ A / div,}</math></p> <p>Current sensitivity <math>= \frac{1}{0.005} = \frac{\phi}{I}</math></p> $(I_g)_{\max} = 0.005 \times 30$ $= 0.15$ <p>Now,</p> $V = IR$ $15 = 0.15(20 + R)$ $100 = 20 + R$ $R = 80 \Omega$	(1) (1) (1)
8)	<p>radius <math>= \frac{mv}{qB}</math></p> $= \frac{\sqrt{2mK}}{eB}$ $= \frac{\sqrt{2meV}}{eB}$ $= \frac{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 500}}{1.6 \times 10^{-19} \times 0.1}$ $\text{Radius} = 7.5 \times 10^{-4} \text{m}$	(0.5) (0.5) (0.5) (1.5)
9)	Magnetic field using BiotSavart's law:	(1)

	$B = \frac{\mu_0}{4\pi} = \frac{I(\overline{dl} \times \vec{r})}{r^3}$ <p>WKT,  <math>I = q/t</math>  Therefore, <math>\vec{B} = \frac{\mu_0 q(\vec{v} \times \vec{r})}{4\pi r^3}</math>  Point A shall record magnetic field (due to <math>\alpha</math> particle) when the <math>\alpha</math> particle is at position P and Q  Shown in the figure since <math>\vec{v} \parallel \vec{r}</math>.  For any other position of the <math>\alpha</math> particle is not parallel  Therefore, <math>\vec{v} \times \vec{r}</math> is not equal to 0, magnetic field is not equal to 0.  Angle POQ = <math>120^\circ</math>  <math>\Rightarrow \omega t = 120^\circ = \frac{2\pi}{3}</math>  <math>\Rightarrow \omega = \frac{2\pi}{3t}</math></p>	(1) (0.5) (0.5) (1) (1)
10)	The magnetic field at the centre of the loop, $B_1 = \frac{\mu_0 I}{2R}$ Dipole moment of circular loop is $m = IA$ $m_1 = IA = I\pi R^2$ (where, R is the radius of loop) If the magnetic moment is doubled (keeping current constant), R becomes $\sqrt{2}R$ $m_2 = I\pi(\sqrt{2}R)^2 = 2I\pi R^2 = 2m_1$ $= \frac{\mu_0 I}{2(\sqrt{2}R)}$ $= \frac{\mu_0 I}{2R} = \sqrt{2}$ $= \frac{\mu_0 I}{2(\sqrt{2}R)}$	(1) (2)



### NUMERICALS FOR PRACTICE

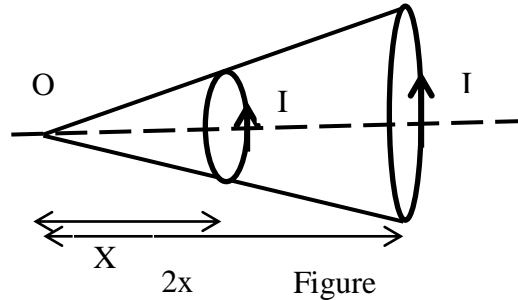
- A current  $I = 1.00$  A circulates in a round thin-wire loop of radius  $R = 100$  mm. Find the magnetic induction
  - at the centre of the loop;
  - at the point lying on the axis of the loop at a distance  $x = 100$  m from its centre.
- A current  $I$  flows along a thin wire shaped as a regular polygon with  $n$  sides which can be inscribed into a circle of radius  $R$ . Find the magnetic induction at the centre of the polygon. Analyse the obtained expression at  $n \rightarrow \infty$ .
- Figure shows two smooth rails M and N separated by a distance 'a' in a uniform magnetic induction  $B$  which are connected to a current generator which supplies a constant current 'I'. A wire PQ of mass 'm' lies over the rails which slides along rails and falls over ground where friction coefficient is  $\mu$ . Find the distance over ground the PQ will slide before coming to rest. (Refer figure)



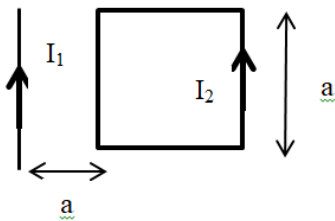
Q

N

4. The figure show two co-axial circular loops 1 and 2 which forms same solid angle  $\theta$  at point O. If  $B_1$  and  $B_2$  are the magnetic fields produced at the point O due to loop 1 and loop 2 respectively then find ratio of  $B_1$  to  $B_2$ . (Refer figure )



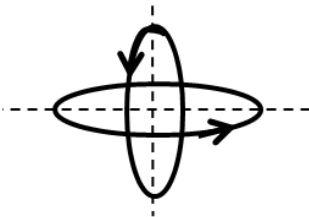
5. A rigid square loop of side 'a' and carrying current  $I_2$  is lying on a horizontal surface near a long current  $I_1$  carrying wire in the same plane as shown in figure. Calculate the net force on the loop due to the wire. (refer figure)



6. A particle of mass 'm' and charge 'q' has initial velocity  $\vec{v} = v_0 \hat{j}$  and magnetic field  $\vec{B} = B_0 \hat{i}$  act on the particle find the time at which its speed will be doubled.

7. A charge particle carrying charge  $1\mu\text{C}$  is moving with velocity  $\vec{v} = 2\hat{i} + 3\hat{j} + 4\hat{k}$ . If an external magnetic field of  $(5\hat{i} + 3\hat{j} - 6\hat{k})10^{-3}\text{T}$  exists in the region where the particle is moving then find the force exerted on the particle

8. Find  $B_{\text{net}}$  at O (centre of both loops) . Consider both loops of equal radius and both loops carrying current I (direction as shown in figure).

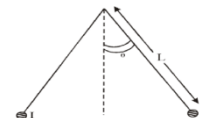


9. An electron is moving along +x direction with a velocity  $6 \cdot 10^6 \text{ m/s}$ . It enters a region of magnetic field of  $300\text{V/cm}$  pointing along +y direction. Find the magnitude and direction of magnetic field so that the electron keeps moving along the x direction.

10. A galvanometer having a resistance of  $8\Omega$  is shunted by a wire of resistance  $2\Omega$  if the total current is 2 A the part of it passing through the shunt is ?

11. A particle of mass 'm' and charge 'q' is in an electric field and magnetic field is given by  $\vec{E} = 2\hat{i} + 3\hat{j}$ ,  $\vec{B} = 4\hat{j} + 6\hat{k}$ . The charged particle shifted from the origin to the point  $P(x=1; y=1)$  along a straight path. Find the magnitude of total work done in terms of 'q'.

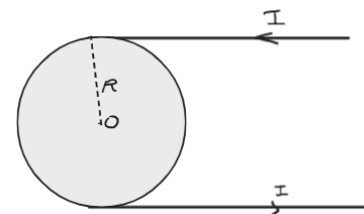
12. Two long current carrying thin wires, both with current  $I$  in opposite direction, are held by insulating threads of length  $L$  and are in equilibrium as shown in the figure, with threads making an angle  $\theta$  with the vertical. If wires have mass per unit length then the value of  $I$  is ( $g$  = gravitational acceleration).(Refer figure)



13. A galvanometer has a resistance of  $30\Omega$  and a current of  $2\text{mA}$  is needed to give a full scale deflection. What is the resistance(shunt) needed to convert this galvanometer into an ammeter of  $0.3\text{ A}$  range?

14. The effective length of a magnet is  $31.4\text{ cm}$  and its pole strength is  $0.5\text{ Am}$ . Find the magnetic moment when it is bent in the form of semicircle.

15. Find  $B_{\text{net}}$  at 'O' Centre of the loop. (Refer figure)



### Hints

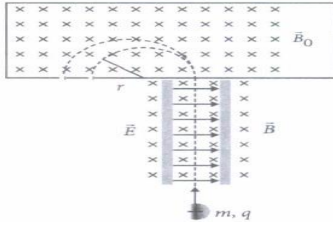
1. Hint: use Biot savarts law for circular arc.
2. Hint: use Biot savarts law for straight current carrying conductor.
3. Hint: Kinematics equations are valid, you can also use acceleration=force /mass.
4. Hint: use trigonometric formula to obtain a relation between radius of both the loops, consider angle subtended at O as  $\alpha$
5. Hint: force between two current carrying parallel wires.
6. Hint: Speed will be only in y-z plane always perpendicular to x-direction
7. Hint: Use cross product
8. Hint: Use vector sum
9. Hint: electron will move in the opposite direction of the electric field.
10. Hint: Shunt resistance is in parallel
11. Hint:  $W = \vec{F} \cdot \vec{S}$
12. Hint: the wires will repel each other with Force= $I\vec{l} \times \vec{B}$ . Resolve tension
13. Hint: small resistance is connected in parallel to make galvanometer into ammeter.
14. Hint: magnetic moment is equal to the product of pole strength and distance of separation between poles
15. Hint: incoming current is equal to outgoing current

### CASE STUDY QUESTIONS

#### CASE STUDY 1

Various methods can be used to measure the mass of an atom. One possibility is through **the use of a mass spectrometer. The basic feature of a Bainbridge mass spectrometer is illustrated in figure. A particle carrying a charge  $+q$  is first sent through a velocity selector and comes out with velocity  $V = E/B$ .**

**The applied electric and magnetic fields satisfy the relation  $E = VB$  so that the trajectory of the particle is a straight line. Upon entering a region where a second magnetic field  $B_0$ , pointing into the page has been applied, the particle will move in a circular path with radius  $r$  and eventually strike the photographic plate.**



- i) In a mass spectrometer, ions are sorted out in which of the following ways?
- By accelerating them through electric field
  - By accelerating them through magnetic field
  - By accelerating them through electric and magnetic field
  - By applying a high voltage
- ii) Radius of particle in second magnetic field  $B_0$  is
- $\frac{2mv}{qE_0}$
  - $\frac{mv}{qE_0}$
  - $\frac{mv}{qB_0}$
  - $\frac{2mE_0v}{qB_0}$
- iii) Which of the following will trace a circular trajectory with the largest radius?
- proton
  - $\alpha$ -particle
  - electron
  - a particle with charge twice and mass thrice that of electron
- iv) Mass of the particle in terms  $q, B_0, B, r$  and  $E$  is
- $\frac{qBr}{E}$
  - $\frac{qB_0Br}{E}$
  - $\frac{qBr}{EB_0}$
  - $\frac{qBrE}{B_0}$
- v) The particle comes out of velocity selector along a straight line because
- electric force is less than magnetic force
  - electric force is greater than magnetic force
  - electric force and magnetic force balance each other
  - can't say

### CASE STUDY 2

A galvanometer can be converted into voltmeter of given range by connecting a suitable resistance  $R_s$  in series with the galvanometer, whose value is given by

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

where  $V$  is the voltage to be measured,  $I_g$  is the current for full scale deflection of galvanometer



and  $G$  is the resistance of galvanometer

Series resistor ( $R_s$ ) increases range of voltmeter and the effective resistance of galvanometer. It also protects the galvanometer from damage due to large currents.

Voltmeter is a high resistance instrument and it is always connected in parallel with the circuit element across which potential difference is to be measured. In order to increase the range of voltmeter  $n$  times the value of resistance to be connected in series with galvanometer is  $R_s = (n-1)G$

- i) 10 mA current can pass through a galvanometer of resistance  $25\Omega$   
 What resistance in series should be connected through it, so that it is converted into a voltmeter of 100 V?
- $0.975\Omega$
  - $99.75\Omega$
  - $975\Omega$
  - $9975\Omega$
- ii) There are 3 voltmeter A, B, C having the same range but their resistance are  $15000\Omega$ ,  $10000\Omega$  and  $5000\Omega$  respectively. The best voltmeter amongst them is the one whose resistance is
- $5000\Omega$
  - $10000\Omega$
  - $15000\Omega$
  - all are equally good

iii) A milliammeter of range 0 to 25 mA and resistance of  $10\Omega$  is to be converted into a voltmeter with a range of 0 to 25 V. The resistance that should be connected in series will be

- a)  $930\Omega$     b)  $960\Omega$     c)  $990\Omega$     d)  $1010\Omega$

iv) To convert a moving coil galvanometer (MCG) into a voltmeter

- a) a high resistance R is connected in parallel with MCG  
 b) a low resistance R is connected in parallel with MCG  
 c) a low resistance R is connected in series with MCG  
 d) a high resistance R is connected in series with MCG

v) The resistance of an ideal voltmeter is

- a) zero    b) low    c) high    d) infinity

### **CASE STUDY -3**

**When the atomic dipoles are aligned partially or fully, there is a net magnetic moment in the direction of the field in any small volume of the material. The actual magnetic field inside material placed in a magnetic field is the sum of the applied magnetic field and the magnetic field due to magnetisation. This field is called magnetic intensity (H).**

$$H = \frac{B}{\mu_0} - M$$

Where M is the magnetization of the material,  $\mu_0$  is the permeability of vacuum and B is the total magnetic field. The measure that tells us how a magnetic material responds to an external field is given by a dimensionless quantity is appropriately called the magnetic susceptibility: for a certain class of magnetic materials, intensity of magnetisation is directly proportional to the magnetic intensity.

(i) Magnetization of a sample is

- a) volume of sample per unit magnetic moment  
 b) net magnetic moment per unit volume  
 c) ratio of magnetic moment and pole strength  
 d) ratio of pole strength to magnetic moment

(ii) Identify the wrongly matched quantity and unit pair.

- |                                |                      |
|--------------------------------|----------------------|
| (a) Pole strength              | Am                   |
| (b). Magnetic susceptibility   | dimensionless number |
| (c) Intensity of magnetization | $A\ m^{-1}$          |
| Magnetic permeability          | Henry m              |

iii) A bar magnet has length- 3 cm, cross-sectional area  $2\text{ cm}^2$  and magnetic moment  $3\text{ Am}^2$ . The intensity of magnetization of bar magnet is

- a)  $2 \times 10^5\text{ A/m}$     b)  $3 \times 10^5\text{ A/m}$     c)  $4 \times 10^5\text{ A/m}$     d)  $5 \times 10^5\text{ A/m}$

iv) A solenoid has a core of a material with relative permeability 500 and its windings carry a current of 1 A. The number of turns of the solenoid is 500 per metre. The magnetization of the material is nearly

- a)  $2.5 \times 10^3\text{ Am}^{-1}$     b)  $2.5 \times 10^5\text{ Am}^{-1}$     c)  $2.0 \times 10^3\text{ Am}^{-1}$     d)  $2.0 \times 10^5\text{ Am}^{-1}$

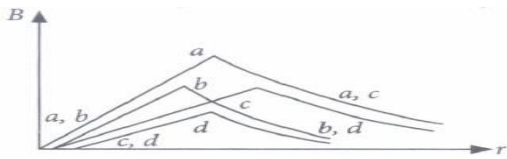
v) The relative permeability of iron is 6000. Its magnetic susceptibility is

- a) 5999    b) 6001    c)  $6000 \times 10^{-7}$     d)  $6000 \times 10^7$

### **CASE STUDY 4**

**The field of a hollow wire with constant current is homogeneous**

**Curves in the graph shown give, as functions of radius distance r, the magnitude B of the magnetic field inside and outside four long wires a, b, c and d, carrying currents that are uniformly distributed across the cross sections of the wires. Overlapping portions of the plots are indicated by double labels.**



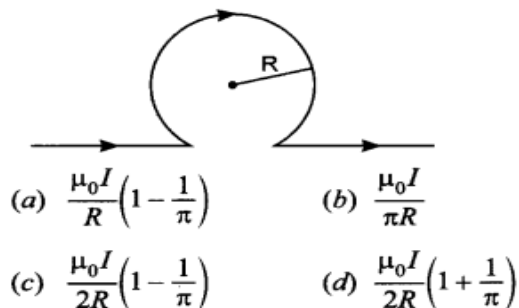
- i) Which wire has the greatest magnitude of the magnetic field on the surface?  
 a) a    b) b    c) c    d) d
- ii) The current density in a wire is  
 a) greater than in wire c    b) less than in wire c    c) equal to that in wire c  
 d) not comparable to that of in wire c due to lack of information
- iii) Which wire has the greatest radius?  
 a) a    b) b    c) c    d) d
- iv) A direct current  $I$  flows along the length of an infinitely long straight thin walled pipe, then the magnetic field is  
 (a) uniform throughout the pipe but not zero  
 (b) zero only along the axis of the pipe  
 (c) zero at any point inside the pipe  
 (d) maximum at the centre and minimum at the edges
- v) In a coaxial, straight cable, the central conductor and the outer conductor carry equal currents in opposite directions. The magnetic field is zero  
 (a) outside the cable                      (b) inside the inner conductor  
 (c) inside the outer conductor            (d) in between the two conductors

**Answer Key:**

S.NO	Q(i)	Q (ii)	Q (iii)	Q (iv)	Q( v)
CS-1	c	C	B	b	c
CS-2	d	C	C	d	d
CS-3	b	D	D	b	a
CS-4	a	B	C	c	a

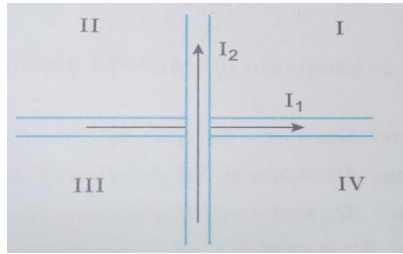
**ASSIGNMENT 1**

- 1) The strength of magnetic field at the centre of the circular coil is



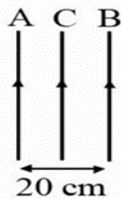
- 2) Identify the mismatched pair  
 (a) Soft magnet – Soft iron    (b) Electromagnet – Loud speaker  
 (c) Bar magnet – Permanent magnet    (d) Hard magnet – Alnico

- 3) A region has a uniform magnetic field in it. A proton enters into the region with velocity making an angle of  $45^\circ$  with the direction of the magnetic field. In this region the proton will move on a path having the shape of  
 (a) Helix (b) Circle (c) Spiral (d) Straight line
- 4) A bar magnet having a magnetic moment of  $2 \times 10 \text{ JT}^{-1}$  is free to rotate in a horizontal plane. A horizontal magnetic field  $B = 6 \times 10^{-4} \text{ T}$  exists in the space. The work done in taking the magnet slowly from a direction parallel to the field to a direction  $60^\circ$  from the field is  
 (a) 5 J (b) 6 J (c) 7 J (d) 8 J
- 5) A circular loop of radius 0.3 cm lies parallel to much bigger circular loop of radius 20 cm. The centre of the small loop is on the axis of the bigger loop. The distance between their centres is 15 cm. If a current of 2.0 A flows through the smaller loop, then the flux linked with the bigger  
 (a)  $3.3 \times 10^{-11}$  (b)  $9.1 \times 10^{-11}$  (c)  $8.1 \times 10^{-11}$  (d)  $7.1 \times 10^{-11}$
- 6) Two wires carrying currents  $I_1$  and  $I_2$  lie, one slightly above the other, in a horizontal plane as shown in figure. The region of vertically upward strongest
- 7)



magnetic field

- (a) I (b) III (c) II (d) IV
- 8) Two long parallel wires carry currents  $i_1$  and  $i_2$  such that  $i_1 > i_2$ . When the currents are in the same direction, the magnetic field at a point midway between the wires is  $6 \times 10^{-6} \text{ T}$ . If the direction of  $i_2$  is reversed, the field becomes  $3 \times 10^{-5} \text{ T}$ . The ratio of  $i_1/i_2$  is  
 (a) 3/2 (b) 1/2 (c) 1/2 (d) 1
- 9) In the figure, two very long, parallel wires A and B carry currents of 10 ampere and 20 ampere respectively, and are at a distance 20 cm apart. If a third wire C (length 15 cm) having a current of 10 ampere is placed between them, then how much force will act on C? The direction of current in all the three wires is same.



- (a)  $3 \times 10^{-5} \text{ N}$  (right) (b)  $3 \times 10^{-5} \text{ N}$  (left) (c)  $6 \times 10^{-5} \text{ N}$  (left) (d)  $6 \times 10^{-5} \text{ N}$  (right)
- 10) A  $2 \mu\text{C}$  charge moving around a circle with a frequency of  $6.25 \times 10^{12} \text{ Hz}$  produces a magnetic field 6.28 tesla at the centre of the circle. The radius of the circle is  
 (a) 2.25 m (b) 1.35 m (c) 1.25 m (d) 2.15 m
- 11) A watch glass containing some powdered substance is placed between the pole pieces of a magnet. Deep concavity is observed at the centre. The substance in the watch glass is  
 (a) Iron (b) chromium (c) carbon (d) wood



- 12) Two short bar magnets P and Q are arranged such that their centres are on the X-axis and are separated by a large distance. The magnetic axes of P and Q are along X and Y axes respectively. At a point R, midway between their centres, if B is the magnitude of induction due to Q, the magnitude of total induction at R due to the both magnets is  
 (a) 3.5 (b)  $\sqrt{5}B$  (c)  $\sqrt{5/2} B$  (d) B
- 13) A particle of charge q and mass m moves in a circular orbit of radius r with angular speed  $\omega$ . The ratio of the magnitude of its magnetic moment to that of its angular momentum depends on  
 (a)  $\omega$  and q (b)  $\omega$ , q and m (c) q and m (d)  $\omega$  and m
- 14) A long solenoid of 50 cm length having 100 turns carries a current of 2.5A. The magnetic field at the centre of the solenoid is  
 (a)  $3.14 \times 10^{-4}T$  (b)  $3.14 \times 10^{-5} T$  (c)  $6.28 \times 10^{-4} T$  (d)  $6.28 \times 10^{-5} T$
- 15) Two circular coils 1 and 2 are made from the same wire but the radius of the 1<sup>st</sup> coil is twice that of the 2<sup>nd</sup> coil. What potential difference in volts should be applied across them so that the magnetic field at their centres is the same  
 (a) 2times of first coil (b) 4 times of first coil (c) 3times of first coil (d) 6 times of first coil
- 16) A current loop consists of two identical semi-circular parts each of radius R, one lying in the x-y plane and the other in x-z plane. If the current in the loop is i., the resultant magnetic field due to the two semi-circular parts at their common centre is  
 (a)  $\frac{\mu_0 i}{2\sqrt{2}R}$  (b)  $\frac{\mu_0 i}{2R}$   
 (c)  $\frac{\mu_0 i}{4R}$  (d)  $\frac{\mu_0 i}{\sqrt{2}R}$
- 17) Two similar coils of radius R are lying concentrically with their planes at right angles to each other. The currents flowing in them are I and 2I, respectively. The resultant magnetic field induction at the centre will be  
 (a)  $\frac{\sqrt{5}\mu_0 I}{2R}$  (b)  $\frac{\sqrt{5}\mu_0 I}{R}$   
 (c)  $\frac{\mu_0 I}{2R}$  (d)  $\frac{\mu_0 I}{R}$
- 18) A metallic rod of mass per unit length  $0.5 \text{ kg m}^{-1}$  lying horizontally on a smooth inclined plane which makes an angle of  $30^\circ$  with the horizontal. The rod is not allowed to slide down by flowing a current through it when a magnetic field of induction 0.25T is acting on it in the vertical direction. The current flowing in the rod to keep it stationary is  
 (a) 7.14 A (b) 5.98 A (c) 14.76 A (d) 11.32 A
- 19) A 250-turn rectangular coil of length 2.1 cm and width 1.25 cm carries a current of 85  $\mu\text{A}$  and subjected to magnetic field of strength 0.85 T Work done for rotating the coil by  $180^\circ$  against the torque is  
 (a) 9.4  $\mu\text{J}$  (b) 2.3  $\mu\text{J}$  (c) 1.15  $\mu\text{J}$  (d) 9.1  $\mu\text{J}$
- 20) A long straight wire of radius a carries a steady current I. The current is uniformly distributed over its cross-section. The ratio of the magnetic fields B and B', at radial distances a/2 and 2a respectively, from the axis of the wire is:  
 (a) 1/4 (b) 1/2 (c) 1 (d) 4
- 21) Under the influence of a uniform magnetic field, a charged particle moves with constant speed v in a circle of radius R. The time period of rotation of the particle:  
 (a) depends on R and not on v

- (b) depends on  $v$  and not on  $R$   
 (c) is independent of both  $v$  and  $R$   
 (d) depends on  $v$  and not on  $R$
- (a) A particle of mass  $m$ , charge  $Q$  and kinetic energy  $T$  enters a transverse uniform magnetic field of induction  $B$ . After 3 seconds, the kinetic energy of the particle will be (a)  $3T$   
 (b)  $2T$  (c)  $T$  (d)  $4T$
- 22) A straight conductor carrying current  $i$  splits into two parts as shown in the figure. The radius of the circular loop is  $R$ . The total magnetic field at the centre  $P$  of the loop is,  
 (a) Zero (b)  $\mu_0 i / 2R$  (c)  $3\mu_0 i / 32R$ , outwards (d)  $3\mu_0 i / 32R$ , inward
- 23) A straight wire of diameter 0.5 mm carrying a current of 1 A is replaced by another wire of 1 mm diameter carrying same current. The strength of magnetic field far away is  
 (a) Twice the earlier value  
 (b) same as earlier value  
 (c) 1/2 of the earlier value  
 (d) 1/4 of the earlier value
- 24) At what distance from a long straight wire carrying a current of 12 A will the magnetic field be equal to  $3 \times 10^{-5} \text{ Wb/m}^2$   
 (a)  $8 \times 10^{-2} \text{ m}$  (b)  $12 \times 10^{-2} \text{ m}$  (c)  $18 \times 10^{-2} \text{ m}$  (d)  $24 \times 10^{-2} \text{ m}$
- 25) The magnetic field at a distance  $r$  from a long wire carrying current  $i$  is 0.4 tesla. The magnetic field at a distance  $2r$  is  
 (a) 0.2 T (b) 0.8 T (c) 0.1 T (d) 1.6 T
- 26) The magnetic induction at a point  $P$  which is at a distance of 4 cm from a long current carrying wire is  $10^{-3} \text{ T}$ . The field of induction at a distance 12 cm from the current will be  
 (a)  $3.33 \times 10^{-4} \text{ T}$  (b)  $1.11 \times 10^{-4} \text{ T}$  (c)  $3 \times 10^{-3} \text{ T}$  (d)  $9 \times 10^{-3} \text{ T}$

**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.

27) **Assertion :** In electric circuits, wires carrying currents in opposite directions are often twisted together

**Reason :** If the wires are not twisted together, the combination of the wires forms a current loop, the magnetic field generated by the loop might affect adjacent circuits or components.

28) **Assertion:** A charge, whether stationary or in motion produces a magnetic field round it

**Reason :** Moving charges produce only electric field in the surrounding space.

29) **Assertion :** We cannot think of a magnetic field configuration with three poles

**Reason :** A bar magnet does exert a torque on itself due to its own field.

30) **Assertion :** In high latitudes one sees colourful curtains of light hanging down from high altitudes











**Reason :** The high energy charged particles from the sun are deflected to polar regions by the magnetic field of the earth.


**ANSWERS KEY**

- 1) C    2) B    3) A    4) B    5) B    6) C    7) D    8) A    9) C    10) A  
 11) B    12) C    13) A    14) B    15) A    16) A    17) D    18) A    19) C    20) A  
 21) C    22) A    23) B    24) A    25) A    26) A    27) A    28) D    29) D    30) A

**Unit - IV Electromagnetic Induction and Alternating (Chapters 6 & 7)**

**FORMULA CHART:**

Magnetic Flux		The magnetic flux $\Phi$ through any surface held in a magnetic field is measured by the total number of magnetic lines of force crossing the surface. Where, $\theta$ is the smaller angle between  and  , which normal to the surface area makes with 
The total induced emf-Faraday's law and Lenz's law		The magnitude of emf induced in a circuit is directly proportional to the rate of change of magnetic flux linked with the circuit.
Induced emf-Motional emf		The induced emf $Blv$ is called motional emf
Induced emf between ends Of rod rotating perpendicular To magnetic field	$(1/2) \omega B R^2$	$\omega$ =angular velocity of rotating conducting rod $f$ = frequency of rotation of rod $R$ = length of rotating rod
Current I in the loop		induced emf due to motion of a conducting rod perpendicular to magnetic field $B$ = magnetic field ; $l$ =length of conductor $v$ =velocity of conductor $R$ = resistance of conductor $P$ = power $H$ = heat energy
The magnitude of this force		
Mechanical power		
This mechanical energy is dissipated as joule heat and is given by		
Induced emf in an inductor	$e = - L (dI / dt)$	<b>If <math>dI / dt = 1</math>, then <math>L = e</math></b> Self inductance ( $L$ ) is the induced emf set up in the coil through which the rate of change of current is unity.
<b>Self inductance of a solenoid:</b>	$L = \mu_0 N^2 A / l = \mu_0 n^2 A l$	$n$ = number of turns per unit length $N = nl$ = total number of turns $l$ =length of solenoid $A$ = area of cross section of solenoid

Self inductance of a solenoid: When medium introduced.	$L = \mu_r \mu_0 n^2 A l$	$\mu_0$ =absolute permeability $\mu_r$ = Relative permeability
Induced emf- two long co-axial solenoids		Varying current in a coil can induce emf (e) in a neighbouring coil. M=mutual inductance I = electric current $\phi_B$ = magnetic flux N = total number of turns
Mutual inductance of two long co-axial solenoids	$M_{21} = \mu_0 N_1 N_2 A / l$ $l = \mu_0 n_1 n_2 A l$	$n_1$ = number of turns per unit length of outer solenoid $n_2$ = number of turns per unit length of inner solenoid l =length of solenoid A = area of cross section of solenoid $\mu_0$ =absolute permeability $\mu_r$ = <b>Relative</b> permeability
Mutual inductance of two long co-axial solenoids: When medium introduced.	$M = \mu_r \mu_0 n_1 n_2 \pi r_1^2 l$	
The instantaneous value of the emf in the coil-AC GENERATOR	$e = NAB \omega \sin \omega t$	$e_m$ = ac voltage amplitude $\varepsilon$ = instantaneous induced emf $\omega$ = angular frequency of ac generator B = magnetic field A = area of coil or armature N = total number of turns t = time
Maximum voltage generated in the coil	$e = NAB \omega$	

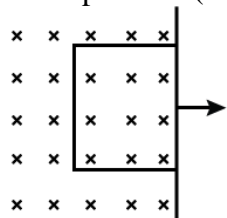
Average or Mean Value of EMF	$E_m = E_{av} = 2 E_0 / \pi = 0.637 E_0$ $E_0 = 63.7 \% E_0$	$E_0$ = Voltage amplitude $I_0$ = Current amplitude
Average or Mean Value of Alternating Current:	$I_m = I_{av} = 2 I_0 / \pi = 0.637 I_0$ $= 63.7 \% I$	
Root Mean Square or Virtual or Effective Value of Alternating emf: Root Mean Square or Virtual or Effective Value of Alternating Current:	$E_v = E_{rms} = E_{eff} = E_0 / \sqrt{2}$ $= 0.707 E_0 = 70.7 \% E_0$ $I_v = I_{rms} = I_{eff} = I_0 / \sqrt{2}$ $= 0.707 I_0 = 70.7 \% I_0$	
AC Circuit with a Pure resistor	$E = E_0 \sin \omega t$ $I = (E_0 / R) \sin \omega t$ (where $I_0 = E_0 / R$ and $R = E_0 / I_0$ )  $I = I_0 \sin \omega t$	Emf and current are in same phase. R= resistance Its SI unit is ohm
AC Circuit with a Pure Inductor	$E = E_0 \sin \omega t$ $I = (E_0 / \omega L) (- \cos \omega t)$	Current lags behind emf by $\pi/2$ rad.

	$I = I_0 \sin(\omega t - \pi/2)$ <p>where <math>I_0 = E_0 / \omega L</math> and  <math>X_L = \omega L = E_0 / I_0</math></p>	$X_L$ is Inductive Reactance. Its SI unit is ohm.
<b>AC Circuit with a Capacitor:</b>	$E = E_0 \sin \omega t$ $I = [E_0 / (1 / \omega C)] (\cos \omega t)$ $I = I_0 \sin(\omega t + \pi/2)$ <p>where <math>I_0 = E_0 / (1 / \omega C)</math> and  <math>X_C = 1 / \omega C = E_0 / I_0</math></p>	Current leads the emf by $\pi/2$ radians.  $X_C$ is Capacitive Reactance. Its SI unit is ohm
<b>AC Circuit with L, C, R in Series Combination:</b>	$Z = \sqrt{R^2 + (X_L - X_C)^2}$ $\tan \Phi = X_L - X_C / R$	Z= impedance Its SI unit is ohm
<b>Resonance in AC Circuit with L, C, R:</b>	<p>When <math>X_L = X_C</math> i.e. <math>\omega L = 1/\omega C</math>, <math>\tan \Phi = 0</math> or <math>\Phi</math> is <math>0^\circ</math> and</p> $Z = \sqrt{R^2 + (\omega L - 1/\omega C)^2}$ <p>becomes <math>Z_{\min} = R</math> and  <math>I_{0\max} = E / R</math></p> <p>At resonant angular frequency <math>\omega_r</math>,</p> $\omega_r L = 1/\omega_r C \text{ or } \omega_r = 1 / \sqrt{LC}$ $\text{or } f_r = 1 / (2\pi \sqrt{LC})$	The impedance offered by the circuit is minimum and the current is maximum. This condition is called resonant condition of LCR circuit and the frequency is called resonant frequency
<b>POWER IN AC CIRCUIT: THE POWER FACTOR</b>	$P = \frac{V_m I_m}{2} \cos \phi = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos \phi$ $= V I \cos \phi$	$V_m = E_0$ , $I_m = I_0$
<b>Power in AC Circuit with R:</b>	In R, current and emf are in phase. $\Phi = 0^\circ$ $P_{av} = E_v I_v \cos \Phi = E_v I_v \cos 0^\circ = E_v I_v$	
<b>Power in AC Circuit with L:</b>	In L, current lags behind emf by $\pi/2$ . $\Phi = -\pi/2$ $P_{av} = E_v I_v \cos(-\pi/2) = E_v I_v (0) = 0$	
<b>Power in AC Circuit with C:</b>	In C, current leads emf by $\pi/2$ . $\Phi = +\pi/2$ $P_{av} = E_v I_v \cos(\pi/2) = E_v I_v (0) = 0$	
<b>Wattless Current</b>	$P = E_v I_v \sin \Phi \cos 90^\circ = 0$	
<b>Transformer</b>	$\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$	$N_s$ = number of secondary coil $N_p$ = number of turns of primary coil $V_s$ = output voltage $V_p$ = input voltage $I_s$ = output current $I_p$ = input current $P_o$ = output power $P_i$ = input power

Step up transformer	$N_s > N_p$ $V_s > V_p$ $I_s < I_p$	
Step down transformer	$N_s < N_p$ $V_s < V_p$ $I_s > I_p$	
Equation of ideal transformer	$V_s I_s = V_p I_p$	
Efficiency of transformer	$\eta = \frac{P_o}{P_i} = \frac{V_s I_s}{V_p I_p}$	

### NUMERICALS FOR PRACTISE WITH SOLUTIONS:

Q1 : A square loop of area  $2.5 \times 10^{-3} \text{ m}^2$  and having 100 turns with a total resistance of  $100 \Omega$  is moved out of a uniform magnetic field of  $0.40 \text{ T}$  in  $1 \text{ s}$  with a constant speed. Then find the work done in pulling the loop? (3m)



Ans: Side of square,  $l = \sqrt{2.5 \times 10^{-3}} = 0.05 \text{ m}$  [1/2]

As the loop of length  $0.05 \text{ m}$  is pulled out in  $1.0 \text{ s}$ , so speed of the loop  $= 0.05 \text{ ms}^{-1}$

The emf induced in the left arm of the loop,

$$\mathcal{E} = NBlv = 100 \times 0.40 \times 0.05 \times 0.05 = 0.1 \text{ V} \quad [1/2]$$

Current in the loop,

$$I = \frac{\mathcal{E}}{R} = \frac{0.1}{100} = 10^{-3} \text{ A} \quad [1/2]$$

Force on the left arm exerted by the magnetic field,

$$F = I l B = 10^{-3} \times 0.05 \times 0.40 = 2 \times 10^{-5} \text{ N, acting towards left} \quad [1/2]$$

In order to pull the loop uniformly, a force of  $2 \times 10^{-5} \text{ N}$  towards right must be applied.

$$W = F l = 2 \times 10^{-5} \times 0.05 = 10^{-6} \text{ J.} \quad [1]$$

Q2: A metal disc of radius  $100 \text{ cm}$  is rotated at a constant angular speed of  $60 \text{ rads}^{-1}$  in a plane at right angles to an external field of magnetic induction  $0.05 \text{ Wbm}^{-2}$ . Find the emf induced between the centre and a point on the rim. -2m

Ans: Given values,

$$\omega = 60 \text{ rad/s}, B = 0.05 \text{ Wb/m}^2$$

$$\text{and } R = 100 \text{ cm} = 1 \text{ m}$$

[1/2]

Induced emf produced between the centre and a point on the disc is given by

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

[1/2]

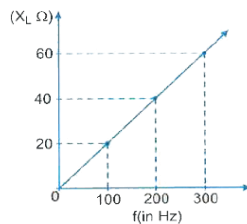
$$\text{We get, } e = \frac{1}{2} \times 60 \times 0.05 \times (1)^2 = 1.5 \text{ V}$$

[1]

Q3: The variation of inductive reactance ( $X_L$ ) of an inductor with the frequency ( $f$ ) of the A.C. source of 100 V and variable frequency is shown in the figure.

(i) Calculate the self-inductance of the inductor.

(ii) When this inductor is used in series with a capacitor of unknown value and a resistor of  $10 \Omega$  at  $300 \text{ s}^{-1}$ , maximum power dissipation occurs in the circuit. Calculate the capacitance of the capacitor. (2m)



Ans: As per  $X_L$ - $f$  graph for a frequency  $f = 100 \text{ Hz}$ ,  $X_L = 20 \Omega$

$$\therefore X_L = L\omega = L \cdot 2\pi f$$

$$\Rightarrow L = X_L / 2\pi f$$

[1/2]

$$= 20 / 2 \times 3.14 \times 100$$

$$= 0.032 \text{ H or } 32 \text{ mH}$$

[1/2]

(ii) As at a frequency  $f_0 = 300 \text{ s}^{-1}$  maximum power dissipation occurs the frequency  $f_0$  is the resonant frequency.

We know that,

$$f_0 = 1 / 2\pi \sqrt{LC},$$

$$\text{so, } C = 1 / 4\pi^2 f_0^2 L$$

[1/2]

$$= C = 1 / 4 \times (3.14)^2 \times (300)^2 \times 0.032$$

$$= 8.85 \text{ F.}$$

[1/2]

Q4: A wheel with 8 metallic spokes each 50 cm long is rotated with a speed of 120 rev/min in a plane normal to the horizontal component of the Earth's magnetic field. The Earth's magnetic field at the plane is 0.4 G and the angle of dip is  $60^\circ$ . Calculate the emf induced between the axle and the rim of the wheel. How will the value of emf be affected if the number of spokes were increased? (3m)

Ans: If a rod of length 'l' rotates with angular speed  $\omega$  in uniform magnetic field 'B'

$$\mathcal{E} = \frac{1}{2} B l^2 \omega \quad [1/2]$$

In case of earth's magnetic field

$$B_H = |B_e| \cos \delta \text{ and } B_V = |B_e| \sin \delta \quad [1/2]$$

$$\mathcal{E} = \frac{1}{2} |B_e| \cos \delta \cdot l^2 \omega \quad [1/2]$$

$$= \frac{1}{2} \times 0.4 \times 10^{-4} \cos 60 \times (0.5)^2 \times 2\pi v$$

$$= \frac{1}{2} \times 0.4 \times 10^{-4} \times \frac{1}{2} \times (0.5)^2 \times 2\pi \times \frac{120 \text{ rev}}{60 \text{ s}}$$

$$= 10^{-5} \times 0.25 \times 2 \times 3.14 \times 2 \quad [1/2]$$

$$\approx 3.14 \times 10^{-5} \text{ volt}$$

Induced emf is independent of the number of spokes i.e., it remains same. [1]

Q5: A town is situated 15 km away from a power plant generating power at 440V, requires 800 kW of electric power at 220V. The resistance of the two-wire line carrying power is 0.5 ohm per km. The town gets power from the line through a 4000-220V step down transformer at a substation in the town.

(i) Find the line power losses in the form of heat.

(ii) How much power must the plant supply, assuming there is negligible power loss due to leakage?

(iii) Characterize the step-up transformer at the plant. (3m)

Ans: (i): The power loss due to the production of heat is  $P_L = I^2 R$ .

$$P_L = I^2 R = (200)^2 \times (30 \times 0.5)$$

$$P_L = 40000 \times 15$$

$$P_L = 600000$$

$$P_L = 600 \text{ kW.}$$

Therefore, the power loss in the circuit line is 600 KW. [1]

(ii): The total power supply

We know, that the total power supply is the sum of demand power and power loss.

So,

$$P = P_d + P_L$$

$$P = 800 + 600$$

$$P = 1400 \text{ KW}$$

The total power supply by the plant is 1400 KW. [1]

(c): Characterization of the transformer

The voltage drop by the circuit is  $V_d = IR$

So,

$$V_d = IR = 200 \times 15 = 3000$$

$$V_d = 3000 \text{ volt.}$$

Now, the secondary voltage is



$$V_s = V_i + V_d = 4000 + 3000$$

$$V_s = 7000 \text{ volt.}$$

[1]

According to the question, the power generation takes place at the primary voltage 440 volt.

Therefore, the transformer rating is 440-7000 volt.

Q6: Determine the current and quality factor at resonance for a series LCR circuit with  $L = 1.00$  mH,  $C = 1.00$  nF and  $R = 100 \Omega$  connected to an A.C. source having peak voltage of 100 V.

(2m)

Ans:  $L = 1.00 \text{ mH} = 1 \times 10^{-3} \text{ H}$ ,

$$C = 1.00 \text{ nF} = 1 \times 10^{-9} \text{ F},$$

$$R = 100 \Omega, E_0 = 100 \text{ V}$$

$$I_0 = \frac{E_0}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}} = \frac{E_0}{Z} [1/2]$$

$$I = \frac{V}{R} = \frac{100}{100} = 1 \text{ A}$$

[1/2]

$$I_v = I_0 / \sqrt{2}$$

$$= \frac{1}{\sqrt{2}}$$

$$= 0.707 \text{ A}$$

[1/2]

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} = \frac{1}{100} \sqrt{\frac{1.0 \times 10^{-3}}{1.0 \times 10^{-9}}}$$

$$= \frac{1}{100} \times 10^{-3}$$

$$= 10$$

[1]

Q7: A capacitor in series with a resistance of  $30 \Omega$  is connected to A.C. mains. The reactance of the capacitor is  $40 \Omega$ . Calculate the phase difference between the current and the supply voltage.

(2m)

Ans: Reactance of the capacitor =  $40 \Omega$

$$\text{Resistance} = 30 \Omega$$

The phase difference,

$$\tan \phi = \frac{\text{reactance of the capacitor}}{\text{resistance of the resistor}}$$

[1/2]

$$= \frac{40}{30}$$

$$= \frac{4}{3}$$

[1/2]

$$\phi = \tan^{-1} \left[ \frac{4}{3} \right]$$

$$\phi = 53 [1]$$

Q8: A transformer of 100% efficiency has 200 turns in the primary and 40000 turns in the secondary. It is connected to a 220-V main supply and the secondary feeds to a  $100 \text{ k}\Omega$  resistance. Calculate the output potential difference per turn and the power delivered to the load.

(3m)

Ans:  $N_p = 200$ ,  $N_s = 40000$ ,  $V_p = 220$  V

$R_s = 100\text{k}\Omega = 10^5\Omega$ ,  $V_s = ?$

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$\begin{aligned} V_s &= V_p \times \frac{N_s}{N_p} \\ &= 220 \times \frac{40000}{200} \\ &= 44000 \text{ V.} \end{aligned} \quad [1]$$

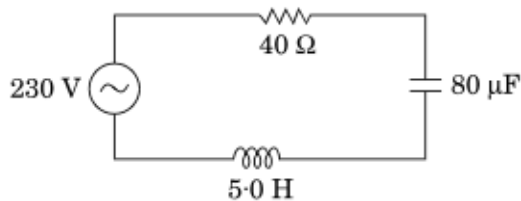
The output potential difference per turn is,

$$\frac{V_s}{N_s} = \frac{44000}{40000} = 1.1 \text{ V} \quad [1]$$

The power delivered by the 'ideal' (100% efficiency) transformer to the load is  $V_s \times i_s = V_s \times \frac{V_s}{R_s} =$

$$\begin{aligned} \frac{V_s^2}{R_s} &= \frac{(44000)^2}{10^5\Omega} = 19360 \text{ W} \\ &= 19.36 \text{ Kw} \end{aligned} \quad [1]$$

Q9: The figure shows a series LCR circuit connected to a variable frequency 230 V source.



- Determine the source frequency which drives the circuit in resonance.
- Calculate the impedance of the circuit and amplitude of current at resonance.
- Show that potential drop across LC combination is zero at resonating frequency. (3m)

Ans: (a) The source frequency is given by

$$\begin{aligned} \omega &= \frac{1}{\sqrt{LC}} \\ &= \frac{1}{\sqrt{5 \times 80 \times 10^{-6}}} = 50 \text{ rad/s} \end{aligned} \quad [1/2]$$

$$f = \frac{\omega}{2\pi} = \frac{50}{2\pi} = \frac{25}{\pi} \text{ Hz} \quad [1/2]$$

(b) At resonance,

$$Z = R = 40\Omega$$

$$\begin{aligned} I_{\max} &= \frac{230\sqrt{2}}{R} \\ &= \frac{230\sqrt{2}}{40} \\ &= 8.1 \text{ A} \end{aligned} \quad [1]$$

$$(c) V_c = I_{\max} \cdot X_c$$

$$= \frac{230\sqrt{2}}{40} \times \frac{1}{50 \times 80 \times 10^{-6}} = 2025 \text{ V}$$

$$V_L = I_{\max} \cdot X_L = \frac{230\sqrt{2}}{40} \times 50 \times 5 = 2025 \text{ V}$$

$$V_C - V_L = 2025 - 2025 = 0 \quad [1]$$

Q10: A rectangular loop of sides 8 cm and 2 cm with a small cut is moving out of a region of uniform magnetic field of magnitude 0.3 tesla directed normal to the loop. What is the voltage developed across the cut if velocity of loop is 1 cm/s in a direction normal to the

- (i) longer side
- (ii) shorter side of the loop?

For how long does the induced voltage last in each case? (3m)

Ans: Length of loop,  $l = 8 \text{ cm} = 8 \times 10^{-2} \text{ m}$

Breadth of loop,  $b = 2 \text{ cm} = 2 \times 10^{-2} \text{ m}$

Strength of magnetic field,  $B = 0.3 \text{ T}$

Velocity of loop  $v = 1 \text{ cm / sec} = 10^{-2} \text{ m/sec}$  [1/2]

Let the field be perpendicular to the plane of the paper directed inwards.

- (i) The magnitude of induced emf,

$$\varepsilon = B.l.v$$

$$= 0.3 \times 8 \times 10^{-2} \times 10^{-2}$$

$$v = 2.4 \times 10^{-4} \text{ V}$$

Time for which induced emf will last is equal to the time taken by the coil to move outside the field is

$$t = \frac{\text{distance travelled}}{\text{velocity}}$$

$$= \frac{2 \times 10^{-2}}{10^{-2}} \text{ m}$$

$$= 2 \text{ sec.} \quad [1]$$

- (ii) The conductor is moving outside the field normal to the shorter side.

$$b = 2 \times 10^{-2} \text{ m}$$

The magnitude of induced emf is

$$\varepsilon = B.b.v$$

$$= 0.3 \times 2 \times 10^{-2} \times 10^{-2}$$

$$= 0.6 \times 10^{-4} \text{ V} \quad [1]$$

$$\text{Time, } t = \frac{\text{distance travelled}}{\text{velocity}} = \frac{(8 \times 10^{-2})}{10^{-2}} \text{ sec} = 8 \text{ sec} \quad [1/2]$$

## NUMERICALS FOR PRACTICE

1. A rectangular coil of 200 turns of dimensions 15 cm X 40 cm rotates about an axis perpendicular to a magnetic field of  $0.08 \text{ Wb/m}^2$  with a speed of 50 rpm. Calculate instantaneous value of induced emf when the plane of the coil makes an angle of
  - (i)  $0^\circ$
  - (ii)  $60^\circ$
  - (iii)  $90^\circ$  with the magnetic field.

**HINT:** Find the angle that the normal to the plane of coil makes with the magnetic field.

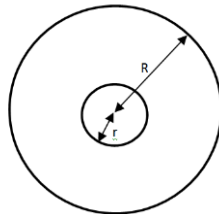
2. A circular loop of radius 0.3 cm lies parallel to a much bigger circular loop of radius 20 cm. The centre of the smaller loop lies on the axis of the bigger loop. The distance between their centres is 15 cm. If a current of 2.0 A flows through the smaller loop, find the value of flux linked with bigger loop.

**[HINT:** Use the formula for magnetic field  $B$  due to an axial point for the bigger loop. The flux linked with the smaller loop on the axis of the bigger loop will be  $\phi = BA$ .]

3. A wheel with 10 metallic spokes each 0.5 m long is rotated with a speed 120 rpm in a plane normal to the horizontal component of a magnetic field of intensity 0.4 Gauss. Calculate the induced emf between the axel and the rim of the wheel.

**[HINT:** Use formula for induced emf in terms of rotational frequency  $\nu$ .]

4. Two concentric circular coils  $L_1$  and  $L_2$  of radii  $r$  and  $R$  carrying changing currents  $I_1$  and  $I_2$  flowing through them respectively are placed coaxially with their centres coinciding. If  $R \gg r$ , then
  - (i) find the mutual inductance between the coils in terms of  $r$  and  $R$ .
  - (ii) find mutual inductance between the coils when  $r = 5 \text{ cm}$  and  $R = 3.14 \text{ m}$ .



5. A 10 m long horizontal wire extends from Northeast to Southwest. It is falling with a speed of 5.0 m/s normal to the horizontal component of the earth's magnetic field of  $3 \times 10^{-4} \text{ Wb/m}^2$ . Calculate the value of induced emf in the wire.
6. A 10 kW transformer has 20 turns in the primary and 100 turns in the secondary circuit. An alternating voltage  $\varepsilon = 600 \sin 314t$  is applied to the primary. Find the (i) maximum value of flux and (ii) maximum value of secondary voltage.
7. The equation of instantaneous current in an AC circuit is  $I = 50 \sin 100\pi t$ . Find:
  - (i) frequency of the a.c.
  - (ii) mean value of a.c. over positive half cycle
  - (iii) rms value of current and

(iv) the value of current after 0.03 seconds.

8. A lamp marked (20 V- 5W) is connected to an a.c. circuit of 200 V, 50 Hz. Find the required capacitance of a capacitor that must be connected in order to run the lamp.

[HINT: Find the current rating  $I$  and resistance  $R$  of lamp. In order to run the lamp on 200 V- 50 Hz a.c., a capacitor of a capacitance  $C$  should be connected increase the effective resistance so that the current through the lamp does not exceed the value of  $I$ . Use  $I = V_{rms}/Z$ .]

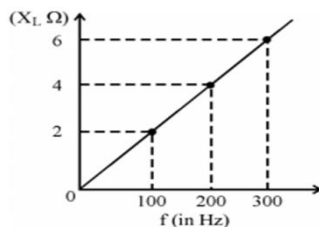
9. A bulb of resistance  $10 \Omega$ , connected to an inductor of inductance  $L$ , is in series with an a.c. source marked 100V, 50Hz. If the phase angle between the voltage and current is  $\pi/4$  radian, calculate the value of  $L$ .

[HINT: Find  $L$  using the formula for phase angle  $\phi$  in terms of inductive reactance  $X_L$  and resistance  $R$ .]

10. An AC with an rms value of 1.5 mA and angular frequency  $\omega = 300 \text{ rad/s}$  flows through a  $10 \text{ k}\Omega$  resistor and  $0.50 \mu\text{F}$  capacitor in series. Calculate the value of rms voltage across the circuit and impedance of the circuit.

11. The following figure shows how the reactance of an inductor varies with frequency.

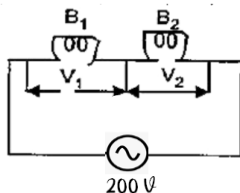
- (i) Calculate the value of inductance of the inductor.  
 (ii) If this inductor is connected in series with a resistor of  $8 \Omega$ , find the impedance at 300 Hz.



12. A circuit draws a power of 550W from a source of 220V, 50Hz. The power factor of the circuit is 0.8. The current in the circuit lags behind the voltage. Find the value of capacitance that has to be connected to bring its power factor to unity.

13. The natural frequency of an LC circuit is 1,25,000 Hz. Then the capacitor  $C$  is replaced by another capacitor with a dielectric medium  $k$ , which decreases the frequency by 25 KHz. What is the value of  $k$ ?

14. Two bulbs  $B_1$  and  $B_2$  are connected in series with an a.c. source of emf 200 V as shown in the figure. The labels on the bulbs read (200 V, 60 W) and (200 V, 100 W) respectively.



Calculate the ratio of:

- (i) The resistance of the bulbs  
 (ii) The power being consumed when connected in series  
 (iii) The potential difference across the bulbs.

15. In a circuit, a metal filament lamp is connected in series with a capacitor of capacitance  $C \mu\text{F}$  across a 200 V, 50 Hz supply. The power consumed by the lamp is 500 W while the voltage

drop across it is 100 V. Assume that there is no inductive load in the circuit. Take rms values of the voltages. The magnitude of the phase-angle (in degrees) between the current and the supply voltage is  $\phi$ . Assuming the value of  $\pi\sqrt{3} \approx 5$ , find the value of  $\phi$ .

## Formulae Used

### ELECTROMAGNETIC INDUCTION :

- ✓  $\varepsilon = NAB\sin\theta$
- ✓  $\varepsilon = NAB\omega\sin\omega t$  where  $\omega = 2\pi\nu$
- ✓  $\varepsilon = Blv$
- ✓  $\phi = BA\cos\theta$
- ✓  $\varepsilon = (\text{instantaneous}) N \frac{d\phi}{dt} = (\text{for interval}) N \frac{\Delta\phi}{\Delta t} = NBA\nu$

### ALTERNATING CURRENT :

- ✓  $I_{rms} = \frac{I_o}{\sqrt{2}}, V_{rms} = \frac{V_o}{\sqrt{2}}$
- ✓ Impedance,  $Z = \frac{e_{rms}}{I_{rms}} = \sqrt{R^2 + (X_L - X_C)^2}$  where  $X_L = \omega L$  and  $X_C = 1/\omega C$
- ✓ Power factor,  $\cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + (X_L - X_C)^2}}$
- ✓ Average Power consumed in purely resistive circuit or LCR circuit,  $P = I_{rms}V_{rms}$  (or)  $P = I_{rms}^2 R$  (or)  $P = V_{rms}^2 / R$
- ✓  $\tan\phi = \frac{X_L}{R}$  where  $\phi =$  Phase angle
- ✓ At resonance,  $X_L = X_C$  and  $Z = R$
- ✓ Resonant frequency of a.c circuit,  $\nu = \frac{1}{2\pi\sqrt{LC}}$  (or)  $\omega = \frac{1}{\sqrt{LC}}$
- ✓ For ideal transformers,  $\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{i_p}{i_s}$

## Solutions

1. (i) 301.6 V (ii) 150.8 V (iii) 0
2.  $9.1 \times 10^{-11} \text{ Wb}$
3.  $6.28 \times 10^{-5} \text{ V}$
4. (i)  $\frac{\mu_o \pi r^2}{2R}$  (ii)  $1.57 \times 10^{-2} \text{ H}$
5.  $1.1 \times 10^{-3} \text{ V}$
6. (i) 0.0955 Wb (ii) 3000 V
7. (i) 50 Hz (ii) 31.8 A (iii) 35.35 A (iv) 43.3 A
8. (i) 500 Hz (ii) 0.11  $\mu\text{F}$
9. 0.0318 H
10. 10V,  $1.25 \times 10^4 \Omega$
11. (i)  $3.18 \times 10^{-3} \text{ H}$  (ii) 10  $\Omega$

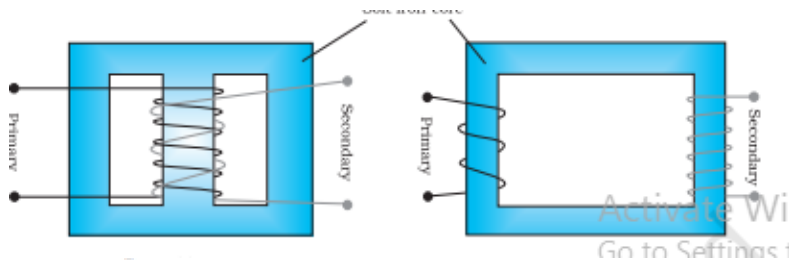
12.  $\frac{1}{42\pi} \times 10^{-2} \text{ F}$

13. 1.56

## CASE STUDY QUESTIONS

### CASE STUDY 1

For many purposes, it is necessary to change (or transform) an alternating voltage from one to another of greater or smaller value. This is done with a device called transformer using the principle of mutual induction. A transformer consists of two sets of coils, insulated from each other. They are wound on a soft-iron core, either one on top of the other as in Fig or on separate limbs of the core as in Fig. One of the coils called the primary coil has  $N_p$  turns. The other coil is called the secondary coil; it has  $N_s$  turns. Often the primary coil is the input coil and the secondary coil is the output coil of the transformer.



$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

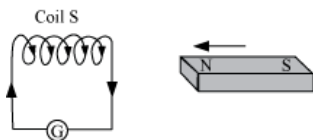
1. What are the three assumptions have been obtained using the above relation?
2. Mention the energy losses in transformer.
3. The large scale transmission and distribution of electrical energy over long distances is done with the use of transformers. Why?

### ANSWERS:

1. (i) the primary resistance and current are small; (ii) the same flux links both the primary and the secondary as very little flux escapes from the core, and (iii) the secondary current is small.
2. ) Flux Leakage, Resistance of the windings, Eddy currents, Hysteresis.
3. (a) output voltage of the power generator is stepped-up so that current is reduced and as a result, line loss  $I^2R$  is also reduced (b) It is then transmitted over long distances to an area sub-station, where voltage is stepped down. (c) It is further stepped down at local sub-stations and poles before a power supply of 220 V reaches our homes

### CASE STUDY-2

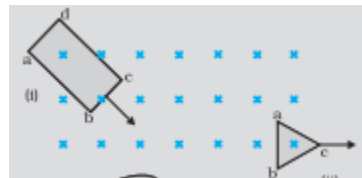
#### Lenz Law and Principle of Conservation of Energy



Lenz law is in accordance with the law of conservation of energy. In the above experiment, when N-pole of magnet is moved towards the coil, the right face of the coil acquires North polarity. Thus, work has to be done against the force of repulsion in bringing the magnet closer to the coil. When N pole of magnet is moved away, South pole develops on the right face of the coil. Therefore, work has to be done against the force of attraction in taking the magnet away from the coil.

This mechanical work in moving the magnet with respect to the coil changes into electrical energy producing induced current. Hence, energy transformation takes place.

1. A closed loop is held stationary in the magnetic field between the north and south poles of two permanent magnets held fixed. Can we hope to generate current in the loop by using very strong magnets?
2. Figure shows planar loops of different shapes moving out of or into a region of a magnetic field which is directed normal to the plane of the loop away from the reader. Determine the direction of induced current in each loop using Lenz's law.



3. A rectangular, a square, a circular and an elliptical loop, all in the (x-y) plane, are moving out of a uniform magnetic field with a constant velocity  $\vec{v} = v\hat{i}$ . The magnetic field is directed along the negative z-axis direction. The induced emf, during the passage of these loops, out of the field region, will not remain constant for

(i) any of the four loops (ii) the circular and elliptical loops (iii) the rectangular, circular and elliptical loops (iv) only the elliptical loops

**ANSWERS:**

1. No. However strong the magnet may be, current can be induced only by changing the magnetic flux through the loop.
2. The magnetic flux through the rectangular loop abcd increases, due to the motion of the loop into the region of magnetic field, The induced current must flow along the path bc dab so that it opposes the increasing flux. (ii) Due to the outward motion, magnetic flux through the triangular loop abc decreases due to which the induced current flows along bacb, so as to oppose the change in flux.
3. (ii) the circular and elliptical loops.

**CASE STUDY-3**

AC generator is a machine that converts mechanical energy into electrical energy. The AC Generator's input supply is mechanical energy supplied by steam turbines, gas turbines and combustion engines. The output is alternating electrical power in the form of alternating voltage and current.

AC generators work on the principle of **Faraday's law of electromagnetic induction**, which states that electromotive force – EMF or voltage – is generated in a current-carrying conductor that cuts a uniform magnetic field. This can either be achieved by rotating a conducting coil in a static magnetic field or rotating the magnetic field containing the stationary conductor. The



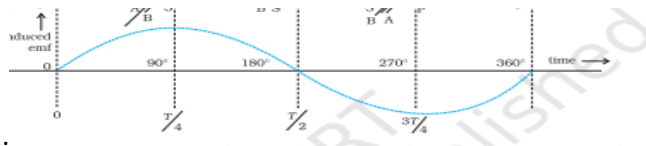
preferred arrangement is to keep the coil stationary because it is easier to draw induced alternating current from a stationary armature coil than from a rotating coil.

**The generated EMF depends on the number of armature coil turns, magnetic field strength, and the speed of the rotating field.**

1. Show graphically how an alternating emf is generated by a loop of wire rotating in a magnetic field.
2. What is the source of energy generation in this device?
3. Can the current produced by an ac generator be measured with a moving coil galvanometer?

**ANSWERS:**

1.



2. The source of energy generation is the mechanical energy of rotation of armature coil.
3. Current produced by an ac generator cannot be measured by moving coil ammeter; because the average value of ac over full cycle is zero.

## ASSIGNMENT 1

1. A planar loop of wire rotates in a uniform magnetic field. Initially, at  $t = 0$ , the plane of the loop is perpendicular to the magnetic field. If it rotates with a period of 10 s about an axis in its plane, then the magnitude of induced emf will be maximum and minimum, respectively at
  - (a) 2.5s and 7.5s
  - (b) 5.0s and 10.0s
  - (c) 2.5s and 5.0s
  - (d) 5.0s and 7.5s
2. A current carrying infinitely long wire is kept along the diameter of a circular wire loop, without touching it, the correct statement(s) is(are)
  - (a) the emf induced in the loop is zero if the current is constant
  - (b) the emf induced in the loop is finite if the current is constant
  - (c) the emf induced in the loop is zero if the current decreases at a steady rate
  - (d) the emf induced in the loop is finite if the current decreases at a steady state
3. According to the Faraday's law of electromagnetic induction which of the following is true?
  - (a) Conservation of charge
  - (b) Conservation of magnetic flux
  - (c) Conservation of energy
  - (d) Newton's law of equal and opposite forces
4. The magnetic flux linked with a coil satisfies the relation  $\phi = 4t^2 + 6t + 9$  Wb, where  $t$  is the time in second. The emf induced in the coil at  $t = 2$  s is
  - a) 22V
  - (b) 18V
  - (c) 16V
  - (d) 40V

5. A coil of cross-sectional area  $A$  having  $n$  turns is placed in a uniform magnetic field  $B$ . When it is rotated with an angular velocity  $\omega$ , the maximum e.m.f. induced in the coil will be

- (a)  $3/2nBA\omega$                       (b)  $nBA\omega$    (c)  $3nBA\omega$         (d)  $1/2nBA\omega$

6. When current in a coil changes from 5A to 2A in 0.1 s, an average voltage of 50V is produced. The self-inductance of the coil is

- (a) 0.67 H                      (b) 1.67H   (c) 3 H        (d) 6 H

7. A flat, rectangular coil is placed in a uniform magnetic field and rotated about an axis passing through its centre, parallel to its shorter edges and perpendicular to the field. The maximum emf induced is  $E$ . If the axis is shifted to coincide with one of the shorter edges, the maximum induced emf will be

- (a) Zero                      (b)  $E/2$         (c)  $E$             (d)  $2E$

8. A small circular loop of wire of radius  $a$  is located at the centre of a much larger circular wire loop of radius  $b$ . The two loops are on the same plane. The outer loop of radius  $b$  carries an alternating current  $I = I_0 \cos(\omega t)$ . The emf induced in the smaller inner loop is nearly :

- (a)  $\frac{\pi\mu_0 I_0}{2} \cdot \frac{a^2}{b} \omega \sin(\omega t)$     (b)  $\frac{\pi\mu_0 I_0}{2} \cdot \frac{a^2}{b} \omega \cos(\omega t)$     (c)  $\pi\mu_0 I_0 \frac{a^2}{b} \omega \sin(\omega t)$

- (d)  $\frac{\pi\mu_0 I_0}{a} b^2 \omega \cos(\omega t)$

9. Two coils of self inductances 6mH and 8mH are connected in series and are adjusted for highest co-efficient of coupling. Equivalent self inductance  $L$  for the assembly is approximately

- (a) 50mH                      (b) 36mH   (c) 28mH        (d) 18mH

10. A solenoid 30cm long is made by winding 2000 loops of wire on an iron rod whose cross-section is  $1.5\text{cm}^2$ . If the relative permeability of the iron is 6000, what is the self-inductance of the solenoid?

- (a) 15H                      (b) 2.5H        (c) 3.5H        (d) 0.5H

11. Two coils are placed close to each other. The mutual inductance of the pair of coils depends upon

- (a) Relative position and orientation of the two coils
- (b) the materials of the wires of the coils
- (c) the current in the two coils
- (d) the rates at which currents are changing in the two coils

12. A circular loop of radius 0.3 cm lies parallel to a much bigger circular loop of radius 20 cm. The centre of the small loop is on the axis of the bigger loop. The distance between their centres is 15 cm. If a current of 2.0 A flows through the smaller loop, then the flux linked with bigger loop is

- (a)  $6.6 \times 10^{-9}$  weber
- (b)  $9.1 \times 10^{-11}$  weber
- (c)  $6 \times 10^{-11}$  weber
- (d)  $3.3 \times 10^{-11}$  weber

13. An alternating current in a circuit is given by  $I = 20 \sin(100\pi t + 0.05\pi)$  A. The r.m.s. value and the frequency of current respectively are

- (a) 10A and 100Hz
- (b) 10A and 50Hz
- (c)  $10\sqrt{2}$ A and 50Hz
- (d) 10A and 500Hz

14. An electric bulb of resistance  $280 \Omega$  is connected to 200 Volt supply line. The peak value of current flowing in the circuit will be

- (a) Nearly 1A
- (b) Nearly 2A
- (c) Nearly 1.4A
- (d) Nearly 2.8A

15. The instantaneous voltages at three terminals marked X, Y and Z are given by  $V_x = V_0 \sin \omega t$ ,  $V_y = V_0 \sin(\omega t + 2\pi/3)$  and  $V_z = V_0 \sin(\omega t + 4\pi/3)$ . An ideal voltmeter is configured to read rms value of the potential difference between its terminals. It is connected between points X and Y and then between Y and Z. The reading(s) of the voltmeter will be

- (a) independent of the choice of the two terminals, (b)  $V_{\text{rms}_{XY}} = V_0$ , (c)  $V_{\text{rms}_{YZ}} = 2V_0$
- (d)  $V_{\text{rms}_{XY}} = V_0\sqrt{3}/2$

16. An alternating voltage  $e = 200\sqrt{2} \sin(100t)$  volt is connected to  $1\mu\text{F}$  capacitor through a.c. ammeter. The reading of ammeter is

- (a) 5mA
- (b) 15mA
- (c) 15mA
- (d) 20mA

17. In AC series circuit, the resistance, inductive reactance and capacitive reactance are  $3 \Omega$ ,  $10 \Omega$ ,  $14 \Omega$  respectively. The impedance of the circuit is

- (a)  $5 \Omega$
- (b)  $4 \Omega$
- (c)  $7 \Omega$
- (d)  $10 \Omega$

18. When a 60 mH inductor and a resistor are connected in series with an AC voltage source, the voltage leads the current by 60°. If the inductor is replaced by a 0.5  $\mu$ F capacitor, the voltage lags behind the current by 30°. What is the frequency of the AC supply?

- (a)  $1/2\pi \times 104$  Hz                      (b)  $1/\pi \times 104$  Hz                      (c)  $3/2\pi \times 104$  Hz  
(d)  $1/2\pi \times 108$  Hz

19. A sinusoidal voltage of peak value 283V and angular frequency 320/s is applied to a series LCR circuit. Given that  $R=5\Omega$ ,  $L=25\text{mH}$  and  $C=1000\mu\text{F}$ . The total impedance, and phase difference between the voltage across the source and the current will respectively be:

- (a)  $10\Omega$  and  $\tan^{-1}(5/3)$                       (b)  $7\Omega$  and  $45^\circ$                       (c)  $10\Omega$  and  $\tan^{-1}(8/3)$   
(d)  $7\Omega$  and  $\tan^{-1}(5/3)$

20. When the frequency of the AC voltage applied to a series LCR circuit is gradually increased from a low value, the impedance of the circuit.

- (a) monotonically increases (b) first increases and then decreases (c) first decreases and then increases (d) monotonically decreases

21. An arc lamp requires a direct current of 10 A at 80 V to function. If it is connected to a 220 V (rms), 50 Hz AC supply, the series inductor needed for it to work is close to

- (a) 80H                      (b) 0.08H                      (c)  $20\sqrt{2}$ H                      (d) 0.065H

22. A series R-C circuit is connected to AC voltage source. Consider two cases, (A) when C is without a dielectric medium and (B) when C is filled with dielectric of constant 4. The current  $I_R$  through the resistor and voltage  $V_C$  across the capacitor are compared in the two cases. Which of the following is/ are true?

- (a)  $I_A > I_B$                       (b)  $I_A < I_B$                       (c)  $V_{AC} > V_{BC}$  (d)  $V_{AC} < V_{BC}$

23. A power transmission line feeds input power at 2300 V to a step-down transformer with its primary windings having 4000 turns. The output power is delivered at 230 V by the transformer. If the current in the primary coil of the transformer is 5 A and its efficiency is 90%. The output current would be

- (a) 50A                      (b) 25A                      (c) 45A                      (d) 20A

24. An electric bulb, a capacitor, battery and a switch are all in series in a circuit. How does the intensity of light vary when the switch is turned on?

- (a) Continues to increase gradually. (b) Gradually increases for some time and then becomes steady.  
(c) Sharply rises initially and then gradually decreases. (d) Gradually increases for some time and then gradually decreases.

25. The number of turns in the primary and secondary coils of a transformer are 100 and 300 respectively. If the input power is 60 watt, the power output is

- (a) 100W                      (b) 300W                      (c) 180W                      (d) 60W

REASONING AND ASSERTION

Two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below. a) Both A and R are true and R is the correct explanation of A b) Both A and R are true and R is NOT the correct explanation of A c) A is true but R is false d) A is false and R is also false

26. Assertion: AC generators are based upon EMI principle.

Reason: Resistance offered by capacitor for alternating current is zero.

27. Assertion- When two coils are wound on each other, the mutual induction between coil is maximum

Reason -- Mutual induction doesn't depend on the orientation of the coils.

28. Assertion- When capacitive reactance is smaller than the inductive reactance in LCR circuit, emf leads the current

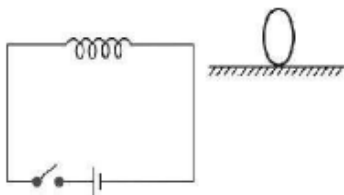
Reason -- The phase angle is angle between alternating emf and alternating current of the circuit

29. Assertion : Figure shows a metallic conductor moving in magnetic field. The induced emf across its ends is zero.



Reason : The induced emf across the ends of a conductor is given by  $e = Bv\ell \sin\theta$ .

30. Assertion : Figure shows a horizontal solenoid connected to a battery and a switch. A copper ring is placed on a smooth surface, the axis of the ring being horizontal. As the switch is closed, the ring will move away from the solenoid.



Reason : Induced emf in the ring,  $e = -d\Phi/dt$

### HINTS AND EXPLANATIONS

1. (c)

2.(a,c) : Total flux associated with loop is zero in both the cases either for a constant current or current decreasing or a steady state. Therefore, Induced emf in any case is zero.

3.(c)

4.(a)

5. (b) :emf induced in the coil is given by

$$e = BA\omega \sin\omega t \quad e_{\max} = BA\omega$$

6. (b): EMF =  $L \times di/dt$

$$50 = L \times (5-2)/0.1 = L \times 30$$

$$L = 5/3 = 1.67$$

7. (c): The flux linked with the coil does not depend upon the position of the axis of rotation. The induced emf depends only on the rate of change of this flux.

8. (a): IF Magnetic field (B) — change -

$$\varepsilon = -NA \cos \Theta \left( \frac{dB}{dt} \right)$$

- Magnetic field produced by outer loop =  $\frac{\mu_0 I}{2R} = \frac{\mu_0 I_0 \cos \omega t}{2b}$

$$\phi = B.A = \left( \frac{\mu_0 I_0 \cos \omega t}{2b} \right) \pi a^2$$

9. (c)

10.(a)

11.(a): Mutual inductance of the pair of coils depends on relative position and orientation of the two coils.

12.(b): As field due to current loop 1 at an axial point

$$B_1 = \frac{2(d^2 + R^2)^{-3/2} \mu_0 I_1 R^2}{2}$$

Flux linked with smaller loop 2 due to  $B_1$  is

$$\phi_2 = B_1 A_2 = \frac{2(d^2 + R^2)^{-3/2} \mu_0 I_1 R^2 \pi r^2}{2}$$

The coefficient of mutual inductance between the loops is

$$M = I_1 \phi_2 = \frac{2(d^2 + R^2)^{-3/2} \mu_0 R^2 \pi r^2}{2}$$

Flux linked with bigger loop 1 is

$$\phi_1 = M I_2 = \frac{2(d^2 + R^2)^{-3/2} \mu_0 R^2 \pi r^2 I_2}{2}$$

Substituting the given values, we get

$$\phi_1 = 2 \left[ \frac{(15 \times 10^{-2})^2 + (20 \times 10^{-2})^2}{2} \right]^{-3/2} \frac{2 \pi \times 10^{-7} \times (20 \times 10^{-2})^2 \times \pi \times (0.3 \times 10^{-2})^2 \times 2}{2}$$

$$\phi_1 = 9.1 \times 10^{-11} \text{ weber}$$

13.(c): Given,  $i = 20 \sin(100\pi t + 0.05\pi)$

The root mean square value of alternating current

$$= I_{rms} = I_0 / \sqrt{2} = 20 / \sqrt{2} = 10\sqrt{2} \text{ A}$$

Also,  $\omega = 100\pi$

$$\Rightarrow 2\pi f = 100\pi \text{ or } f = 50 \text{ Hz}$$

14.(a):  $i_{max} = 200 \text{ A}$  , So  $i_0 = i_{max} \times \sqrt{2} = 200\sqrt{2} \approx 283 \text{ A}$

$$\sqrt{2} \approx 1.414 \text{ A } i_0 = i_{max} \times \sqrt{2} = 200 \times 1.414 \approx 283 \text{ A}$$

15.(a,d):

$$V_{XY} = V_X - V_Y$$

$$V_{XY} = (V_{XY})_0 \sin(\omega t + \theta_1)$$

$$\text{where } (V_{XY})_0 = \sqrt{V_0^2 + V_0^2 - 2V_0^2 \cos \frac{2\pi}{3}} = \sqrt{3}V_0$$

$$\text{and } (V_{XY})_{rms} = \frac{(V_{XY})_0}{\sqrt{2}} = \sqrt{\frac{3}{2}}V_0$$

Now the potential difference between Y and Z is

$$V_{YZ} = V_Y - V_Z$$

$$V_{YZ} = (V_{YZ})_0 \sin(\omega t + \theta_2)$$

$$\text{Where } (V_{YZ})_0 = \sqrt{V_0^2 + V_0^2 - 2V_0^2 \cos \frac{2\pi}{3}} = \sqrt{3}V_0$$

$$\text{and } (V_{YZ})_{rms} = \frac{(V_{YZ})_0}{\sqrt{2}} = \sqrt{\frac{3}{2}}V_0$$

16.(d): Ammeter reads r.m.s. value so

$$\therefore i_{rms} = \frac{V_{rms}}{X_C} = V_{rms} \times \omega \times C$$

$$\begin{aligned} \Rightarrow i_{rms} &= \left( \frac{200\sqrt{2}}{\sqrt{2}} \right) \\ &\quad \times 100 \times (1 \times 10^{-6}) \\ &= 2 \times 10^{-2} = 20 \text{ mA}. \end{aligned}$$

17.(a): Here, Resistance,  $R=3\Omega$

Inductive reactance,  $X_L=10\Omega$

Capacitive reactance,  $X_C=14\Omega$

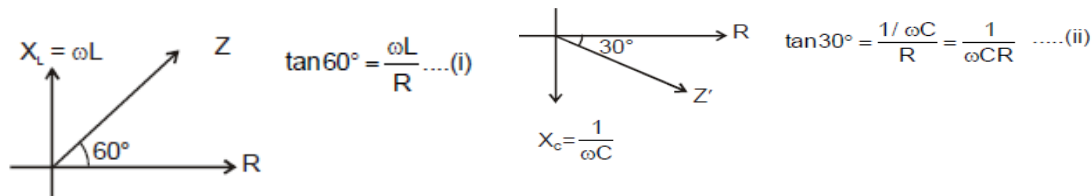
The impedance of the series LCR circuit is:

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

$$= \sqrt{(3)^2 + (14 - 10)^2}$$

$$Z = 5\Omega$$

18.(a):



from (i) and (ii)

$$\tan 30^\circ / \tan 60^\circ = \omega L / R \times 1 / \omega C R = \omega^2 LC$$

$$\sqrt{3}/1\sqrt{3} = \omega^2 \times 60 \times 10^{-3} \times 0.5 / 10 \times 10^{-6} \Rightarrow 3 = \omega^2 \times 3 \times 10^{-8} \text{ or, } \omega^2 = 10^8 \text{ or, } \omega = 10^4$$

$$2\pi f = 10^4 \therefore f = 10^4 / 2\pi$$

19.(b): Impedance

$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

$$V_0 = 283 \text{ V}$$

$$R = 5\Omega, L = 25 \text{ mH}, C = 1000 \mu\text{F}$$

$$\omega = 320/\text{s}$$

$$X_L = \omega L = (2\pi f)L = 320 \times 25 \times 10^{-3} \Omega = 8\Omega$$

$$X_C = \frac{1}{\omega C} = \frac{1}{320 \times 10^{-3}} \Omega = \frac{1}{0.32} \Omega = 3.125\Omega$$

Total Impedance

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \cong 5\sqrt{2}$$

$$\text{Phase difference} = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$



$$\cong 45^\circ$$

20.(c):

We Know  $Z = \sqrt{(\omega L - 1/\omega C)^2 + R^2}$  IF ,  
 $= 0$  then  $\omega = 1/\sqrt{LC}$

then  $dZ/d\omega \leq 0$  i.e., Z is a decreasing function.

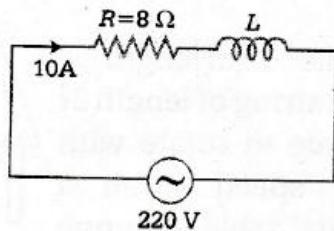
$dZ/d\omega > 0$  i.e., Z is a increasing function.

21.(d):

Given,  $I = 10A$ ,  $V = 80V$ ,

$$R = \frac{V}{I} = \frac{80}{10} = 8\Omega \text{ and } \omega = 50 \text{ Hz}$$

For AC circuit, we have



$$I = \frac{V}{\sqrt{R^2 + X_L^2}} \Rightarrow 10 = \frac{220}{\sqrt{64 + X_L^2}}$$

$$\Rightarrow \sqrt{64 + X_L^2} = 22$$

Squaring on both sides, we get

$$64 + X_L^2 = 484$$

$$\Rightarrow X_L^2 = 484 - 64 = 420$$

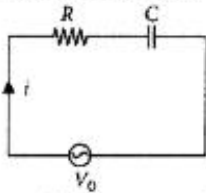
$$X_L = \sqrt{420} \Rightarrow 2\pi \times \omega L = \sqrt{420}$$

Series inductor on an arc lamp,

$$L = \frac{\sqrt{420}}{(2\pi \times 50)} = 0.065 \text{ H}$$

22.(b,c):

Current through resistor,  $i$   
= Current in the circuit



$$= \frac{V_0}{\sqrt{R^2 + X_C^2}} = \frac{V_0}{\sqrt{R^2 + (1/\omega C)^2}}$$

Voltage across capacitor,  $V = iX_C$

$$= \frac{V_0}{\sqrt{R^2 + (1/\omega C)^2}} \times \frac{1}{\omega C}$$

$$= \frac{V_0}{\sqrt{R^2 \omega^2 C^2 + 1}}$$

As  $C_a < C_b$   
 $\therefore i_a < i_b$  and  $V_a > V_b$

23.(c):

We know that, efficiency is given by

$\eta = \text{output power}/\text{input power}$

$$= E_s \cdot I_s / E_p \cdot I_p$$

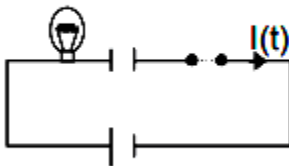
Here,  $\eta = 90\%$ ,  $E_p = 2300V$ ,  $I_p = 5A$  and  $E_s = 230V$

Therefore,  $90/100 = 230 \cdot I_s / 2300 \cdot 5$

$$I_s = 90 \cdot 2300 \cdot 5 / 230 \cdot 100 = 45A$$

24.(c):

$$I(t) = \frac{\epsilon}{R} e^{-t/RC}$$



$$\text{Intensity} \propto I^2 R = \epsilon^2 R e^{-2t/RC}$$

25.(d):

For an ideal transformer,  $\eta = 1$

Therefore, Power Output = Power Input = 60 W

26.c) A is true but R is false

27. c) A is true but R is false

28. b) Both A and R are true and R is NOT the correct explanation

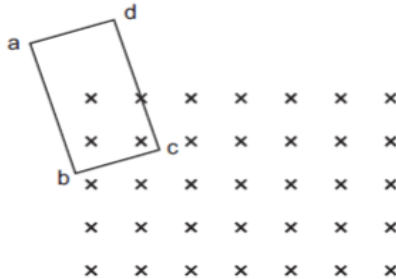
29.a) Both A and R are true and R is the correct explanation of A

30.a) Both A and R are true and R is the correct explanation of A

## ASSIGNMENT 2

- 1) Same current is flowing in two alternating circuits: the first circuit contains only inductance and the other contains only a capacitor. If the frequency of the EMF of the ac is increased, the effect on the value of the current in respective circuits will be? [1]
- 2) In an AC circuit, the EMF ( $e$ ) and the current ( $I$ ) at any instant are given respectively by  $E = E_0 \sin \omega t$  and  $I = I_0 \sin (\omega t - \phi)$ . The average power in the circuit over one cycle of AC is given by \_\_\_\_\_ [1]
- 3) An alternating current generator has an internal resistance  $R_g$  and an internal reactance  $X_g$ . It is used to supply power to a passive load consisting of a resistance  $R_g$  and a reactance  $X_L$ . For maximum power to be delivered from the generator to the load, the value of  $X_L$  is equal to [1]
- 4)

Use Lenz's law to determine the direction of the induced current when a rectangular conducting loop  $abcd$  is moved into a region of magnetic field which is directed normal to the plane of the loop away from the reader.

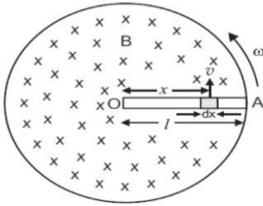


[1]

- 5) A metallic rod of length  $l$  is moved perpendicular to its length with velocity  $v$  in a magnetic field  $B$  acting perpendicular to the plane in which the rod moves. Derive an expression for the induced EMF. [2]
- 6) Define self inductance, and mention its SI unit. Give two factors on which self inductance of an air-cored coil depend. [2]
- 7) How is mutual inductance of coils affected when
  - a. Separation between the coils is increased?
  - b. Number of turns of each coil is increased?
  - c. A thin iron sheet is placed between the coils, other factors remaining the same?Explain your answer. [2]
- 8) A device  $x$  is connected across an ac source of voltage  $V = V_0 \sin \omega t$ . The current through  $x$  is given as  $I = I_0 \sin (\omega t + \pi/4)$ . Identify the device  $x$  and write the expression for its reactance. [2]

- 9) State the conditions for resonance to occur in a series LCR AC circuit. [2]
- 10) An iron bar falling through the hollow region of a thick cylindrical shell made of copper experiences a retarding force. What can you conclude about the nature of the iron bar? Explain. [2]
- 11) Show that the current leads the voltage in phase by  $\pi/2$  in an ac circuit containing an ideal capacitor. [2]
- 12) An inductor L of reactance  $X_L$  is connected in series with a bulb B to an ac source as shown in figure. Explain briefly how the brightness of the bulb changes when
- Number of turns of the inductor is reduced
  - An iron rod is inserted in the inductor and
  - A capacitor of reactance  $X_C = X_L$  is included in the circuit. [2]
- 13) You are given three circuit elements X, Y and Z. When the element X is connected across an ac source of a given voltage, the current and the voltage are in the same phase. When the element Y is connected in series with X across the source, voltage is ahead of the current in phase by  $\pi/4$ . But the current is ahead of the voltage in phase by  $\pi/4$  when Z is connected in series with X across the source.
- Identify the circuit elements X, Y and Z. When all the three elements are connected in series across the same source, determine the impedance of the circuit.
  - Draw a plot of the current versus the frequency of applied source and mention the significance of this plot. [3]
- 14) Show that the average power dissipated per cycle in an ac circuit is given by  $P = V_{rms} \times I_{rms} \times R/Z$ , where R is the resistance of the circuit (defined as the real part of the complex impedance) and Z is the impedance. Under what conditions
- a. no power is dissipated even though current flows through the circuit,
  - b. Maximum power dissipated in the circuit? [3]
- 15) An alternating voltage  $E = E_0 \sin \omega t$  is applied to a circuit containing a resistor R connected in series with a black box. The current in the circuit is found to be  $I = I_0 \sin(\omega t + \pi/4)$ .
- a. State whether the element in the black box is a capacitor or inductor.
  - b. Draw the corresponding phasor diagram and find the impedance in terms of R. [3]
- 16) Write principle and working of A.C generator with labeled diagram. [3]
- 17) Describe briefly with the help of labeled diagram, Principle & working theory of a transformer.
- A step up transformer converts a low voltage into high voltage. Does it violate the principle of conservation of energy? [5]

Q no	Solutions	Marks

1.	<p>Circuit one contains inductance &amp; two contains capacitor.</p> $X_L = L\omega = 2\pi fL$ $X_C = (1/\omega c) = [1/\{2\pi f c\}]$ <p>As frequency increases, <math>X_L</math> increases, <math>X_C</math> will decrease.</p> <p>Hence in first circuit, <math>X_L</math> increases hence current decreases. And in second circuit, <math>X_C</math> decreases hence current will increase.</p> <p><math>\therefore</math> Current decreases in first and increases in other.</p>	1
2	$P_{av} = \frac{(E_0 I_0 \cos \phi) T/2}{T}$ $P_{av} = \frac{E_0 I_0 \cos \phi}{2}$	1
3	For delivering maximum power from the generator to the load, total internal reactance must be equal to conjugate of total external reactance.	1
4	anticlockwise	1
5	<p>The emf induced across the ends of element</p> $d\varepsilon = B \frac{dA}{dt} = B v dx$ <p>But <math>v = x\omega</math></p> <p><math>\therefore d\varepsilon = B x \omega dx</math></p> <p><math>\therefore</math> The emf induced across the rod</p> $\varepsilon = \int_0^l B x \omega dx = B\omega \int_0^l x dx$ $= B\omega \left[ \frac{x^2}{2} \right]_0^l = B\omega \left[ \frac{l^2}{2} - 0 \right] = \frac{1}{2} B \omega l^2$ <p>Current induced in rod <math>I = \frac{\varepsilon}{R} = \frac{1}{2} \frac{B \omega l^2}{R}</math>.</p> 	2
6	<p>The phenomenon of the production of emf induced in a coil due to change of flux through the coil by means of varying the current through the same coil.</p> <p>Its SI unit is Henry.</p> <p>Self inductance depends on</p> <ol style="list-style-type: none"> <li>cross-sectional area of the coil</li> <li>permeability of the core material</li> <li>the number of turns per unit length of the coil</li> </ol>	2

	any three	
7	<ul style="list-style-type: none"> <li>a) Decrease</li> <li>b) Increases</li> <li>c) Increases</li> </ul>	2
8	The device is capacitor. The reactance of capacitor is given by $X_c = 1/\omega C = 1/2\pi fC$	2
9	For resonance to occur <ul style="list-style-type: none"> <li>• Current and voltage should to in the same phase</li> <li>• <math>X_L = X_C</math></li> </ul>	2
10	This shows that the iron bar is magnets as when it falls through a conducting cylinder it brings change in flux and according to Lenz's law induced EMF in the conducting cylinder tries to retard the motion of the falling magnet	2
11	<p>Given that,  Phase = <math>2\pi</math>  If,  <math>V = V_0 \sin \omega t</math>  We know that,  <math>q = CV</math>  <math>q = CV_0 \sin \omega t</math>  Now, the current  <math>I = dt/dq</math>  <math>I = dt/d(CV_0 \sin \omega t)</math>  <math>I = \omega CV_0 \cos \omega t</math>  <math>I = \omega CV_0 \sin(\omega t + 2\pi)</math>  Hence, the current is <math>\omega CV_0 \sin(\omega t + 2\pi)</math></p>	2
12	<ul style="list-style-type: none"> <li>• Brightness increases</li> <li>• Brightness decreases</li> <li>• Brightness increases</li> </ul>	2
13	<ul style="list-style-type: none"> <li>X – Resistor</li> <li>Y – Inductor</li> <li>Z – Capacitor</li> <li>Impedance = <math>\sqrt{R^2 + (X_L - X_C)^2}</math></li> </ul>	[1/2] [1/2] [1/2] 1 ½

14

Instantaneous power dissipation in the circuit

$$P = VI$$

$$= V_0 \sin \omega t \times I_0 \sin(\omega t - \phi)$$

$$= \frac{V_0 I_0}{2} \times 2 \sin \omega t \sin(\omega t - \phi)$$

$$= \frac{V_0 I_0}{2} (\cos \phi - \cos(2\omega t - \phi))$$

$$[\cos(A - B) - \cos(A + B) = 2 \sin A \sin B]$$

Average power loss over one complete cycle

$$\bar{P} = \frac{1}{T} \int_0^T P dt$$

$$= \frac{V_0 I_0}{2T} \left[ \int_0^T \cos \phi dt - \int_0^T \cos(2\omega t - \phi) dt \right]$$

However

$$\int_0^T \cos(2\omega t - \phi) dt = 0$$

$$= \frac{V_0 I_0}{2T} \cdot \cos \phi \int_0^T dt = \frac{V_0 I_0}{2} \cos \phi$$

$$P_{av} = \frac{V_0}{\sqrt{2}} \frac{I_0}{\sqrt{2}} \cos \phi$$

$$P_{av} = V_{eff} \cdot I_{eff} \cos \phi$$

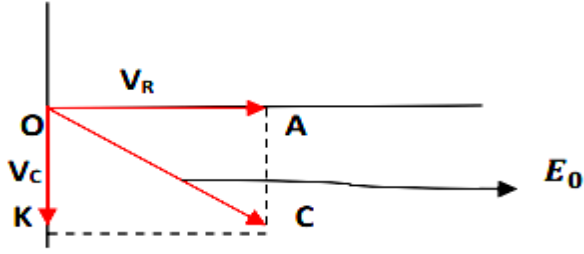
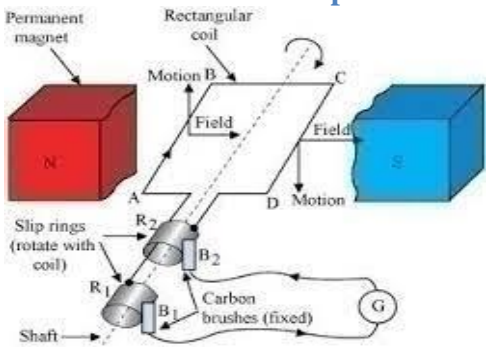
(i) If phase angle  $\phi = 90^\circ$  (resistance  $R$  is used in the circuit) then no power dissipated.(ii) If phase angle  $\phi = 0^\circ$  or circuit is pure resistive (or  $X_L = X_C$ ) at resonance then

$$\text{Max power } P = V_{eff} \times I_{eff} = \frac{V_0 I_0}{2}$$

[1]

[1]

[1]

15	 $\tan\phi = \frac{AK}{OA} = \frac{OC}{OA} = \frac{V_C}{V_R} = \frac{-I_0 X_C}{I_0 R} = \frac{-X_C}{R}$ <p>From diagram,</p> $OK = \sqrt{OA^2 + AK^2} = \sqrt{OA^2 + OC^2}$ $\therefore E_0 = \sqrt{V_R^2 + V_C^2}$ $= \sqrt{(I_0 R)^2 + (-I_0 X_C)^2}$ $E_0 = I_0 \sqrt{R^2 + X_C^2}$ $\therefore \text{Impedance} = \frac{E_0}{I_0} = \sqrt{R^2 + X_C^2}$ <p>a) Capacitor [ 2]</p>	[1]
16	<p><b>It works on the principle of Faraday's law of electromagnetic induction. Whenever a coil is rotated in a uniform magnetic field about an axis perpendicular to the field, the magnetic flux linked with coil changes and an induced EMF is set up across its ends.</b></p> 	3
17	<p><b>TRANSFORMER DERIVATION AND DIAGRAM</b></p> <p>A] The purpose of the transformer is to increase/decrease voltage. It definitely obeys law of conservation of energy as the increase in voltage is compensated by the decrease in current (which is generally in the ratio of number of turns in primary and secondary coils). Thus the overall product <b>VI= constant</b> in both sides of transformer. So input power = power output</p>	3 +1=4  [1]



## REVISION QUESTION PAPER

(CHAPTERS 3 & 4)

35 MARKS

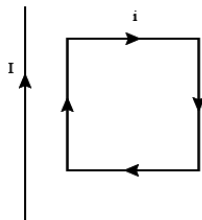
Time: 90 minutes

### General instructions:

1. There are 18 questions in all. (All questions are compulsory)
2. Section A: Question no. 1 to 9 (1 mark)
3. Section B: Question no. 10 to 13 (2 mark)
4. Section C: Question no. 14 to 16 (3 mark)
5. Section D: Question no. 17 (5 mark)
6. Section E: Question no. 18 (4 mark)
7. Internal choices are given in section B, C, D and E

### SECTION A (1 mark)

- 1) The magnetic moment of a current  $I$  carrying a circular coil of radius  $r$  and number of turns  $N$  varies as  
a)  $r^4$    b)  $r^2$    c)  $1/r^4$    d)  $r$
- 2) Which among the following materials display higher magnetic susceptibility?  
a) Ferromagnetic material                      b) Paramagnetic material  
c) Diamagnetic material                         d) None of these options
- 3) When current in a coil changes from 5 A to 2 A in 0.1 s, average voltage of 50 V is produced. The self-inductance of the coil is  
a) 1.67 H   b) 6 H            c) 3 H                      d) 0.67 H
- 4) If the frequency of an A.C. is made 4 times of its initial value, the inductive reactance will  
a) be 4 times                      b) be 2 times                      c) be half                      d) remain the same
- 5) A charged particle is moving on circular path with velocity  $v$  in a uniform magnetic field  $B$ , if the velocity of the charged particle is doubled and strength of magnetic field is halved, the radius becomes  
a) 8 times            b) 4 times            c) 2 times            d) 16 times
- 6) A diamagnetic material in a magnetic field moves  
a) perpendicular to the field                      b) from stronger to the weaker parts of the field  
c) from weaker to the stronger parts of the field                      d) none of these
- 7) A coil having 500 sq. loops of side 10 cm is placed normal to magnetic flux which increases at a rate of 1 T/s. The induced emf is  
a) 0.1 V                      b) 0.5 V                      c) 1 V                      d) 5 V
- 8) A capacitor has capacitance  $C$  and reactance  $X$ , if capacitance and frequency become double, then reactance will be  
a)  $4X$                       b)  $X/2$                       c)  $X/4$                       d)  $2X$
- 9) a rectangular loop carrying a current  $I$  is situated near a long straight wire such that the wire is parallel to the one of the sides of the loop and is in the plane of the loop. If a steady current  $I$  is established in wire as shown in the figure, the loop will



- a) rotate about an axis parallel to the wire    b) move away from the wire or towards right  
 c) move towards the wire                            d) remain stationary

**SECTION B (2 mark)**

10) If the solenoid is free to turn about the vertical direction and a uniform horizontal magnetic field of 0.25 T is applied, what is the magnitude of torque on the solenoid when its axis makes an angle of  $30^\circ$  with the direction of applied field?

(or)

A closely wound solenoid of 800 turns and area of cross section  $2.5 \times 10^{-4} \text{ m}^2$  carries a current of 3.0 A. Explain the sense in which the solenoid acts like a bar magnet. What is its associated magnetic moment?

11) A pair of adjacent coils has a mutual inductance of 1.5 H. If the current in one coil changes from 0 to 20 A in 0.5 s, what is the change of flux linkage with the other coil?

12) A  $15.0 \mu\text{F}$  capacitor is connected to 220 V, 50 Hz source. Find the capacitive reactance and the rms current.

13) It is desired to pass only 10% of the current through a galvanometer of resistance 90 ohm. How much shunt resistance be connected across the galvanometer?

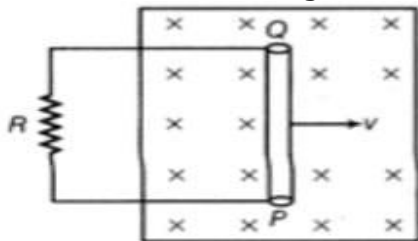
**SECTION C (3 mark)**

14) A short bar magnet of magnetic moment  $m = 0.32 \text{ JT}^{-1}$  is placed in a uniform magnetic field of 0.15 T. If the bar is free to rotate in the plane of the field, which orientation would correspond to its

- (a) stable, and (b) unstable equilibrium?

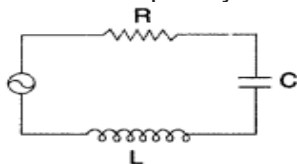
What is the potential energy of the magnet in each case?

15) A conducting rod PQ, of length  $l$ , connected to a resistor  $R$ , is moved at a uniform speed  $v$ , normal to a uniform magnetic field  $B$ , as shown in the figure



- i) Deduce the expression for the emf induced in the conductor.  
 ii) Find the force required to move the rod in the magnetic field.  
 iii) Mark the direction of induced current in the conductor.

16) The figure shows a series LCR circuit with  $L = 5.0 \text{ H}$ ,  $C = 80 \mu\text{F}$ ,  $R = 40 \Omega$  connected to a variable frequency 240 V source. Calculate



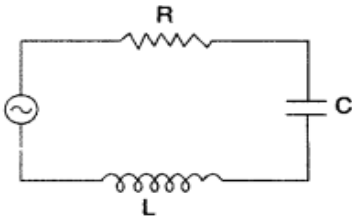
- i) The angular frequency of the source which drives the circuit at resonance.  
 ii) The current at the resonating frequency.  
 iii) The rms potential drop across the capacitor at resonance.

(or)

A series LCR circuit with  $L = 4.0 \text{ H}$ ,  $C = 100 \mu\text{F}$  and  $R = 60 \Omega$ . is connected to a variable frequency 240 V source as shown in the figure.

Calculate :

- (i) the angular frequency of the source which drives the circuit at resonance;
- (ii) the current at the resonating frequency;
- (iii) the rms potential drop across the inductor at resonance.



**SECTION D (5 mark)**

17) a) Draw a labelled diagram of a moving coil galvanometer. Prove that in a radial magnetic field, the deflection of the coil is directly proportional to the current flowing in the coil.

b) A galvanometer can be converted into a voltmeter to measure up to

i) V volt by connecting a resistance R<sub>1</sub> in series with the coil.

ii)  $v/2$  volt by connecting a resistance R<sub>2</sub> in series with the coil.

Find R in terms of R<sub>1</sub> and R<sub>2</sub> required to convert it into a voltmeter that can read upto '2v' volt.

(or)

i) Describe a simple experiment (or activity) to show that the polarity of emf induced in a coil is always such that it tends to produce a current which opposes the change of magnetic flux that produces it.

(ii) The current flowing through an inductor of self-inductance L is continuously increasing. Plot a graph showing the variation of

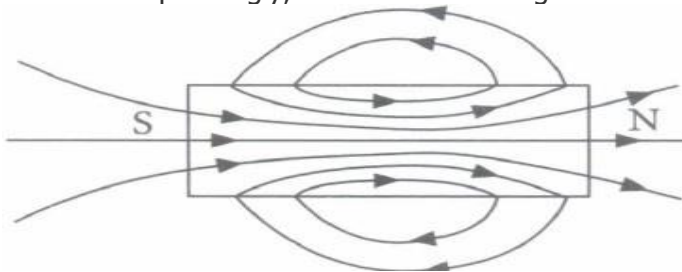
(a) magnetic flux versus the current (b) induced emf versus  $dl/dt$

(c) magnetic potential energy stored versus the current.

**SECTION E ( Case Based – 4 mark) – Answer any four.**

18) By analogy to Gauss's law of electrostatics, we can write Gauss's law of magnetism as  $\oint \vec{B} \cdot d\vec{s} = \mu_0 m_{\text{inside}}$  where  $\oint \vec{B} \cdot d\vec{s}$  is the magnetic flux and  $m_{\text{inside}}$  is the net pole strength inside the closed surface.

We do not have an isolated magnetic pole in nature. At least none has been found to exist till date. The smallest unit of the source of magnetic field is a magnetic dipole where the net magnetic pole is zero. Hence, the net magnetic pole enclosed by any closed surface is always zero. Correspondingly, the flux of the magnetic field through any closed surface is zero.



(i) Consider the two idealized systems

(1) a parallel plate capacitor with large plates and small separation and

(2) a long solenoid of length  $L \gg R$ , radius of cross-section.

In (i)  $\vec{E}$  is ideally treated as a constant between plates and zero outside. In (ii) magnetic field is constant inside the solenoid and zero outside. These idealized assumptions, however, contradict fundamental laws as below

(a) case (1) contradicts Gauss's law for electrostatic fields

(b) case (2) contradicts Gauss's law for magnetic fields

(c) case (1) agrees with  $\oint \vec{E} \cdot d\vec{l} \rightarrow 0$ .

(d) case (2) contradicts  $\oint \vec{H} \cdot d\vec{l} \rightarrow I_{en}$

(ii) The net magnetic flux through any closed surface, kept in a magnetic field is

(a) zero            (b)  $\mu_0/4\pi$             (c)  $4\pi\mu_0$             (d)  $4\mu_0/\pi$

(iii) A closed surface S encloses a magnetic dipole of magnetic moment  $2m$ . The magnetic flux emerging from the surface is

(a)  $\mu_0 m$             (b) zero            (c)  $2\mu_0 m$             (d)  $2m/\mu_0$

(iv) Which of the following is not a consequence of Gauss's law?

(a) The magnetic poles always exist as unlike pairs of equal strength.

(b) If several magnetic lines of force enter in a closed surface, then an equal number of lines of force must leave that surface

(c) There are abundant sources or sinks of the magnetic field inside a closed surface

(d) Isolated magnetic poles do not exist

(v) The surface integral of a magnetic field over a surface

(a) is proportional to mass enclosed

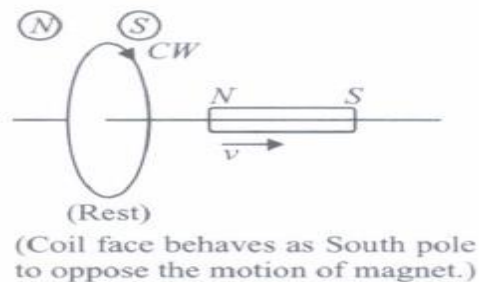
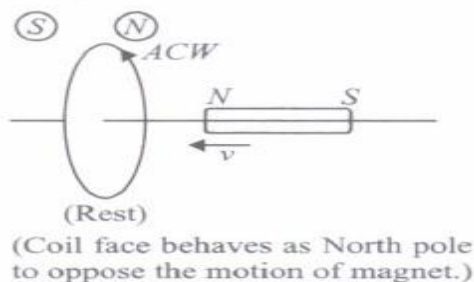
(b) is proportional to charge enclosed

(c) is zero

(d) equal to its magnetic flux through that surface.

(or)

Lenz's law states that the direction of induced current in a circuit is such that it opposes the change which produces it. Thus, if the magnetic flux linked with a closed circuit increases, the induced current flows in such a direction that magnetic flux is created in the opposite direction of the original magnetic flux. If the magnetic flux linked with the closed circuit decreases, the induced current flows in such a direction so as to create magnetic flux in the direction of the original flux.



(i) Which of the following statements is correct?

(a) Induced e.m.f is not in the direction opposing the change in magnetic flux so as to oppose the cause which produces it.

(b) The relative motion between the coil and magnet produces change in magnetic flux.

(c) Emf is induced only if the magnet is moved towards coil.

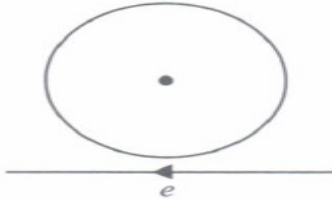
(d) Emf is induced only if the coil is moved towards magnet

(ii) The polarity of induced emf is given by

- (a) Ampere's circuital law                      (b) Biot-Savart law  
 (c) Lenz's law                                      (d) Fleming's right hand rule

(iii) Lenz's law is a consequence of the law of conservation of  
 (a) charge              (b) mass              (c) momentum              (d) energy

(iv) Near a circular loop of conducting wire as shown in the figure, an electron moves along a straight line. The direction of the induced current if any in the loop is



- (a) variable                                      (b) clockwise  
 (c) anticlockwise                              (d) zero

(v) Two identical circular coils A and B are kept in a horizontal tube side by side without touching each other. If the current in coil A increases with time, in response, the coil B.

- (a) is attracted by A                              (c) is repelled  
 (c) is repelled                                      (d) rotates

### ANSWER KEY

#### **SECTION A**

- 1) b)  $r^2$
- 2) a) ferromagnetic material
- 3) a) 1.67 H
- 4) a) be 4 times
- 5) b) 4 times
- 6) b) from stronger to the weaker parts of the field
- 7) d) 5V
- 8) c)  $X/4$
- 9) c) move towards the wire

#### **SECTION B**

10) Given: Magnetic field strength,  $B=0.25T$

Magnetic moment,  $m=0.6JT^{-1}$

The angle between the axis of the solenoid and the direction of the applied field,  $\theta=30^\circ$ .

We know, the torque acting on the solenoid is:

$$\begin{aligned} \tau &= m \times B = mB \sin \theta \\ &= (0.6JT^{-1})(0.25T)(\sin 30^\circ) \\ &= 0.075J \quad = 7.5 \times 10^{-2}J \end{aligned}$$

The magnitude of torque is  $7.5 \times 10^{-2}J$

(or)

Given:  $n=800$ ,  $A=2.5 \times 10^{-4}m^2$ ,  $I=3.0A$

A magnetic field develops along the axis of the solenoid. Therefore current-carrying solenoid acts like a bar magnet.

$$m = nIA = 800 \times 3 \times 2.5 \times 10^{-4}JT^{-1}$$

=0.6JT-1 along the axis of the solenoid

11) We know that  $e = dt d\phi = M dt di$

Therefore,  $d\phi = M di = 1.5 \times (20 - 0) = 30 \text{ Wb}$

12) Given :  $C = 15 \times 10^{-6} \text{ F}$

Rms value of voltage  $V_{\text{rms}} = 220 \text{ V}$

Frequency of source  $f = 50 \text{ Hz}$

Capacitive reactance  $X_C = 2\pi f C = 2\pi \times 50 \times 15 \times 10^{-6} = 212.3 \Omega$

Rms value of current  $I_{\text{rms}} = X_C V_{\text{rms}} = 212.3 / 220 = 1.04 \text{ A}$

13) we know  $S = (n-1)G$

According to question:  $\therefore i_g = 10\% \text{ of } i = 10i \Rightarrow S = (n-1)G = (10-1)90 = 10\Omega$

SECTION C

14) (a) In stable equilibrium, the bar magnet is aligned along the magnetic field, i.e.,  $\theta = 0^\circ$ .

Potential energy  $= -mB \cos \theta = -4.8 \times 10^{-2} \text{ J}$

(a) In unstable equilibrium, the bar magnet is aligned reversed to magnetic field, i.e.,  $\theta = 180^\circ$ .

(b) Potential energy  $= -mB \cos \theta = 4.8 \times 10^{-2} \text{ J}$

15) (i) Let the lengths of horizontal arms of circuit be  $x_1$  and  $x_2$  at instants  $t_1$  and  $t_2$  respectively.

Area of loop inside the magnetic field,  $A_1 = lx_1$ ,  $A_2 = lx_2$

$\Delta A = A_2 - A_1 = l(x_2 - x_1) = l \Delta x \Delta \phi = B \Delta A = Bl \Delta x$

$\Delta \phi / \Delta t = Blv$

By Faraday's law of induced emf (in magnitude),  $e = \Delta \phi / \Delta t = Blv$

$e = Blv$

(iii) Current  $I$  in the loop, force required must be equal to magnetic force acting on conductor PQ in the opposite directions.

$F = IB l \sin 90^\circ = (vBl/R)Bl$

$F = v(B^2)(l^2)/R$

(iii) By Fleming's right hand rule, the direction of flow of current is along anti-clockwise direction.

16) Given  $L = 5 \text{ H}$ ,  $C = 80 \times 10^{-6} \text{ F}$ ,  $R = 40 \Omega$

$V_{\text{eff}} = 240 \text{ V}$ ,  $V_{\text{peak}} = 2 \times 240 \text{ V}$

a) Resonance angular frequency is  $\omega_r = 1/LC = 1/5 \times 80 \times 10^{-6} = 50 \text{ rad/s}$ .

b) At resonance

Peak value of current  $\Rightarrow I_0 = R V_{\text{peak}} = 40 \times 240 = 8.48 \text{ A}$

RMS value of current  $\Rightarrow I_V = I_0 / \sqrt{2} = 8.48 / \sqrt{2} = 5.99 \text{ A}$

b) Potential drop across C:-

$V_C(\text{rms}) = I_{\text{rms}}(\omega C) = 5.99[50 \times 80 \times 10^{-6}] = 1497.5 \text{ V}$

(or) Given -  $L = 4.0 \text{ H}$ ,  $C = 100 \mu\text{F} = 100 \times 10^{-6} \text{ F}$ ,  $R = 60 \Omega$ ,  $V_{\text{rms}} = 240 \text{ V}$

(i) for an L-C-R circuit to be in resonance ,  
angular frequency  $\omega = 1/LC = 1/4.0 \times 100 \times 10^{-6} = 50 \text{ rad/s}$

(ii) at resonant frequency , impedance = resistance ,  $Z = R$

Therefore current  $I_{\text{rms}} = V_{\text{rms}}/Z = V_{\text{rms}}/R$

$$\text{or } I_{\text{rms}} = 240/60 = 4\text{A}$$

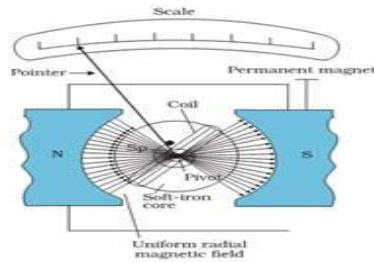
(iii)

$$I_{\text{rms}}\omega L$$

$$= 4 \times 15.81 \times 4.0 = 252.96\text{V}$$

### SECTION D

17)(a) When a current  $I$  is passed through a coil two equal and opposite forces act on the arms of a coil to form a couple which exerts a Torque on the coil.



$$\tau = NIAB \sin \theta \quad \text{If } \theta = 90^\circ (\sin 90^\circ = 1)$$

$\theta$  is the angle made by the normal to the plane of coil with B  
 $= NIAB \text{ ---(1)}$

This is called as deflecting torque

As the coil deflected the spring is twisted and a restoring torque per unit twist then the restoring torque for the deflecting  $\theta$  is given by

$$= k \theta \text{ ---(2)}$$

In equilibrium

Deflecting Torque = Restoring Torque

$$NIAB = \frac{K\theta}{NAB}$$

$$I = \frac{K\theta}{NAB}$$

$I = G \theta$  where  $G = \frac{K}{NAB}$  (galvanometer constant)

=>

Thus deflection of the coil is directly proportional to the current flowing in the coil.

$$\frac{R + R_G}{R + R_G}$$

(b) We know  $I_g =$

$$\Rightarrow I_g = \frac{V}{R_1 + R_G} \text{ ---(1)}$$

$$\frac{2}{R_2 + R_G} \text{ ----- (2)}$$

And  $I_g =$

Equating (1) & (2)

$$\frac{V}{R_1 + R_G} = \frac{2}{R_2 + R_G}$$

$$I_e R_1 + R_G = 2(R_2 + R_G)$$

$$R_G = -2R_2 + R_1$$

$$\frac{2V}{R + R_G}$$

For conversion  $I_g = \frac{2V}{R + R_G}$

$$\frac{2V}{R + R_G} = \frac{2V}{R + R_G}$$

$$\bar{I}_g = I_g \Rightarrow 2R_1 + 2R_G = R + R_G$$

$$R = 2R_1 + R_G$$

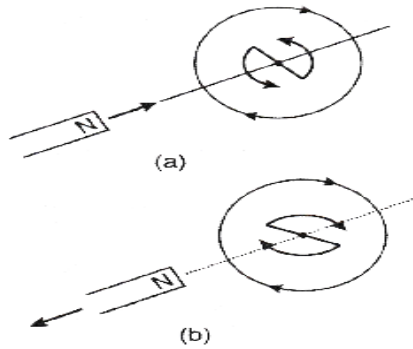
$$R = 2R_1 + R_1 - 2R_2$$

$$R = 3R_1 - 2R_2$$

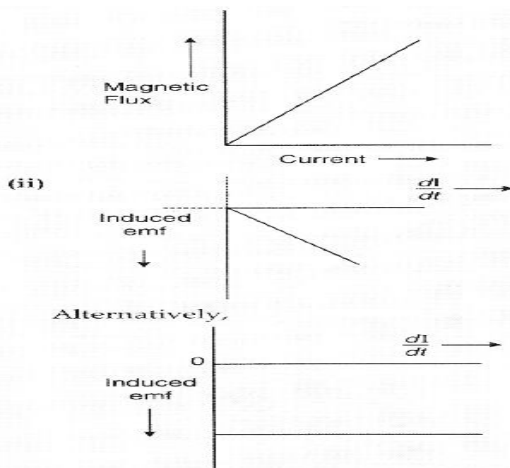
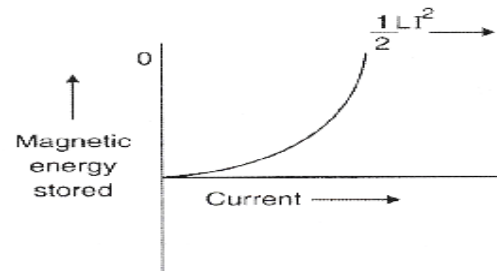
(or)



(i) When a bar magnet is brought close to the coil (fig a), the approaching North pole of the bar magnet increases the magnetic flux linked to it. This produces an induced emf which produces (or tends to produce, if the coil is open) an induced current in the anticlockwise direction. The face of the coil, facing the approaching magnet, then has the same polarity as that of the approaching pole of the magnet. The induced current, therefore, is seen to oppose the change of magnetic flux that produces it.



(ii)



### **SECTION E**

18) i) b) case (2) contradicts Gauss's law for magnetic fields

ii) a) zero      iii) b) zero

iv) c) There are abundant sources or sinks of the magnetic field inside a closed surface

v) d) equal to its magnetic flux through that surface.

(or)

19) i) b) The relative motion between the coil and magnet produces change in magnetic flux.

ii) c) Lenz's law

iii) d) energy

iv) a) variable

v) c) is repelled

## Unit - V Electromagnetic Waves (Chapter-8)

### FORMULA CHART

Wave velocity,  $c = v\lambda$

Energy of photon,  $E = h\nu = \frac{hc}{\lambda}$

Speed of e.m. wave in vacuum,  $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$

Speed of e.m. wave in a material medium,  $c = \frac{1}{\sqrt{\mu\epsilon}}$

For a wave of frequency  $\nu$ , wavelength  $\lambda$  propagating along  $x$ -direction, the equations for electric and magnetic fields are

$$E_y = E_0 \sin(kx - \omega t) = E_0 \sin \left[ 2\pi \left( \frac{x}{\lambda} - \frac{t}{T} \right) \right]$$

$$B_z = B_0 \sin(kx - \omega t) = B_0 \sin \left[ 2\pi \left( \frac{x}{\lambda} - \frac{t}{T} \right) \right]$$

Amplitude ratio of electric and magnetic fields,

$$\frac{E_0}{B_0} = c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

Propagation constant,  $k = \frac{2\pi}{\lambda} = \frac{\omega}{c}$

Average energy density of  $E$ -field,

$$u_E = \frac{1}{4} \epsilon_0 E_0^2 = \frac{1}{2} \epsilon_0 E_{\text{rms}}^2$$

Average energy density of B-field,

$$u_B = \frac{1}{4\mu_0} B_0^2 = \frac{1}{2\mu_0} B_{\text{rms}}^2$$

Average energy density of e.m. wave,

$$u_{\text{av}} = \frac{1}{2} \epsilon_0 E_{\text{rms}}^2 + \frac{1}{2\mu_0} B_{\text{rms}}^2 = \epsilon_0 E_{\text{rms}}^2 = \frac{B_{\text{rms}}^2}{\mu_0}$$

$$\text{or } u_{\text{av}} = \frac{1}{4} \epsilon_0 E_0^2 + \frac{1}{4\mu_0} B_0^2 = \frac{1}{2} \epsilon_0 E_0^2 = \frac{1}{2\mu_0} B_0^2$$

Momentum delivered by an e.m. wave.

$$p = \frac{U}{c}$$

$$\text{Intensity of a wave} = \frac{\text{Energy / time}}{\text{Area}} = \frac{\text{Power}}{\text{Area}}$$

$$\text{or } I = u_{\text{av}} c = \epsilon_0 E_{\text{rms}}^2 c$$

## NUMERICALS FOR PRACTICE WITH SOLUTIONS

1: Electromagnetic waves are produced by

- A static charge
- An accelerated charge
- A moving charge
- Charged particles

Q2: The direction in which electromagnetic waves propagate is the same as that of

- $\vec{E} \times \vec{B}$
- $\vec{B} \times \vec{E}$
- $\vec{E}$
- $\vec{B}$

Q3: In electromagnetic waves the phase difference between electric field vector and magnetic field vector is

- zero
- $\pi/2$
- $\pi$
- $\pi/3$

**Q4: In an electromagnetic wave in free space, the root mean square value of the electric field is 6 V/m. The peak value of the magnetic field is**

- a.  $2.83 \times 10^{-8}$  T
- b.  $1.51 \times 10^{-8}$  T
- c.  $0.80 \times 10^{-8}$  T
- d.  $4 \times 10^{-8}$  T

**Q5: Which of the following can be used to produce a propagating electromagnetic wave?**

- a. Charge moving at a constant speed
- b. Chargeless particle
- c. Stationary charge
- d. An accelerating charge

**Q6: To which part of the spectrum does EM waves belong if the energy of the wave is of the order of 15 KeV.**

- a. X rays
- b. Infrared rays
- c. Ultraviolet rays
- d. Gamma rays

**Q7: The ratio of the amplitude of the magnetic field to the amplitude of the electric field for electromagnetic wave propagation in a vacuum is equal to**

- a. Unity
- b. Speed of light in vacuum
- c. Reciprocal of the speed of light in vacuum
- d. The ratio of magnetic permeability to electrical susceptibility in a vacuum.

**Q8: Which properties amount the following is false about electromagnetic waves?**

- a. The energy in an electromagnetic wave is divided equally between electric and magnetic vectors.
- b. Both electric and magnetic field vectors are parallel to each other and perpendicular to the direction of propagation of the wave.
- c. These waves do not require any material medium for propagation
- d. Both electric and magnetic field vectors attain the maxima and minima at the same place and the same time

**Q9: The velocity of electromagnetic radiation in a medium of permittivity  $\epsilon_0$  and permeability  $\mu_0$  is given by**

- a.  $\sqrt{\epsilon_0/\mu_0}$
- b.  $\sqrt{\epsilon_0\mu_0}$
- c.  $1/\sqrt{\epsilon_0\mu_0}$
- d.  $\sqrt{\mu_0/\epsilon_0}$

**Q10: Which of the following rays are not electromagnetic waves?**

- a. Gamma rays
- b. Beta rays
- c. Heat rays
- d. X rays

**11.**

Angle between the electric component and magnetic component of an electromagnetic wave is \_\_\_\_.

1. The refractive index of the following transparent material medium with respect to air are given below:

2.

water  $\mu = 1.33$ ; glass  $\mu = 1.5$ ; kerosene  $\mu = 1.44$ ; diamond  $\mu = 2.42$

3.

$aw$   $ag$   $ak$   $ad$

4. Which of the following is the correct order of refractive indices when light travels from one medium to the other?

12

1.  $\mu_{aw} > \mu_{kg} > \mu_{wk} > \mu_{gd}$

2.  $\mu_{gd} > \mu_{aw} > \mu_{wk} > \mu_{kg}$

3.  $\mu_{aw} > \mu_{gd} > \mu_{kg} > \mu_{wk}$

4.  $\mu_{kg} > \mu_{wk} > \mu_{gd} > \mu_{aw}$

**Q.13. Which of the following has minimum wavelength?**

(c) Blue light (b)  $\gamma$ -rays (c) infrared rays (d) microwave

**Q.13. In electromagnetic wave if  $u_e$  and  $u_m$  are mean electric and magnetic energy densities respectively, then**

(a)  $u_e = u_m$

(b)  $u_e > u_m$

(c)  $u_e < u_m$

(d)  $u_e^2 = \frac{1}{2}u_m^2$

**Q.14. Which of the following is called heat radiation?**

(a) X-rays

(b)  $\gamma$ -rays

(c) Infrared radiation

(d) Microwave

**ANSWERS**

1)b 2)a 3)a 4)a 5)d 6)a 7)c 8)b 9)c 10)b 11)4 12)2 13)b 14)a  
15)c

**CASE STUDY QUESTIONS**

Maxwell showed that the speed of an electromagnetic wave depends on the permeability and permittivity of the medium through which it travels. The speed of an electromagnetic wave in free space is given by  $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$ .

The fact led Maxwell to predict that light is an electromagnetic wave. The emergence of the speed of light from purely electromagnetic considerations is the crowning achievement of Maxwell's electromagnetic theory. The speed of an electromagnetic wave in any medium of permeability  $\mu$  and permittivity  $\epsilon$  will be  $\frac{c}{\sqrt{K\mu_r}}$  where  $K$  is the dielectric constant of the medium and  $\mu_r$  is the relative permeability.

- (i) The dimensions of  $\frac{1}{2}\epsilon_0 E^2$  ( $\epsilon_0$  : permittivity of free space;  $E$  = electric field) is  
 (a)  $MLT^{-1}$                       (b)  $ML^2T^{-2}$                       (c)  $ML^{-1}T^{-2}$                       (d)  $ML^2T^{-1}$
- (ii) Let  $[\epsilon_0]$  denote the dimensional formula of the permittivity of the vacuum. If  $M$  = mass,  $L$  = length,  $T$  = time and  $A$  = electric current, then  
 (a)  $[\epsilon_0] = M^{-1}L^{-3}T^2A$                       (b)  $[\epsilon_0] = M^{-1}L^{-3}T^4A^2$   
 (c)  $[\epsilon_0] = MLT^{-2}A^{-2}$                       (d)  $[\epsilon_0] = ML^2T^{-1}$
- (iii) An electromagnetic wave of frequency 3 MHz passes from vacuum into a dielectric medium with permittivity  $\epsilon = 4$ . Then  
 (a) wavelength and frequency both remain unchanged  
 (b) wavelength is doubled and the frequency remains unchanged  
 (c) wavelength is doubled and the frequency becomes half  
 (d) wavelength is halved and the frequency remains unchanged.
- (iv) Which of the following are not electromagnetic waves?  
 (a) cosmic rays                      (b)  $\gamma$ -rays                      (c)  $\beta$ -rays                      (d) X-rays
- (v) The electromagnetic waves travel with  
 (a) the same speed in all media  
 (b) the speed of light  $c = 3 \times 10^8 \text{ m s}^{-1}$  in free space  
 (c) the speed of light  $c = 3 \times 10^8 \text{ m s}^{-1}$  in solid medium  
 (d) the speed of light  $c = 3 \times 10^8 \text{ m s}^{-1}$  in fluid medium.
- (c)  $E_x = 33 \cos \pi \times 10^{11} \left( t - \frac{x}{c} \right)$ ,  $B_x = 11 \times 10^{-7} \cos \pi \times 10^{11} \left( t - \frac{x}{c} \right)$   
 (d)  $E_y = 66 \cos 2\pi \times 10^{11} \left( t - \frac{x}{c} \right)$ ,  $B_z = 2.2 \times 10^{-7} \cos 2\pi \times 10^{11} \left( t - \frac{x}{c} \right)$
- (v) A plane electromagnetic wave travels in free space along  $x$ -axis. At a particular point in space, the electric field along  $y$ -axis is  $9.3 \text{ V m}^{-1}$ . The magnetic induction ( $B$ ) along  $z$ -axis is  
 (a)  $3.1 \times 10^{-8} \text{ T}$                       (b)  $3 \times 10^{-5} \text{ T}$                       (c)  $3 \times 10^{-6} \text{ T}$                       (d)  $9.3 \times 10^{-6} \text{ T}$

## ANSWERS

1)

$$(i) (c): \frac{1}{2} \epsilon_0 E^2 = \text{energy density} = \frac{\text{Energy}}{\text{Volume}}$$
$$\therefore \left[ \frac{1}{2} \epsilon_0 E^2 \right] = \frac{ML^2T^{-2}}{L^3} = [ML^{-1}T^{-2}]$$

$$(ii) (b): \text{As } \epsilon_0 = \frac{q_1 q_2}{4\pi F R^2} \text{ (from Coulomb's law)}$$

$$\epsilon_0 = \frac{C^2}{Nm^2} \frac{[AT]^2}{MLT^{-2}L^2} = M^{-1}L^{-3}T^4A^2$$

(iii) (d): The frequency of the electromagnetic wave remains same when it passes from one medium to another.

$$\text{Refractive index of the medium, } n = \sqrt{\frac{\epsilon}{\epsilon_0}} = \sqrt{\frac{4}{1}} = 2$$

Wavelength of the electromagnetic wave in the medium,

$$\lambda_{\text{med}} = \frac{\lambda}{n} = \frac{\lambda}{2}$$

(iv) (b):  $\beta$ -rays consists of electrons which are not electromagnetic in nature.

(v) (b): The velocity of electromagnetic waves in free space (vacuum) is equal to velocity of light in vacuum (i.e.,  $3 \times 10^8 \text{ m s}^{-1}$ ).

2)

(i) (b): Infrared rays can be converted into electric energy as in solar cell.

(ii) (d): Radiowaves have longest wavelength.

(iii) (c): Cathode rays are invisible fast moving streams of electrons emitted by the cathode of a discharge tube which is maintained at a pressure of about 0.01 mm of mercury.

(iv) (c):  $\gamma$ -rays have minimum wavelength.

(v) (a):  $\lambda_{\text{micro}} > \lambda_{\text{infra}} > \lambda_{\text{ultra}} > \lambda_{\text{gamma}}$



3)

(i) (d): Given :  $\vec{B} = B_0 \sin(kx + \omega t) \hat{j}$  T

The relation between electric and magnetic field is,

$$c = \frac{E}{B} \text{ or } E = cB$$

The electric field component is perpendicular to the direction of propagation and the direction of magnetic field. Therefore, the electric field component along z-axis is obtained as  $\vec{E} = cB_0 \sin(kx + \omega t) \hat{k}$  V/m

(ii) (c) :  $\frac{dE}{dz} = -\frac{dB}{dt}$

$$\frac{dE}{dz} = -2E_0 k \sin kz \cos \omega t = -\frac{dB}{dt}$$

$$dB = +2E_0 k \sin kz \cos \omega t dt$$

$$B = +2E_0 k \sin kz \int \cos \omega t dt = +2E_0 \frac{k}{\omega} \sin kz \sin \omega t$$

$$\frac{E_0}{B_0} = \frac{\omega}{k} = c$$

$$B = \frac{2E_0}{c} \sin kz \sin \omega t \quad \therefore \quad \vec{B} = \frac{2E_0}{c} \sin kz \sin \omega t \hat{j}$$

E is along y-direction and the wave propagates along x-axis.

$\therefore$  B should be in a direction perpendicular to both x- and y-axis.

(iii) (d): Here,  $E = 6.3 \hat{j}$ ;  $c = 3 \times 10^8$  m/s

The magnitude of B is

$$B_z = \frac{E}{c} = \frac{6.3}{3 \times 10^8} = 2.1 \times 10^{-8} \text{ T} = 0.021 \mu\text{T}$$

(iv) (d): Here :  $E_0 = 66 \text{ V m}^{-1}$ ,  $E_y = 66 \cos \omega(t - \frac{x}{c})$ ,

$$\lambda = 3 \text{ mm} = 3 \times 10^{-3} \text{ m}, k = \frac{2\pi}{\lambda}$$

$$\frac{\omega}{k} = c \Rightarrow \omega = ck = 3 \times 10^8 \times \frac{2\pi}{3 \times 10^{-3}}$$

$$\text{or } \omega = 2\pi \times 10^{11}$$

$$\therefore E_y = 66 \cos 2\pi \times 10^{11} (t - \frac{x}{c})$$

$$B_z = \frac{E_y}{c} = \left( \frac{66}{3 \times 10^8} \right) \cos 2\pi \times 10^{11} \left( t - \frac{x}{c} \right)$$

$$= 2.2 \times 10^{-7} \cos 2\pi \times 10^{11} (t - \frac{x}{c})$$

(v) (a): At a particular point,  $E = 9.3 \text{ V m}^{-1}$

$$\therefore \text{Magnetic field at the same point} = \frac{9.3}{3 \times 10^8} = 3.1 \times 10^{-8} \text{ T}$$

1. A radio can tune into any station in 7.5 MHz to 12 MHz band. What is the corresponding wavelength band ?

**Ans.** A radio can turn to minimum frequency,

$$\nu_1 = 7.5 \text{ MHz} = 7.5 \times 10^6 \text{ Hz}$$

Maximum frequency,

$$\nu_2 = 12 \text{ MHz} = 12 \times 10^6 \text{ Hz}$$

Speed of light,  $c = 3 \times 10^8 \text{ m/s}$

Corresponding wavelength for  $\nu$  is

$$\lambda_1 = \frac{c}{\nu_1} = \frac{3 \times 10^8}{7.5 \times 10^6} = 40 \text{ m}$$

Corresponding wavelength for  $\nu_2$  is

$$\lambda_2 = \frac{c}{\nu_2} = \frac{3 \times 10^8}{12 \times 10^6} = 25 \text{ m}$$

Hence, the wavelength band of the radio is 40 m to 25 m.

2. The amplitude of the magnetic field part of a harmonic electromagnetic wave in vacuum is  $B_0 = 510 \text{ nT}$ . What is the amplitude of the electric field part of the wave ?

**Ans.** Amplitude of magnetic field of an electromagnetic wave in a vacuum,  $B_0 = 510 \text{ nT} = 510 \times 10^{-9} \text{ T}$

Speed of light in vacuum,  $c = 3 \times 10^8 \text{ m/s}$

Amplitude of electric field of electromagnetic wave is,

$$\begin{aligned} E_0 &= c B_0 \\ &= 3 \times 10^8 \times 510 \times 10^{-9} \\ &= 153 \text{ N/C} \end{aligned}$$

Hence, the electric field part of wave is 153 N/C

An EM wave radiates outwards from a dipole antennae, with  $E_0$  as the amplitude of its electric field vector. The electric field  $E_0$  which transports significant energy from the sources falls off as

(a)  $\frac{1}{r^3}$

(b)  $\frac{1}{r^2}$

(c)  $\frac{1}{r}$

(d) remains constant

**Ans.** (c)  $\frac{1}{r}$

Let an electromagnetic wave propagate along the x direction, the magnetic field oscillates at a frequency of  $10^{10}$  Hz and has an amplitude of  $10^{-5}$  T, acting along the y - direction. Then, compute the wavelength of the wave. Also write down the expression for electric field in this case.

**Given data**

$$\gamma = 10^{10} \text{ Hz (x - axis)}$$

$$B_0 = 10^{-5} \text{ T (Y - axis)}$$

$$\lambda = ?$$

$$E = ?$$

**Solution**

$$C = \gamma \lambda$$

$$C = \frac{c}{\gamma} = \frac{3 \times 10^8}{10^{10}} = 3 \times 10^{-2} \text{ m}$$

$$\text{ii) } E = E_0 \sin (k x - \omega t)$$

$$C = \frac{E_0}{B_0}$$

$$E_0 = C \times B_0 = 3 \times 10^8 \times 10^{-5} = 3 \times 10^3$$

$$K = \frac{\omega}{c} = \frac{2\pi\gamma}{c} = \frac{2 \times 3.14 \times 10^{10}}{3 \times 10^8}$$

$$= 2.09 \times 10^2$$

$$\omega = 2\pi\gamma = 2 \times 3.14 \times 10^{10} = 6.28 \times 10^{10}$$

$$E = 3 \times 10^3 \sin ( 2.09 \times 10^2 x - 6.28 \times 10^{10} t ) \text{ NC}^{-1}$$

$$\text{Answer: } \lambda = 3 \times 10^{-18} \text{ m and } \vec{E}(x, t) = 3 \times 10^3 \sin(2.09 \times 10^{18} x - 6.28 \times 10^{10} t) \hat{i} \text{ NC}^{-1}$$

- If the relative permeability and relative permittivity of the medium is 1.0 and 2.25, respectively. Find the speed of the electromagnetic wave in this medium.

**Given data:**

$$\mu_r = 1$$

$$\epsilon_r = 2.25$$

$$v = ?$$

**Solution:**

$$v = \frac{c}{\sqrt{\mu_r \epsilon_r}} = \frac{3 \times 10^8}{\sqrt{1 \times 2.25}} = \frac{3 \times 10^8}{1.5}$$

$$v = 2 \times 10^8 \text{ ms}^{-1}$$

$$\text{Answer: } v = 2 \text{ ms}^{-1}$$

## ASSIGNMENT 1

- 1) In an electromagnetic wave in free space, the root mean square value of the electric field is 6 V/m. The peak value of the magnetic field is  
a)  $2.83 \times 10^{-8}$  T   b)  $1.51 \times 10^{-8}$  T   c)  $0.80 \times 10^{-8}$  T   d)  $4 \times 10^{-8}$  T
- 2) The oscillating magnetic field in a plane electromagnetic wave is given as  $B_y = (8 \times 10^{-6}) \sin [2 \times 10^{11}t + 300\pi x]$  T, wavelength of the em wave is  
a) 0.80 cm   b)  $1 \times 10^3$  m   c)  $2 \times 10^{-2}$  cm   d) 0.67 cm
- 3) The velocity of all radio waves in free space is  $3 \times 10^8$  m/s. The frequency of a radio wave of wavelength 150m is  
a) 20 kHz   b) 2 kHz   c) 2 MHz   d) 1 MHz
- 4) Electromagnetic waves are produced by  
a) A static charge   b) An accelerated charge   c) A moving charge   d) Charged particles
- 5) Which of the following rays are not electromagnetic waves?  
a) Gamma rays   b) Beta rays   c) Heat rays   d) X rays
- 6) In electromagnetic waves the phase difference between electric and magnetic field vectors are  
a) zero   b)  $\pi/4$    c)  $\pi/2$    d)  $\pi$
- 7) Which of the following has minimum wavelength?  
a) Blue light   b)  $\gamma$ -rays   c) infrared rays   d) microwave
- 8) The correct option, if speeds of gamma rays, X-rays and microwave are  $V_g$ ,  $V_x$  and  $V_m$  respectively will be.  
a)  $V_g > V_x > V_m$    b)  $V_g < V_x < V_m$    c)  $V_g > V_x > V_m$    d)  $V_g = V_x = V_m$
- 9) The quantity  $\sqrt{\mu_0 \epsilon_0}$  represents  
a) speed of sound   b) speed of light in vacuum  
c) speed of e.m. waves   d) inverse of speed of light in vacuum
- 10) Which of the following is called heat radiation?  
a) X-rays   b)  $\gamma$ -rays   c) Infrared radiation   d) Microwave
- 11) From Maxwell's hypothesis, a charging electric field gives rise to  
a) an electric field.   b) an induced emf.   c) a magnetic field.   d) a magnetic dipole.
- 12) The ultra high frequency band of radio waves in electromagnetic wave is used as in  
a) television waves   b) cellular phone communication  
c) commercial FM radio   d) both (a) and (c)
- 13) 10 cm is a wavelength corresponding to the spectrum of

- a) infrared rays b) ultraviolet rays c) microwaves d) X-rays
- 14) The condition under which a microwave over heats up a food item containing water molecules most efficiently is
- a) The frequency of the microwaves must match the resonant frequency of the water molecules.
- b) The frequency of the microwaves has no relation with natural frequency of the water molecules.
- c) Microwaves are heat waves, so always produce heating.
- d) Infrared waves produce heating in a microwave oven.
- 15) Waves in decreasing order of their wavelength are
- a) X-rays, infrared rays, visible rays, radio waves
- b) radio waves, visible rays, infrared rays, X-rays.
- c) radio waves, infrared rays, visible rays, X-rays.
- d) radio waves, ultraviolet rays, visible rays, X-rays.
- 16) Maxwell in his famous equations of electromagnetism introduced the concept of
- a) ac current b) displacement current c) impedance d) impedance
- 17) Which of the following statement is false for the properties of electromagnetic waves?
- a) Both electric and magnetic field vectors attain the maxima and minima at the same place and same time.
- b) The energy in electromagnetic waves is divided equally between electric and magnetic field vectors.
- c) Both electric and magnetic field vectors are parallel to each other and perpendicular to the direction of propagation of wave.
- d) These waves do not require any material medium for propagation.
- 18) The waves used by artificial satellites for communication is
- a) microwaves b) infrared waves c) radio waves d) X-rays
- 19) Which of the following electromagnetic waves is used in medicine to destroy cancer cells?
- a) IR-rays b) Visible rays c) Gamma rays d) Ultraviolet rays
- 20) In electromagnetic spectrum, the frequencies  $\gamma$ -rays, X-rays and ultraviolet rays are denoted by  $n_1$ ,  $n_2$  and  $n_3$  respectively then
- a)  $n_1 > n_2 > n_3$  b)  $n_1 < n_2 < n_3$  c)  $n_1 > n_2 < n_3$  d)  $n_1 < n_2 > n_3$
- 21) Microwaves are electromagnetic waves with frequency in the range of
- a) Micro hertz b) Giga hertz c) Mega hertz d) Hertz
- 22) Which of the following laws was modified by Maxwell by introducing the displacement current?
- a) Gauss's law b) Ampere's law c) Biot-Savart's law d) None of these
- 23) Displacement current is due to:

- a) the flow of electrons    b) the Varying electric field  
 c) the ionization of atmosphere    d) the flow of protons

**(ASSERTION AND REASON)**

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.

24)**Assertion :** The velocity of electromagnetic waves depends on electric and magnetic properties of the medium.

**Reason :** Velocity of electromagnetic waves in free space is constant.

25)**Assertion :** The basic difference between various types of electromagnetic waves lies in their wavelength or frequencies.

**Reason :** Electromagnetic waves travel through vacuum with the same speed.

**ANSWER KEY**

- 1)a)  $2.83 \times 10^{-8}$  T  
 2)d) 0.67 cm  
 3)c) 2 MHz  
 4) b)An accelerated charge  
 5) b)Beta rays  
 6)a) zero  
 7)b)  $\gamma$ -rays  
 8)d)  $V_g = V_x = V_m$   
 9)d) inverse of speed of light in vacuum  
 10)c) Infrared radiation  
 11)c) a magnetic field.  
 12)b) cellular phone communication  
 13)c) microwaves  
 14)a)The frequency of the microwaves must match the resonant frequency of the water molecules.  
 15)c)radio waves, infrared rays, visible rays, X-rays.  
 16)b) displacement current

17)c) Both electric and magnetic field vectors are parallel to each other and perpendicular to the direction of propagation of wave

18)a) microwaves

19)c) Gamma rays

20)a)  $n_1 > n_2 > n_3$

21)b) Giga hertz

22)b) Ampere's law

23)b) the Varying electric field

24)(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

25)(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

## **ASSIGNMENT 2** (Marks: 25)

### **General instructions:**

- 1. There are 9 questions in all. (All questions are compulsory.)**
- 2. Section A: Question no. 1 to 4 (2 mark)**
- 3. Section B: Question no. 5 to 8 (3 mark)**
- 4. Section C: Question no. 9 (5 mark)**

### **SECTION A** (2 mark)

1) **Electric field in a plane electromagnetic wave is given by**

$$E_z = 60 \sin \left( \frac{10^3 x}{2} + (10^{11}) \frac{3t}{2} \right) V / m.$$

(a) **Write an expression for the magnetic field**

(b) **What is the magnitude of wavelength and frequency of the wave?**

2) **A plane electromagnetic wave travels in vacuum along z-direction. What can you say about the directions of its electric and magnetic field vectors? If the frequency of the wave is 30 MHz, what is its wavelength?**

3) **The amplitude of the magnetic field part of a harmonic electromagnetic wave in vacuum is  $B_0 = 510$  nT. What is the amplitude of the electric field part of the wave?**

4)(i) **An electromagnetic wave is travelling in a medium, with a velocity  $v = v_i$ . Draw a sketch showing the propagation of the electromagnetic wave, indicating the direction of the oscillating electric and magnetic fields.**

(ii) **How are the magnitudes of the electric and magnetic fields related to velocity of the electromagnetic wave?**

### **SECTION B** (3 mark)

5) A capacitor, made of two parallel plates each of plate area A and separation d, is being charged by an external ac source. Show that the displacement current inside the capacitor is the same as the current charging the capacitor.

6) Find the wavelength of electromagnetic waves of frequency  $6 \times 10^{12} \text{ Hz}$  in free space. Give two applications of the type of wave.

7) A plane monochromatic wave lies in the visible region. It is represented by the sinusoidal variation with time by the following components of electric field

$$E_x = 0, E_y = 4 \sin \left[ \frac{2\pi}{\lambda}(x - vt) \right], E_z = 0$$

Where  $v = 5 \times 10^{14} \text{ Hz}$  And  $\lambda$  is the wavelength of light.

(a) What is the direction of propagation of the wave?

(b) What is its amplitude?

(c) Compute the component of magnetic field?

8) Write the characteristics of em waves? Write the expression for velocity of electromagnetic waves in terms of permittivity and permeability of the medium?

**SECTION C (5 mark)**

9) Suppose that the electric field amplitude of an electromagnetic wave is  $E_0 = 120$

N/C and that its frequency is  $\nu = 50.0 \text{ MHz}$ . (a) Determine,  $B_0, \omega, k,$  and  $\lambda$ . (b) Find expressions for E and B.

**ELECTROMAGNETIC WAVES (DESCRIPTIVE QUESTIONS) – ANSWER KEY  
SECTION A**

$$c = \frac{E_0}{B_0}$$

1) (a)

$$B_0 = \frac{E_0}{c} = \frac{60}{3 \times 10^8}$$

$$B_0 = 2 \times 10^{-7} \text{ T}$$

Since magnetic field and electric field are  $\perp$  to each other

$$B_y = 2 \times 10^{-7} \text{ T} \sin \left( \frac{10^3}{2} x + (10^{11}) \frac{3t}{2} \right) \text{ ---(1)}$$

(b) Compare e.g. (1) with standard equation

$$B_y = B_0 \sin 2\pi \left( \frac{x}{\lambda} + \frac{t}{T} \right)$$

$$\lambda = 4\pi \times 10^{-3} \text{ m}$$

$$\text{Also } 2\pi \frac{1}{T} = (10)^{11} \frac{3}{2} \quad \frac{1}{T} = \nu = \frac{3 \times 10^{11}}{2 \times 2\pi}$$



$$\nu = \frac{3}{4\pi} \times 10^{11} \text{ Hz}$$

2) The electromagnetic wave travels in a vacuum along the z-direction. The electric field ( $E$ ) and the magnetic field ( $H$ ) are in the  $x$ - $y$  plane. They are mutually perpendicular.

Frequency of the wave,  $\nu = 30 \text{ MHz} = 30 \times 10^6 \text{ s}^{-1}$

Speed of light in a vacuum,  $c = 3 \times 10^8 \text{ m/s}$

Wavelength of a wave is given as:

$$\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{30 \times 10^6} = 10 \text{ m}$$

3) Amplitude of magnetic field of an electromagnetic wave in a vacuum,

$$B_0 = 510 \text{ nT} = 510 \times 10^{-9} \text{ T}$$

Speed of light in a vacuum,  $c = 3 \times 10^8 \text{ m/s}$

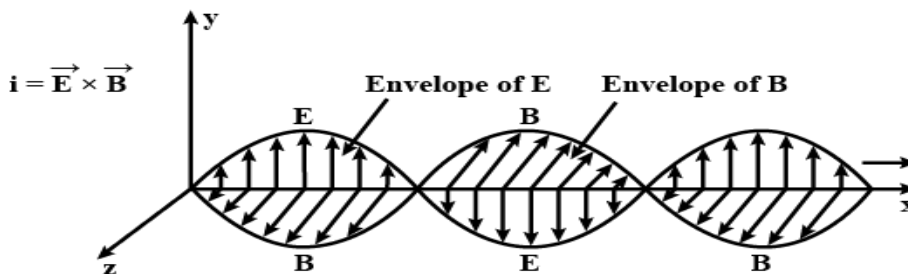
Amplitude of electric field of the electromagnetic wave is given by the relation,

$$E = c B_0$$

$$= 3 \times 10^8 \times 510 \times 10^{-9} = 153 \text{ N/C}$$

Therefore, the electric field part of the wave is 153 N/C.

4)(i)



(ii) Speed of electromagnetic wave is  $V = B_0 E_0$

Where  $E_0$  = Magnitude of electric field       $B_0$  = Magnitude of magnetic field

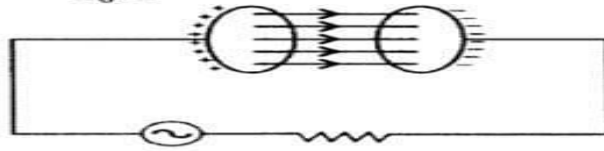
### SECTION B

5) The displacement current produces due to varying electric field is given by

$$I_D = E D (d\phi/dt) \quad I_D = E D (d\phi/dt)$$

If  $q$  is the instantaneous charge,  $E$  is the electric field between the plates of capacitor at a specific period and  $A$  is the area of the plates, then,

$$E = \frac{q}{\epsilon_0 A}$$



$\Phi$  (flux between the capacitors)

$$= \left( \frac{q}{\epsilon_0 A} \right) \times A = \frac{q}{\epsilon_0}$$

$$I_D = \epsilon_0 \frac{d}{dt} \left( \frac{q}{\epsilon_0} \right) = \frac{dq}{dt} \Rightarrow I_D = \frac{dq}{dt} \quad \dots(i)$$

Conduction current  $I_C = \frac{dq}{dt} \quad \dots(ii)$

From (i) and (ii)  $\boxed{I_C = I_D}$

6)  $\nu = 6 \times 10^{12} \text{ Hz}$

Using  $\lambda = \frac{c}{\nu}$

$$\lambda = \frac{3 \times 10^8}{6 \times 10^{12}}$$

$$\lambda = 5 \times 10^{-5} \text{ m}$$

These are infra-red radiations

**Applications**

- (1) It keeps the earth warm.
- (2) Infra-red lamps are used to treat muscular strains.
- 7) (a) The direction of propagation of wave is along + x – axis.
- (b) Amplitude = 4 units
- (c) Component of magnetic of field

$$B_z = \frac{E_0}{C} = \frac{4}{3 \times 10^8}$$

$$B_z = 1.33 \times 10^{-8} \text{ Tesla}$$

8) Characteristics of em waves

- (1) It travels in free space with speed of light  $c = 3 \times 10^8 \text{ m/s}$ .
- (2) Electromagnetic waves are transverse in nature.

Velocity of em waves in vacuum C

$$= \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

**SECTION C**

9) Electric field amplitude,  $E_0 = 120 \text{ N/C}$

Frequency of source,  $\nu = 50.0 \text{ MHz} = 50 \times 10^6 \text{ Hz}$

Speed of light,  $c = 3 \times 10^8$  m/s

(a) Magnitude of magnetic field strength is given as:

$$\begin{aligned} B_0 &= \frac{E_0}{c} \\ &= \frac{120}{3 \times 10^8} \\ &= 4 \times 10^{-7} T = 400 \text{ nT} \end{aligned}$$

Angular frequency of source is given as:

$$\begin{aligned} \omega &= 2\pi\nu = 2\pi \times 50 \times 10^6 \\ &= 3.14 \times 10^8 \text{ rad/s} \end{aligned}$$

Propagation constant is given as:

$$\begin{aligned} k &= \frac{\omega}{c} \\ &= \frac{3.14 \times 10^8}{3 \times 10^8} = 1.05 \text{ rad/m} \end{aligned}$$

Wavelength of wave is given as:

$$\begin{aligned} \lambda &= \frac{c}{\nu} \\ &= \frac{3 \times 10^8}{50 \times 10^6} = 6.0 \text{ m} \end{aligned}$$

(b) Suppose the wave is propagating in the positive  $x$  direction. Then, the electric field vector will be in the positive  $y$  direction and the magnetic field vector will be in the positive  $z$  direction. This is because all three vectors are mutually perpendicular.

Equation of electric field vector is given as:

$$\begin{aligned} \vec{E} &= E_0 \sin(kx - \omega t) \hat{j} \\ &= 120 \sin[1.05x - 3.14 \times 10^8 t] \hat{j} \end{aligned}$$

And, magnetic field vector is given as:

$$\begin{aligned} \vec{B} &= B_0 \sin(kx - \omega t) \hat{k} \\ \vec{B} &= (4 \times 10^{-7}) \sin[1.05x - 3.14 \times 10^8 t] \hat{k} \end{aligned}$$

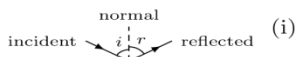
## Unit - VI Optics (Chapters 9&10)

# FORMULA CHART

## 1 Reflection of Light

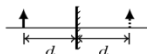
### Laws of reflection:

Incident ray, reflected ray, and normal lie in the same plane (ii)  $\angle i = \angle r$

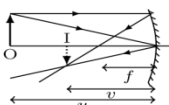


### Plane mirror:

(i) the image and the object are equidistant from mirror (ii) virtual image of real object



### Spherical Mirror:

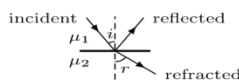


1. Focal length  $f = R/2$
2. Mirror equation:  $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$
3. Magnification:  $m = -\frac{v}{u}$

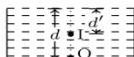
## 2 Refraction of Light

**Refractive index:**  $\mu = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}} = \frac{c}{v}$

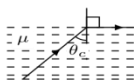
**Snell's Law:**  $\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$



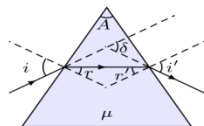
**Apparent depth:**  $\mu = \frac{\text{real depth}}{\text{apparent depth}} = \frac{d}{d'}$



**Critical angle:**  $\theta_c = \sin^{-1} \frac{1}{\mu}$

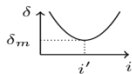


### Deviation by a prism:

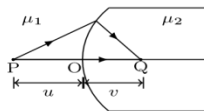


$\delta = i + e - A$ , general result  
 $\mu = \frac{\sin \frac{A + \delta_m}{2}}{\sin \frac{A}{2}}$ ,  $i = e'$  for minimum deviation

$\delta_m = (\mu - 1)A$ , for small  $A$



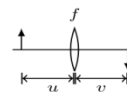
### Refraction at spherical surface:



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

**Lens maker's formula:**  $\frac{1}{f} = (\mu - 1) \left[ \frac{1}{R_1} - \frac{1}{R_2} \right]$

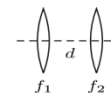
**Lens formula:**  $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ ,  $m = \frac{v}{u}$



**Power of the lens:**  $P = \frac{1}{f}$ ,  $P$  in diopter if  $f$  in metre.

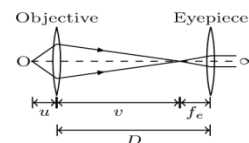
**Two thin lenses separated by distance  $d$ :**

$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$



## 3 Optical Instruments

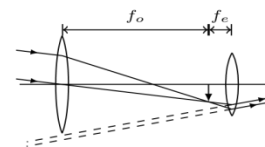
**Simple microscope:**  $m = D/f$  in normal adjustment.



**Compound microscope:**

1. Magnification in normal adjustment:  $m = \frac{v}{u} \frac{D}{f_e}$
2. Resolving power:  $R = \frac{1}{\Delta d} = \frac{2\mu \sin \theta}{\lambda}$

**Astronomical telescope:**



1. In normal adjustment:  $m = -\frac{f_o}{f_e}$ ,  $L = f_o + f_e$
2. Resolving power:  $R = \frac{1}{\Delta \theta} = \frac{1}{1.22 \lambda}$

## 4 Dispersion

**Cauchy's equation:**  $\mu = \mu_0 + \frac{A}{\lambda^2}$ ,  $A > 0$

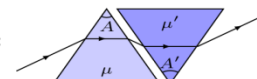
**Dispersion by prism with small  $A$  and  $i$ :**

1. Mean deviation:  $\delta_y = (\mu_y - 1)A$
2. Angular dispersion:  $\theta = (\mu_v - \mu_r)A$

**Dispersive power:**  $\omega = \frac{\mu_v - \mu_r}{\mu_y - 1} \approx \frac{\theta}{\delta_y}$  (if  $A$  and  $i$  small)

**Dispersion without deviation:**

$(\mu_y - 1)A + (\mu'_y - 1)A' = 0$

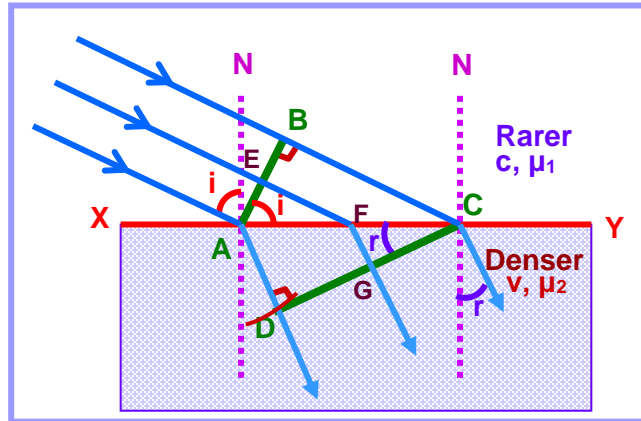


**Deviation without dispersion:**

$(\mu_v - \mu_r)A = (\mu'_v - \mu'_r)A'$

• **Laws of Refraction at a Plane Surface (On Huygens' Principle):**

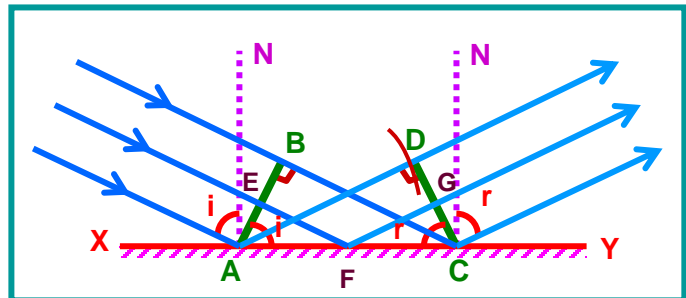
$$\frac{\sin i}{\sin r} = \frac{c}{v} = \mu$$



AB – Incident wavefront  
 CD – Refracted wavefront  
 XY – Refracting surface

• **Laws of Reflection at a Plane Surface (On Huygens' Principle)**

$$\sin i = \sin r \quad \text{or} \quad i = r$$



AB – Incident wavefront  
 CD – Reflected wavefront  
 XY – Reflecting surface

**Young's Double Slit Experiment**

Let  $S_1$  and  $S_2$  be coherent sources at separation  $d$  and  $D$  be the distance of screen from sources, then path difference between waves reaching at  $P$  can be shown as

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

For maxima  $\Delta = n\lambda$

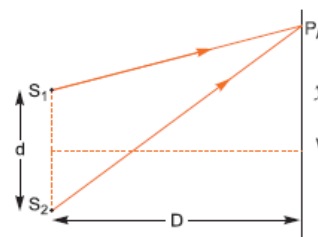
$$\therefore \text{Position of } n\text{th maxima } y_n = \frac{nD\lambda}{d}$$

$$\therefore \text{Position of } n\text{th minima } y_n = \left(n - \frac{1}{2}\right) \frac{D\lambda}{d}$$

**Fringe width:** Fringe width is defined as the separation between two consecutive maxima or minima.

$$\text{Linear fringe width, } \beta = y_{-n+1} - y_n = \frac{D\lambda}{d}$$

$$\text{Angular fringe width, } \beta_\theta = \frac{\beta}{D} = \frac{\lambda}{d}$$



## Diffraction of Light

The bending of light from the corner of small obstacles or apertures is called diffraction of light.

### Diffraction due to a Single Slit:

When a parallel beam of light is incident normally on a single slit, the beam is diffracted from the slit and the diffraction pattern consists of a very intense central maximum, and secondary maxima and minima on either side alternately.

If  $a$  is width of slit and  $\theta$  the angle of diffraction, then the directions of maxima are given by

$$a \sin \theta = \left(n + \frac{1}{2}\right)\lambda \quad n = 1, 2, 3, \dots$$

The position of  $n$ th minima are given by

$$a \sin \theta = n\lambda,$$

where  $n = \pm 1, \pm 2, \pm 3, \dots$  for various minima on either side of principal maxima.

### Width of Central Maximum:

The width of central maximum is the separation between the first minima on either side.

The condition of minima is

$$a \sin \theta = \pm n\lambda \quad (n = 1, 2, 3, \dots).$$

The angular position of the first minimum ( $n=1$ ) on either side of central maximum is given by

$$a \sin \theta = \pm \lambda$$

$$\Rightarrow \theta = \pm \sin^{-1}\left(\frac{\lambda}{a}\right)$$

## NUMERICALS FOR PRACTICE WITH SOLUTIONS

1

In Young's double slit experiment two coherent sources of intensity ratio of 64 : 1, produce interference fringes. Calculate the ratio of maximum and minimum intensities.

$$\text{Data : } I_1 : I_2 :: 64 : 1 \quad \frac{I_{\max}}{I_{\min}} = ?$$

$$\text{Solution : } \frac{I_1}{I_2} = \frac{a_1^2}{a_2^2} = \frac{64}{1}$$

$$\therefore \frac{a_1}{a_2} = \frac{8}{1}; \quad a_1 = 8a_2$$

$$\frac{I_{\max}}{I_{\min}} = \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2} = \frac{(8a_2 + a_2)^2}{(8a_2 - a_2)^2}$$

$$= \frac{(9a_2)^2}{(7a_2)^2} = \frac{81}{49}$$

$$I_{\max} : I_{\min} :: 81 : 49$$

2

In Young's experiment, the width of the fringes obtained with light of wavelength  $6000 \text{ \AA}$  is  $2 \text{ mm}$ . Calculate the fringe width if the entire apparatus is immersed in a liquid of refractive index  $1.33$ .

**Data :**  $\lambda = 6000 \text{ \AA} = 6 \times 10^{-7} \text{ m}$ ;  $\beta = 2 \text{ mm} = 2 \times 10^{-3} \text{ m}$   
 $\mu = 1.33$ ;  $\beta' = ?$

**Solution :**  $\beta' = \frac{D\lambda'}{d} = \frac{\lambda D}{\mu d} = \frac{\beta}{\mu}$   $\left[ \because \mu = \frac{\lambda}{\lambda'} \right]$

$$\therefore \beta' = \frac{2 \times 10^{-3}}{1.33} = 1.5 \times 10^{-3} \text{ m (or) } 1.5 \text{ mm}$$

3

Two slits  $0.3 \text{ mm}$  apart are illuminated by light of wavelength  $4500 \text{ \AA}$ . The screen is placed at  $1 \text{ m}$  distance from the slits. Find the separation between the second bright fringe on both sides of the central maximum.

**Data :**  $d = 0.3 \text{ mm} = 0.3 \times 10^{-3} \text{ m}$ ;  $\lambda = 4500 \text{ \AA} = 4.5 \times 10^{-7} \text{ m}$ ,  
 $D = 1 \text{ m}$ ;  $n = 2$ ;  $2x = ?$

**Solution :**  $2x = 2 \frac{D}{d} n\lambda$

$$= \frac{2 \times 1 \times 2 \times 4.5 \times 10^{-7}}{0.3 \times 10^{-3}}$$

$$\therefore 2x = 6 \times 10^{-3} \text{ m (or) } 6 \text{ mm}$$

4. Two harmonic waves of monochromatic light

$$y_1 = a \cos \omega t \text{ and } y_2 = a \cos(\omega t + \phi)$$

Are superimposed on each other. Show that maximum intensity in interference pattern is four times the intensity due to each slit. Hence write the conditions for constructive and destructive Interference in terms of the phase angle  $\phi$

The resultant displacement will be given by

$$\begin{aligned} y &= y_1 + y_2 \\ &= a \cos \omega t + a \cos(\omega t + \phi) \\ &= a[\cos \omega t + \cos(\omega t + \phi)] \\ &= 2a \cos(\phi/2) \cos(\omega t + \phi/2) \end{aligned}$$

The amplitude of the resultant displacement is  $2a \cos(\phi/2)$

The intensity of light is directly proportional to the square of amplitude of the wave. The resultant intensity will be given by

$$I = 4a^2 \cos^2 \frac{\phi}{2}$$

$\therefore$  Intensity  $= 4I_0 \cos^2 \left( \frac{\phi}{2} \right)$ , where  $I_0 = a^2$  is the intensity of each harmonic wave

At the maxima,  $\phi = \pm 2n\pi$

$$\therefore \cos^2 \frac{\phi}{2} = 1$$

At the maxima,  $I = 4I_0 = 4 \times$  intensity due to one slit

$$I = 4I_0 \cos^2 \left( \frac{\phi}{2} \right)$$

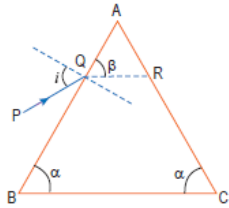
For constructive interference,  $I$  is maximum.

It is possible when  $\cos^2 \left( \frac{\phi}{2} \right) = 1$ ;  $\frac{\phi}{2} = n\pi$ ;  $\phi = 2n\pi$

For destructive interference,  $I$  is minimum, i.e.,  $I = 0$

It is possible when  $\cos^2 \left( \frac{\phi}{2} \right) = 0$ ;  $\frac{\phi}{2} = \frac{(2n-1)\pi}{2}$ ;  $\phi = (2n \pm 1) \frac{\pi}{2}$

5. A ray of light incident on the face  $AB$  of an isosceles triangular prism makes an angle of incidence ( $i$ ) and deviates by angle  $b$  as shown in the figure. Show that in the position of minimum deviation  $+b=+a$ . Also find out the condition when the refracted ray  $QR$  suffers total internal reflection.



For minimum deviation

$$r_1 + r_2 = A; \quad r_1 = r_2$$

Also,  $(90 - \beta) + (90 - \beta) = A$

$$\Rightarrow 180 - 2\beta = A$$

$$\Rightarrow 2\beta = 180 - A$$

$$\Rightarrow 2\beta = 2\alpha$$

$$\Rightarrow \beta = \alpha$$

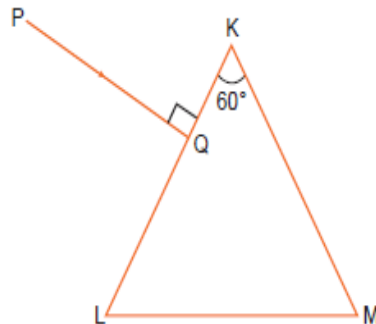
We have,  $r_1 + r_2 = A$

$$r_1 + i_c = A \quad (\text{Take } r_2 = i_c)$$

$$i_c = A - r_1$$

$$i_c = A - (90 - \beta)$$

6. A triangular prism of refracting angle  $60^\circ$  is made of a transparent material of refractive index  $2/\sqrt{3}$ . A ray of light is incident normally on the face  $KL$  as shown in the figure. Trace the path of the ray as it passes through the prism and calculate the angle of emergence and angle of deviation.



When light ray incident on face  $KL$ , it is pass undeviated, because it is normal to the surface and incident on face  $KM$ . The angle of incidence for face  $KM$  is equal to  $60^\circ$ .

$$\frac{\sin 60^\circ}{\sin r} = \frac{n_2}{n_1}$$

$$\left[ \begin{array}{l} n_2 = \text{Second medium} = \text{air} \\ n_1 = \text{Glass medium} = 2/\sqrt{3} \end{array} \right.$$



$$\frac{\sin 60^\circ}{\sin r} = \frac{1}{2/\sqrt{3}} = \frac{\sqrt{3}}{2}$$

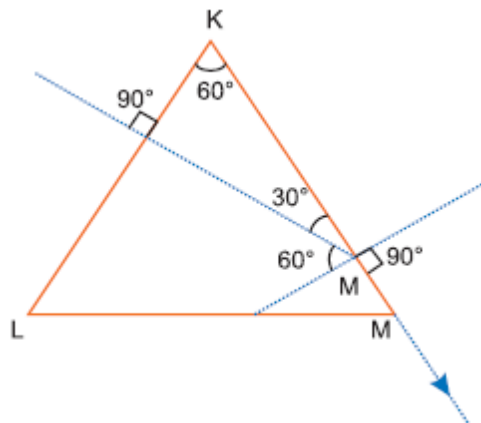
$$\Rightarrow \sin r = \frac{\sin 60^\circ}{\frac{\sqrt{3}}{2}} = 1$$

$$\sin r = 1$$

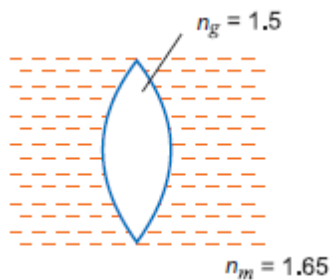
$$r = 90^\circ$$

Angle of emergence =  $90^\circ$

Angle of deviation =  $30^\circ$



7. A biconvex lens of glass of refractive index 1.5 having focal length 20 cm is placed in a medium of refractive index 1.65. Find its focal length. What should be the value of the refractive index of the medium in which the lens should be placed so that it acts as a plane sheet of glass?



**From lens formula, when lens in a medium**

$$\frac{1}{f_m} = \left( \frac{n_g}{n_m} - 1 \right) \left( \frac{1}{R_1} - \frac{1}{R_2} \right) \quad \dots(i)$$

When lens in air  $\frac{1}{f_a} = (n_g - 1) \left( \frac{1}{R_1} - \frac{1}{R_2} \right) \quad \dots(ii)$

From equation (i) and (ii), we get

$$\frac{f_a}{f_m} = \frac{\left( \frac{n_g}{n_m} - 1 \right)}{(n_g - 1)}$$

$$\frac{20 \text{ cm}}{f_m} = \frac{\left( \frac{1.5}{1.65} - 1 \right)}{(1.5 - 1)}$$

$$\Rightarrow f_m = \frac{20 \times (1.5 - 1)}{\left( \frac{1.5}{1.65} - 1 \right)} = \frac{20 \times 0.5 \times 1.65}{-0.15} = -110 \text{ cm}$$

If lens in the medium behave as a plane sheet of glass. Then  $f_m = \infty$

8. Calculate the speed of light in a medium whose critical angle is  $45^\circ$ . Does critical angle for a given pair of media depend on wave length of incident light? Give reason.

Critical angle in the medium,  $i_c = 45^\circ$

So, refractive index,  $n = \frac{1}{\sin i_c} = \frac{1}{\sin 45^\circ}$

$\Rightarrow n = \sqrt{2}$

Refractive index,  $n = \frac{c_0}{c_m}$

$$\sqrt{2} = \frac{3 \times 10^8}{c_m}$$

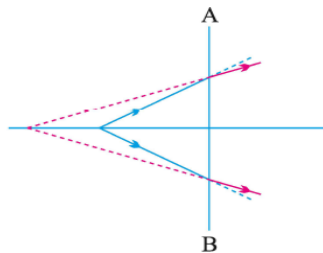
$$c_m = \frac{3 \times 10^8}{\sqrt{2}} = 2.1 \times 10^8 \text{ m/s}$$

Yes, critical angle for a pair of media depends on wavelength, because  $n = a + \frac{b}{\lambda^2}$ , where  $a$  and  $b$  are constants of the media.

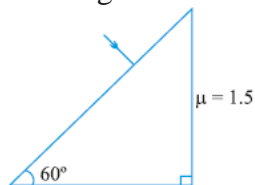
### NUMERICALS FOR PRACTICE

1. At what angle should a ray of light be incident on the face of a prism of refracting angle  $60^\circ$  so that it just suffers total internal reflection at the other face? The refractive index of prism is 1.524.

2. The line AB in the ray diagram represents a lens. State whether the lens is convex or concave.



3. Complete the path of light with correct value of angle of emergence.



4. If a jogger runs with constant speed towards a vehicle, how fast does

The image of the jogger appear to move in the rear view mirror when

(I) the vehicle is stationary

(ii) The vehicle is moving with constant speed towards jogger.

**HINT:** The speed of the image of the jogger appears to increase substantially though jogger is moving with constant speed.

Similar phenomenon is observed when vehicle is in motion.

5. The image of a small bulb fixed on the wall of a room is to be obtained

On the opposite wall's  $m$  away by means of a large convex lens. What

Is the maximum possible focal length of the lens required?

**HINT.** For fixed distance's' between object and screen, for the lens equation

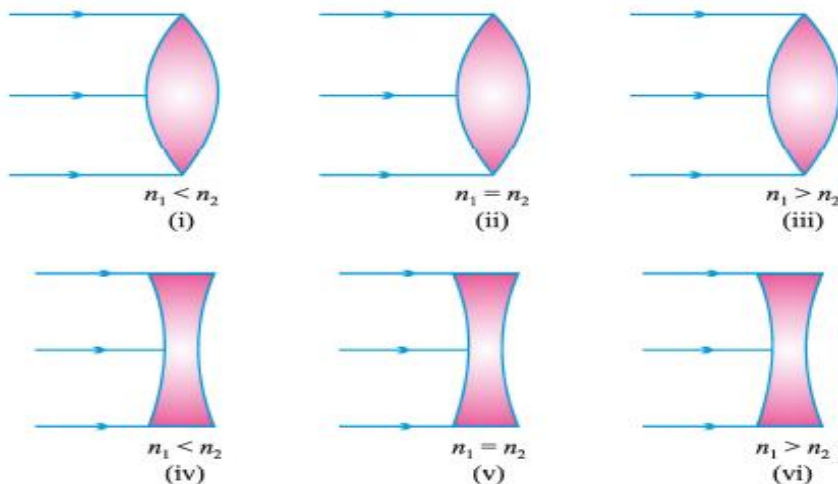
To give real solution for  $u = v = 2f$ , ' $f$ ' should not be greater than  $4f = s$ .

..  $f = s/4$

6. Define total internal reflection. State its two conditions. Using a ray Diagram show how optical fibres transmits light.

7. A plane wave front is incident on (i) a prism (ii) A convex lens (iii) a Concave mirror. Draw the emergent wave front in each case.

8. Complete the ray diagram in the following figure where,  $n_1$  is refractive Index of medium and  $n_2$  is refractive index of material of lens.



9. Two thin lenses when in contact produce a net power of +10D. If they are at 0.25m apart, the net power falls to +6 D. Find the focal lengths of the two lenses

Ans. 0.125m, 0.5m)

10. Show that a concave lens always produces a virtual image, irrespective of the position of the object.

Hint:  $v = \frac{uf}{u+f}$  But  $u$  is -ve and  $f$  is -ve for concave lens

Hence  $v$  is always -ve. that is virtual

11. A convex lens is differentiated to  $n$  regions with different refractive indices. How many images will be formed by the lens?

Ans.  $n$  images but less sharp

12. A convex lens has focal length  $f$  in air. What happens to the focal length of the lens, if it is immersed in (i) water ( $n=4/3$ ) (ii) a medium whose refractive index is twice that of glass.

Ans.  $4f$ ,  $-f$

13. Calculate the critical angle for glass air surface, if a ray falling on the surface from air, suffers a deviation of  $15^\circ$  when the angle of incidence is  $40^\circ$ .

14. A glass prism has an angle of minimum deviation  $D$  in air. What happens to the value of  $D$  if the prism is immersed in water?

Hint: Decreases

### CASE STUDY QUESTIONS

1. Refraction involves change in the path of light due to change in the medium. When a beam of light encounters another transparent medium, a part of light gets reflected back into the first medium, while the rest enters the other. The direction of propagation of an obliquely incident ray

of light, that enters the other medium, changes at the interface of two media. This phenomenon is called refraction of light.

(I) For the same value of angle of incidence, the angles of refraction in three media A, B and C are  $15^\circ$ ,  $25^\circ$  and  $35^\circ$ , respectively. In which medium, would the velocity of light be minimum?

(II) Why does a crack in a glass window pane appear silvery?

(III) The refractive index of diamond is much higher than that of glass. How does a diamond cutter make use of this fact?

(IV) What is the apparent position of an object below a rectangular block of glass 6 cm thick, if a layer of water 4 cm thick is on the top of the glass? (Take,  $n = 1.5$  and  $n = 1.33$ )

## 2. Young's Experiment

In 1801, Thomas Young was the first who demonstrated the interference of light. In his experimental arrangement (as shown in figure), monochromatic light (single wavelength) from a narrow vertical slit S falls on two other narrow slits S<sub>1</sub> and S<sub>2</sub>, which are very close together and equidistant to S. S<sub>1</sub> and S<sub>2</sub> act as two coherent sources (both being derived from S). The emerging beams spread into the region beyond the slits. Superposition occurs in the shaded area, where the beams overlap. Alternate bright and dark equally spaced vertical bands (interference fringes) can be observed on a screen placed at same distance from the slits. If either of S<sub>1</sub> or S<sub>2</sub> is covered, then the fringes disappear.

(I) Suppose while performing double slit experiment, space between the slits and the screen is filled with water. How does the interference pattern change?

(II) In Young's double slit experiment, if the distance between the slits is halved, what changes in the fringe width will take place?

(III) 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.

(IV) Which of the following is not total internal reflection?

(a) Working of optical fibre

(b) Difference between apparent and real depth of a pond

(c) Mirage on hot summer days

(d) What are the conditions for?

## 3. Total Internal Reflection

If light passes from an optically denser medium to a rarer medium, then at the interface, the light is reflected back into the denser medium and partly refracted to the rarer medium. This reflection is called internal reflection. As the angle of incidence  $i$  increases, the angle of refraction  $r$  also increases. At a certain value of  $i$ , the angle of refraction becomes  $90^\circ$ . This angle of incidence in the denser medium for which the angle of refraction in the rarer medium is  $90^\circ$  is called the critical angle of the denser medium (1). If  $i$  is increased beyond, no refraction is possible, and the incident ray is totally reflected. This phenomenon is known as total internal reflection. Multiple internal reflections in diamond ( $24.4^\circ$ ), totally reflecting prisms and mirage, are some examples of total internal reflection. Optical fibres consist of glass fibres coated with a thin layer of

material of lower refractive index. Light incident at an angle at one end comes out at the other, after multiple internal reflections, even if the fibre is bent.

QUESTIONS (Answers any four of the following questions)

1. For a wave to undergo total internal reflection ( $i_c$ , critical angle and  $i$  incident angle) is

- (a) Light moves from rarer to denser medium and  $i > i_c$
- (b) Light moves from denser to rarer medium and  $i > i_c$
- (c) Light moves from rarer to denser medium and  $i < i_c$
- (d) Light moves from denser to rarer medium and  $i < i_c$

2. Light travelling from a transparent medium to air undergoes total internal reflection at an angle of incidence of  $45^\circ$ . Then refractive index of the medium may be

- (a) 1.4
- (b) 1.3
- (c) 1.1
- (d)  $1/\sqrt{2}$

3. A diver at a depth 12 m inside water ( $n=4/3$ ) sees the sky in a cone of semi-vertical angle

- (a)  $\sin^{-1}(4/3)$
- (b)  $\tan^{-1}(4/3)$
- (c)  $\sin^{-1}(3/4)$
- (d)  $90^\circ$

4. In optical fibres, propagation of light is due to

- (a) Diffraction
- (b) total internal reflection
- (c) reflection
- (d) refraction.

5. A typical optical fibre consists of a fine core of a material of refractive index  $\mu_1$  surrounded by a glass or plastic cladding with refractive index  $\mu_2$ . Then

- (a)  $\mu_2$  is slightly less than  $\mu_1$
- (b)  $\mu_2$  is slightly greater than  $\mu_1$
- (c)  $\mu_2$  should be equal to  $\mu_1$
- (d) the difference  $\mu_2 - \mu_1$  should be strictly equal to 1.

## **ASSIGNMENT 1**

1. Refractive index of glass is 1.5. Time taken for light to pass through a glass plate of thickness 10 cm is

- (A)  $2 \times 10^{-8}$  s
- (B)  $2 \times 10^{-10}$  s
- (C)  $5 \times 10^{-8}$  s
- (D)  $5 \times 10^{-10}$  s

2. If the wavelength of the light is reduced to one fourth, then the amount of scattering is

- (A) Increased by 16 times
- (B) Decreased by 16 times
- (C) Increased by 256 times
- (D) Decreased by 256 times

3. The path difference between two monochromatic light waves of wavelength  $4000 \text{ \AA}$  is  $2 \times 10^{-7}$  m. The phase difference between them is

- (a)  $\pi$
- (b)  $2\pi$
- (c)  $3\pi/2$
- (d)  $\pi/2$

4 In Young's experiment, the third bright band for wavelength of light 6000 Å coincides with the fourth bright band for another source in the same arrangement. The wave length of the another source is

(A) 4500 Å (B) 6000 Å (C) 5000 Å (D) 4000 Å

5 A diffraction pattern is obtained using a beam of red light. What happens if the red light is replaced by blue light?

(a) Bands disappear (b) No change  
(C) Diffraction pattern becomes narrower and crowded together  
(D) Diffraction pattern becomes broader and farther apart

6 For a plane convex lens for which  $\mu = 1.5$  has radius of curvature of 10 cm. It is silvered on its plane surface. Find the focal length after silvering.

(A) 10 cm (B) 20 cm (C) 30 cm (D) 25 cm

7 A beam of monochromatic light is refracted from vacuum into a medium of refractive index 1.5. The wavelength of the refracted light will be

(a) Dependent on the intensity of refracted light (b) Same  
(c) Smaller (d) Larger

8 The refractive index of the material of an equi-double convex lens is 1.5. What is its focal length? (Radius of curvature = R).

(A) 3R (B) 2R (C) 4R (D) R

9 A ray of light from air is incident in water then which property of light will not change in water?

(A) Velocity (b) Frequency (c) Amplitude (D) Colour

10 An air bubble in a glass slab ( $\mu = 1.5$ ) is 5 cm deep when viewed from one face and 2 cm deep when viewed from the opposite face. The thickness of the slab is

(a) 7 cm (b) 10 cm (c) 7.5 cm (d) 10.5 cm

11 An object of height 1.5 cm is placed on the axis of a convex lens of focal length 25 cm. A real image is formed at a distance of 75 cm from the lens. The size of image will be

(A) 4.5 cm (B) 5 cm (C) 3.0 cm (D) 0.75 cm

12 The critical angle for a ray of light coming from a medium to air is  $30^\circ$ . The velocity of light in the medium is

(A)  $1.5 \times 10^8$  m/s (B)  $3 \times 10^8$  m/s  
(C)  $6 \times 10^8$  m/s (D)  $2.5 \times 10^8$  m/s

13 An optician prescribes spectacles to a patient with a combination of a convex lens of focal length 40 cm and a concave lens of focal length 25 cm. The power of the spectacles is

(A) -6.5 (B) -1.5 D (C) 1.5 D (D) .5 D

14 When light enters glass, its wavelength

(A) Decreases (b) Increases (C) Remains same (d) Data incomplete

15 A point source of light is placed 4 m below the surface of a transparent liquid of refractive index  $\frac{5}{3}$ . The minimum diameter of a disc which should be placed over the surface of the liquid to cut off all light coming out of the liquid is

- (a) 3 m      (b) 4 m      (c) 1 m      (d) 6 m

16 A double convex lens made of glass ( $\mu = 1.5$ ) has both radii of curvature of magnitude 20 cm. Incident rays parallel to the axis of the lens such that lens will converge at a distance  $L$  from the lens such that

- A)  $L = 10\text{cm}$       (b)  $L = \frac{20}{3}\text{CM}$   
(C) 20 cm      (D)  $L = 40\text{cm}$

17 An air Bubble under water shines brightly because of the phenomenon of

- (A) Interference      (B) Total internal reflection  
(c) Dispersion      (D) Diffraction

18 A convex lens is dipped in a liquid, whose refractive index is equal to the refractive index of the lens. Then, its focal length will

- (A) Become zero      (B) Become infinite  
(C) Remain unchanged      (D) Become small, but non-zero.

19 When a biconvex lens of glass having refractive index 1.47 is dipped in a liquid, it acts as a plane sheet of glass. This implies that the liquid must have refractive index

- (A) Equal to that of glass      (B) Less than one  
(C) greater than that of glass  
(D) less than that of glass

20 A Plano convex lens is made of refractive index 20 if the radius of curvature of the curved surface is 60 cm, then focal length of the lens is

- (a) 50 cm      (b) 100 cm  
(c) 200 cm      (d) 400 cm

21 Focal length of a convex lens of refractive index 1.5 is 2 cm. Focal length of lens, when immersed in a liquid of refractive index of 1.25 will be

- (a) 10 cm      (b) 7.5 cm  
(c) 5 cm      (d) 2.5 cm

22 A Plano-convex lens is made of a material of refractive index  $\mu = 1.5$ . The radius of curvature of curved surface of the lens is 20 cm. If its plane surface is silvered, the focal length of the silvered lens will be

- (a) 10 cm      (b) 20 cm  
(c) 40cm      (d) 80 cm.

23 A converging beam of rays is incident on a diverging lens. Having passed through the lens, the rays intersect at a point 15 cm from the lens on the opposite side. If the lens is removed the point where the rays meet will move 5 cm closer to the lens. The focal length of the lens is

- (a) -30 cm      (b) 5 cm

- (c)-10 cm (d) 20 cm

24 A biconvex lens has a radius of curvature of magnitude 20 cm. Which one of the following options describe best the image formed of an object of height 2 cm placed 30 cm from the lens?

- (A) Virtual, upright, height = 1cm (B) Virtual, upright, height = 0.5cm  
(c) Real, inverted, height = 4 cm (d) Real, inverted, height = 1 cm

25 Yellow light is used in a single slit diffraction experiment with slit width of 0.6 mm. If yellow light is replaced by X-rays, then the observed pattern will reveal

- (a) That the central maximum is narrower. (b) More number of fringes.  
(c) Less number of fringes. (d) No diffraction pattern.

26 A beam of light of wavelength 600 nm from a distant source falls on a single slit 1.00 mm wide and the resulting diffraction pattern is observed on a screen 2 m away. The distance between the first dark fringes on either side of the central bright fringe is

- (A) 1.2 cm. (b) 1.2 mm  
(c) 2.4 cm (d) 2.4 mm

27 In the Young's double slit experiment, the interference pattern is found to have an intensity ratio between bright and dark fringes as 9. This implies that

- (a) The intensities at the screen due to two slits are 5 units and 4 units respectively.  
(b) The intensities at the screen due to slits are 4 units and 1 unit respectively.  
(c) The amplitude ratio is 3.  
(d) The amplitude ratio is 2.

28 White light is used to illuminate the two slits in a Young's double slit experiment. The separation between the slits is  $b$  and the screen is at a distance  $d$  ( $>b$ ) from the slits. At a point on the screen directly in front of one of the slits, certain wavelengths are missing.

Some of these missing wavelengths are

- (a)  $\lambda = (b^2)/d$  (b)  $\lambda = (2b^2)/d$   
(C)  $\lambda = (b^2)/(3d)$  (D)  $\lambda = (2b^2)/(3d)$

29 A parallel monochromatic beam of light is incident normally on a narrow slit. A diffraction pattern is formed on a screen placed perpendicular to the direction of the incident beam. At the first mini mum of the diffraction pattern, the phase difference between the rays coming from the two edges of the slit is

- (a) 0 (b)  $\pi / 2$   
(C)  $\pi$  (d)  $2 \pi$

30.**Assertion:** It is not possible to have interference between the waves produced by two violins.

**Reason:** For interference of two waves the phase difference between the waves must remain constant.

31.**Assertion:** To observe diffraction of light, the size of obstacle/aperture should be of the order of  $10^{-7}$  m.

**Reason:**  $10^{-7}$  m is the order of wavelength of visible light.

**ANSWER KEY**

1. D 2.C 3.A 4.A 5.C 6.C 7.C 8.D 9.B. 10D.  
11. C. 12.A 13.B 14.A 15.D 16.C 17.B 18.B 19.A 20.B  
21. C 22.B 23.A 24.C 25.D 26.D 27.A 28.A 29D.

30.Both assertion and reason are true and the reason is the correct explanation of the assertion. The waves produced by the two violins are not coherent.



31. Both assertion and reason are true and reason is the correct explanation of the assertion. Diffraction is prominent when the size of the obstacle or the aperture is comparable to the wavelength of light used.

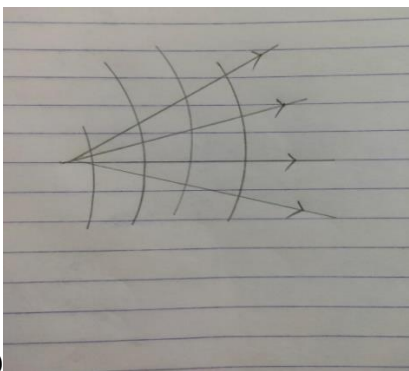
## ASSIGNMENT 2

1. State Huygens' postulates of wave theory. Sketch the wavefront emerging from a (i) point source of light and (ii) linear source of light like a slit.

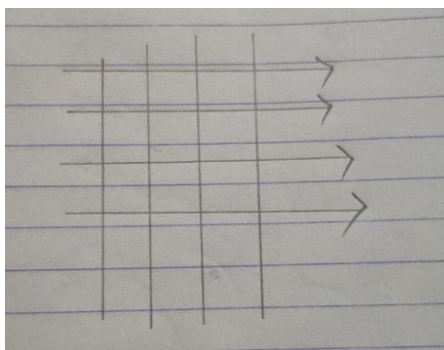
### ANSWER

The postulates of Huygens's wave theory are:

- Every particle of the medium situated on the wave-front acts as a new wave-source from which fresh waves originate. These waves are called secondary wavelets.
- The secondary wavelets travel in the medium in all directions with the speed of the original wave in the medium.
- The envelope of the secondary wavelets in the forward direction at any instant gives the new wave-front at that point.



(I)



(II)

2. State Huygens Principle. Use it to show that a plane wavefront advances as a plane wavefront in a homogeneous medium. Is a backward wavefront possible? Give reason in support of your answer.

3. The absolute refractive indices of glass and water are  $\frac{3}{2}$  and  $\frac{4}{3}$ . Determine the ratio of the speeds of light in glass and water.

### ANSWER

$$v \propto \frac{1}{\mu} \quad \therefore \frac{v_g}{v_w} = \frac{\mu_w}{\mu_g} = \frac{4/3}{3/2} = 8:9$$

4. The refractive index of glass is 1.5 and that of water is 1.3, the speed of light in water is  $2.25 \times 10^8$  m/s. What is the speed of light in glass?

### ANSWER

$$\frac{v_g}{v_w} = \frac{\mu_w}{\mu_g} \quad \text{or} \quad v_g = \frac{\mu_w}{\mu_g} \times v_w = \frac{1.3}{1.5} \times 2.25 \times 10^8$$

5. Monochromatic light of wavelength 600 nm is incident from air on a glass surface. What are the wavelength, frequency and speed of refracted light? Refractive index of glass is 1.5.

**ANSWER**

During refraction, frequency remains unchanged. Both wavelength and speed get changed.

Frequency,

$$v = \frac{c}{\lambda} = \frac{3 \times 10^8 \text{ ms}^{-1}}{600 \times 10^{-9} \text{ m}} = 5 \times 10^{14} \text{ Hz}$$

Speed of refracted light,

$$v_{\text{glass}} = \frac{c}{\mu} = \frac{3 \times 10^8}{1.5} = 2 \times 10^8 \text{ ms}^{-1}$$

Wavelength of refracted light,

$$\lambda_{\text{glass}} = \frac{v_{\text{glass}}}{v} = \frac{2 \times 10^8}{5 \times 10^{14}} = 4 \times 10^{-7} \text{ m} = 400 \text{ nm}$$

6. When monochromatic light travels from a rarer to a denser medium, explain the following, giving reasons: (i) Is the frequency of reflected and refracted light same as the frequency of incident light? (ii) Does the decrease in speed imply a reduction in the energy carried by light wave?

**ANSWER**

(I) Both the reflected and refracted lights have the same frequency as the frequency of incident light.

(II) No, the reduction in the speed of light does not imply the reduction in the energy of the light wave because the energy carried by a wave depends on the amplitude of the wave, not on the speed of wave propagation.

7. Define a wave front. How is it different from a ray?

**ANSWER**

A wave front is the locus of all such points of the medium which have the same phase.

**Differences of a wave front from a ray:** (i) A ray is normal to the wave front at each point. (ii) A ray indicates the direction of propagation of a wave while the wave front is the surface of constant phase.

8. What is interference of light? Give one example from daily life. State two necessary conditions for sustained interference.

**ANSWER:** What is interference of light? –definition

1. Coherent sources of light are needed.
2. Amplitudes and intensities must be nearly equal to produce sufficient contrast between maxima and minima.
3. The source must be small enough that it can be considered as a point source of light.  
+suitable example

9. Why cannot two independent monochromatic sources produce sustained interference pattern? Explain.

**ANSWER**

Two independent monochromatic sources of light cannot produce a sustained interference because:

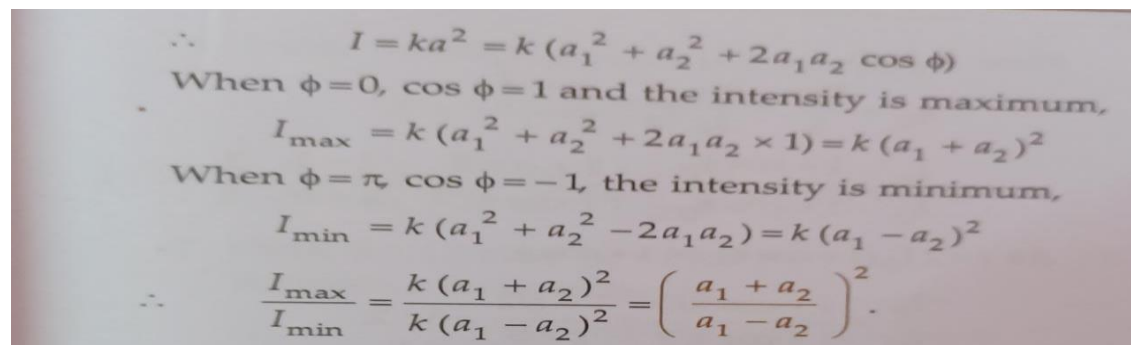
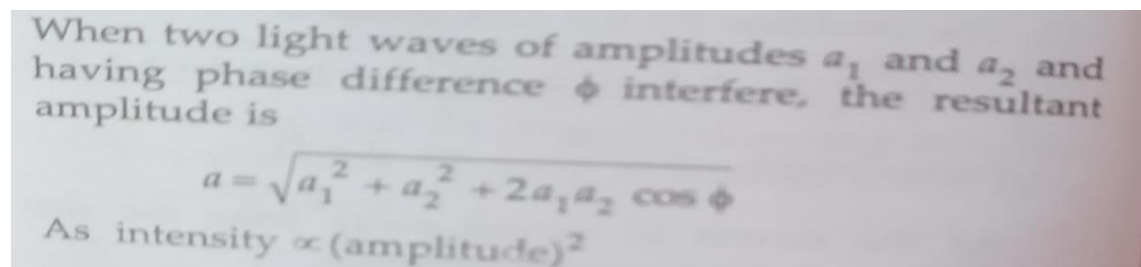
- (1) If the sources are not coherent, they cannot emit waves continuously.
- (2) Independent sources emit the waves, which don't have the same phase or a constant phase difference.

10. Does the appearance of bright and dark fringes in the interference pattern violate, in any way, conservation of energy? Explain.

**ANSWER**

No. Law of conservation of energy is obeyed. In case of constructive interference, intensity becomes maximum and bright fringes are formed in the screen whereas in case of destructive interference, intensity being minimum, dark fringes are formed.

11. Two sources of intensity  $I_1$  and  $I_2$  undergo interference in Young's double slit experiment. Show that  $I_{\text{MAX}}/I_{\text{MIN}} = \{(a_1 + a_2 / a_1 - a_2)\}^2$  where  $a_1$  and  $a_2$  are the amplitudes of disturbance for two sources  $S_1$  and  $S_2$



12.State two conditions for sustained interference of light. Draw the variation of intensity with position, in the interference pattern of Young's double slit experiment

### ANSWER

Conditions for sustained interference: The two essential conditions of sustained interference are as follows:

- (i) The two sources of light should emit light continuously.
- (ii) The light waves should be of same wavelength. (Monochromatic).

## Unit - VII Dual Nature of Radiation and Matter (Chapter- 11)

### FORMULA CHART

1) **DE-BROGLIE WAVE OR MATTER WAVE** : Wave associated with moving particle of mass  $m$  and speed  $v$ , Wavelength  $\lambda = h / mv = h / \sqrt{2mk}$ ,  $K$  = Kinetic Energy.

2) **BRAGG'S LAW** -  $2d \sin\theta = n\lambda$

3) **PHOTOELECTRIC EFFECT** : Emission of electron from metal surface when radiation of frequency ( $\nu$ ) greater than threshold frequency, i.e.  $\nu > \nu_0$  on incident on surface.

**WORK FUNCTION OF METAL**: Minimum energy of incident photon.  $\Phi = h\nu_0$

4) **LAW OF PHOTOELECTRIC EMISSION** :

*It is an instantaneous process.*

*Number of photoelectrons ejected per second is proportional to the intensity of incident light.*

*Saturation current & Intensity of light.*

*Stopping potential  $\propto$  Frequency of incident light*

*Einstein's photoelectric equation*

$$h\nu = h\nu_0 + \frac{1}{2} mv_{\max}^2$$

5) **ENERGY OF PHOTON** :  $E = h\nu = hc / \lambda$

6) **MOMENTUM OF PHOTON** :  $P = h / \lambda$

7) **DE-BROGLIE'S WAVELENGTH** :  $\lambda = h / P$

8) **KINETIC ENERGY OF DE-BROGLIE WAVES** :  $K = \frac{1}{2} mv^2 = P^2 / 2m$

9) **EINSTEIN'S PHOTOELECTRIC EQUATION** :  $K_{\max} = h\nu - \Phi$

10) **WORK FUNCTION AND THRESHOLD FREQUENCY** :  $\Phi_0 = hc / \lambda_0$

### NUMERICALS FOR PRACTICE WITH SOLUTIONS

1. A blue lamp mainly emits light of wavelength  $4500 \text{ \AA}$ . The lamp is rated at  $150 \text{ W}$  and  $8\%$  of the energy is emitted as visible light. How many photons are emitted by the lamp per second?

2. Monochromatic light of wavelength  $632.8 \text{ nm}$  is produced by a helium-neon laser. The power emitted is  $9.42 \text{ mW}$ . (a) Find the energy and momentum of each photon in the light beam. (b) How many photons per second, on the average, arrive at a target irradiated by this beam?

(Assume the beam to have uniform cross-section which is less than the target area), and (c) How fast does a hydrogen atom have to travel in order to have the same momentum as that of the photon?

3. Radiations of frequencies  $\nu_1$  and  $\nu_2$  are made to fall in turn, on a photosensitive surface. The stopping potentials required for stopping the most energetic emitted photoelectrons in the two cases are  $V_1$  and  $V_2$  respectively. Obtain a formula for determining Planck's constant and the threshold frequency in terms of these parameters.

4. X-rays fall on a photosensitive surface to cause photoelectric emission. Assuming that the work function of the surface can be neglected, find the relation between the de-Broglie wavelength ( $\lambda$ ) of the electrons emitted to the energy ( $E_\nu$ ) of the incident photons. Draw the nature of the graph for  $\lambda$  as a function of  $E_\nu$ .

5. When light of wavelength 400 nm is incident on the cathode of a photocell, the stopping potential recorded is 6 V. If the wavelength of the incident light is increased to 600 nm, calculate the new stopping potential.

6. A particle of a mass  $M$  at rest decays into two particles of masses  $m_1$  and  $m_2$  having non-zero velocities. What is the ratio of the de-Broglie wavelengths of the two particles?

7. An electromagnetic wave of wavelength  $\lambda$  is incident on a photosensitive surface of negligible work function. If the photoelectrons emitted from this surface have the de-Broglie wavelength  $\lambda_e$ , prove that  $\lambda = 2mc/h \times \lambda_e^2$ .

8. Calculate the de-Broglie wavelength of (i) an electron (in the hydrogen atom) moving with a speed of 1/100 of the speed of light in vacuum and (ii) a ball of radius 5 mm and mass  $3 \times 10^{-2}$  kg moving with a speed of  $100 \text{ ms}^{-1}$ . Hence show that the wave nature of matter is important at the atomic level but is not really relevant at the macroscopic level.

9. Find the : (a) maximum frequency, and (b) minimum wavelength of X-rays produced by 30 kV electrons.

10. The work function of caesium metal is 214 eV. When light of frequency  $6 \times 10^{14}$  Hz is incident on the metal surface, photoemission of electrons occurs. What is the:

(a) maximum kinetic energy of the emitted electrons,

(b) stopping potential, and

(c) maximum speed of the emitted photoelectrons ?

11. The energy flux of sunlight reaching the surface of the earth is  $1.388 \times 10^3 \text{ Wm}^{-2}$ . How many photons (nearly) per square metre are incident on the Earth per second? Assume that the photons in the sunlight have an average wavelength of 550 nm.

12. The wavelength of light from the spectral emission line of sodium is 589 nm.

Find the kinetic energy at which:

(a) an electron, and

(b) a neutron, would have the same de-Broglie wavelength.

### Solutions -

$$1. E = hc/\lambda, N = P/E$$

$$N = 8\% \text{ of } P/E = 8P\lambda/100 hc \quad (1M)$$

$$= 8 \times 150 \times 4500 \times 10^{-10}/100 \times 6.63 \times 10^{-34} \times 3 \times 10^8$$

$$= 2.71 \times 10^{29} \text{ photons/second.} \quad (1M)$$

$$2. \lambda = 632.8 \text{ nm} = 632.8 \times 10^{-9} \text{ m}$$

$$P = 9.42 \text{ mW} = 9.42 \times 10^{-3} \text{ W}$$

(a) Energy of each photon,

$$E = hc/\lambda$$

$$= 6.63 \times 10^{-34} \times 3 \times 10^8 / 632.8 \times 10^{-9} = 3.14 \times 10^{-19} \text{ J}$$

Momentum of each photon,

$$p = h/\lambda = 6.63 \times 10^{-34} / 632.8 \times 10^{-9} = 1.05 \times 10^{-27} \text{ kg ms}^{-1}$$

(b) Number of photons arriving per second at the target,

$$N = P/E = 9.42 \times 10^{-3} / 3.14 \times 10^{-19} = 3 \times 10^{16} \text{ photons per second. (1M)}$$

(c) Momentum of a hydrogen atom = Momentum of a photon

$$\text{or } mv = p$$

∴ Velocity,

$$v = p/m = 1.05 \times 10^{-27} \text{ kg ms}^{-1} / 1.67 \times 10^{-27} \text{ kg} = 0.63 \text{ ms}^{-1} \quad (1M)$$

3. Let  $W_0$  be the work function of the metal. Then maximum kinetic energies of the photoelectrons ejected in the two cases will be

$$eV_1 = hv_1 - W_0 \text{ and } eV_2 = hv_2 - W_0$$

$$e(V_2 - V_1) = h(v_2 - v_1)$$

$$h = e(V_2 - V_1) / v_2 - v_1 \quad (1M)$$

If  $\nu_0$  is the threshold frequency, the

$$eV_1 = hv_1 - W_0 = hv_1 - h\nu_0$$

$$\text{or } \nu_0 = v_1 - eV_1 / h = v_1 - V_1 (v_1 - v_2) / V_2 - V_1$$

$$= v_1 V_2 - v_1 V_1 - v_2 V_1 + v_1 V_1 / V_2 - V_1$$

$$= v_1 V_2 - v_2 V_1 / V_2 - V_1 \quad (1M)$$

4. Energy of a photon,

$$E_v = W_0 + K_{\max}$$

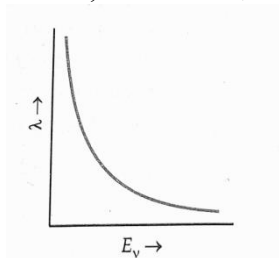
$$\text{As } W_0 = 0, \text{ so } E_v = K_{\max} = p^2 / 2m$$

$$\therefore p = \sqrt{2mE_v} \quad (1M)$$

Wavelength of the emitted electrons,

$$\lambda = h/p = h / \sqrt{2mE_v}$$

$$\text{i.e., } \lambda \propto 1 / \sqrt{E_v} \quad (1M)$$



Hence, the graph of  $\lambda$  vs.  $E$  is a parabola as shown in the Fig.

5. As  $K_{\max} = h\nu - W_0$

$$\text{or } eV_0 = hc / \lambda - W_0 \text{ or } V_0 = hc / e\lambda - W_0 / e \quad (1M)$$

$$\therefore \Delta V_0 = (V_0)_2 - (V_0)_1$$

$$\begin{aligned}
&= [hc / e\lambda_2 - W_0 / e] - [hc / e\lambda_1 - W_0 / e] = hc / e[1 / \lambda_2 - 1 / \lambda_1] \\
&= 6.6 \times 10^{-34} \times 3 \times 10^8 / 1.6 \times 10^{-19} [1 / 4 \times 10^{-7} - 1 / 6 \times 10^{-7}] = 1.03 \\
(V_0)_2 &= (V_0)_1 - 1.03 = 6 - 1.03 = 4.97V \quad (1M)
\end{aligned}$$

6. By conservation of linear momentum ,

$$m_1 v_1 + m_2 v_2 = M \times 0 \quad (1M)$$

or  $m_1 v_1 = -m_2 v_2$

$\therefore |m_1 v_1| = |m_2 v_2|$

or  $|p_1| = |p_2|$

$$\lambda_1 / \lambda_2 = |p_2| / |p_1| = 1 \quad (1M)$$

7. As proved in the above problem ,

$$\lambda = \sqrt{h\lambda} / \sqrt{2mc} \quad (1M)$$

$$\lambda_e^2 = h\lambda / 2mc$$

$$\lambda = (2mc / h) \lambda_e^2 \quad (1M)$$

8. (i)  $\lambda_e = 6.6 \times 10^{-34} / 9 \times 10^{-31} \times 1/100 \times 3 \times 10^8 = 2.44 \times 10^{-10}m$ . (1M)

(ii)  $\lambda_b = 6.6 \times 10^{-34} / 3 \times 10^{-2} \times 100 = 2.2 \times 10^{-34}$  (1M)

As the de-Broglie wavelength of the electron has a significant value while that of the ball is negligibly small, it shows that the wave nature of matter is important at the atomic level but it is not really relevant at the macroscopic level.

9. (a) Maximum energy of X-ray photon = Maximum energy of an accelerated electron

$$or h\nu_{max} = eV$$

$$\therefore \nu_{max} = eV / h = 1.6 \times 10^{-19} \times 30 \times 10^3 / 6.63 \times 10^{-34} = 7.24 \times 10^{18} \text{ Hz} . \quad (1M)$$

(b)  $\lambda_{min} = c / \nu_{max} = 3 \times 10^8 / 7.24 \times 10^{18}$

$$= 0.0414 \times 10^{-9}m = 0.0414nm \quad (1M)$$

10. Here  $W_0 = 2.14 \text{ eV}$  ,  $\nu = 6 \times 10^{14} \text{ Hz}$

(a)  $K_{max} = h\nu - W_0$

$$= 6.63 \times 10^{-34} \times 6 \times 10^{14}J - 2.14 \text{ eV}$$

$$= 6.63 \times 6 \times 10^{-20} / 1.6 \times 10^{-19}eV - 2.14 \text{ eV}$$

$$= 2.48 - 2.14 = 0.34 \text{ eV}.$$

(b) As  $eV_0 = K_{max} = 0.34 \text{ eV}$

$\therefore$  Stopping potential,  $V_0 = 0.34 \text{ V}$ . (1M)

(c)  $K_{max} = 1 / 2 m v_{max}^2 = 0.34 \text{ eV} = 0.34 \times 1.6 \times 10^{-19}J$

or  $v_{max}^2 = 2 \times 0.34 \times 1.6 \times 10^{-19} / m$

$$= 2 \times 0.34 \times 1.6 \times 10^{-16} / 9.1 \times 10^{-31}J = 119560.4 \times 10^6$$

or  $v_{max} = 345.8 \times 10^3 \text{ ms}^{-1} = 345.8 \text{ kms}^{-1}$

11. Energy of each photon,

$$E = hc / \lambda = 6.63 \times 10^{-34} \times 3 \times 10^8 / 550 \times 10^{-9} = 3.62 \times 10^{-19} \text{ J} . \quad (1M)$$

Number of photons incident on earth's surface per second per square metre

$$= \text{Total energy per square metre per second} / \text{Energy of each photon}$$

$$= 1.388 \times 10^3 / 3.62 \times 10^{-19} = 3.8 \times 10^{21} . \quad (1M)$$

12. Here  $\lambda = 589 \text{ nm} = 589 \times 10^{-9} \text{ m}$

But  $\lambda = h/p = h / \sqrt{2mk}$

$$\lambda^2 = h^2 / 2mK$$

or  $K = h^2 / 2m\lambda^2$

(a) Kinetic energy of an electron,

$$K = (6.63 \times 10^{-34})^2 / (2 \times 9.1 \times 10^{-31} \times 589 \times 10^{-9})^2$$

$$= 6.95 \times 10^{-25} \text{ J}$$

$$= 4.34 \mu\text{eV}. \quad (1\text{M})$$

(b) Kinetic energy of a neutron,

$$K = (6.63 \times 10^{-34})^2 / (2 \times 1.67 \times 10^{-27} \times 589 \times 10^{-9})^2 = 3.78 \times 10^{-28} \text{ J}$$

$$= 0.236 \text{ neV}. \quad (1\text{M})$$

### **NUMERICALS FOR PRACTICE**

1. For the light of wavelength 400 nm incident on the cathode of a photocell, the stopping potential is 6V. If the wavelength of incident light is increased to 600 nm, calculate the new stopping potential.
2. Monochromatic light of frequency  $6.0 \times 10^{14}$  Hz is produced by a laser. The power emitted is  $2.0 \times 10^{-3}$  W. Estimate the number of photons emitted per second on an average by the source.
3. Consider a metal exposed to light of wavelength 600 nm. The maximum energy of the electron is doubled when light of wavelength 400 nm is used. Find the work function in eV.
4. When radiation of wavelength  $3000 \text{ \AA}$  and  $4000 \text{ \AA}$  fall on the surface of metals A and B, and the photoelectrons emitted have maximum kinetic energies of 2eV and 1eV respectively. Calculate the maximum wavelength of the incident radiation for which there will be photoelectron emission from the same surface.
5. By how much would the stopping potential for a given photosensitive surface go up if the frequency of the incident radiations were to be increased from  $4 \times 10^{15}$  Hz to  $8 \times 10^{15}$  Hz?
6. Light of wavelength  $2500 \text{ \AA}$  falls on a metal surface of work function 3.5 eV. What is the kinetic energy (in eV) of (i) the fastest and (ii) the slowest electrons emitted from the surface? If the same light falls on another surface of work function 5.5 eV, what will be the energy of emitted electrons?
7. The ground state energy of hydrogen atom is - 13.6eV. The photon emitted during the transition of electron from  $n = 2$  to  $n = 1$  state, is incident on a photosensitive material of unknown work function. The photoelectrons are emitted from the materials with a maximum kinetic energy of 8 eV. Calculate the threshold wavelength of the material used.
8. If light of wavelength 412.5 nm is incident on each of the metals given below, which ones will show photoelectric emission and why?

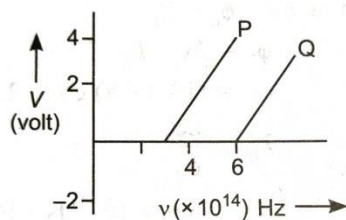
Metal	Work function (eV)
Na	1.92
K	2.15
Ca	3.20
Mo	4.17



9. The kinetic energy of the electron orbiting in the first excited state of hydrogen atom is 3.4 eV. Determine the de Broglie wavelength associated with it.

10. 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?

11. In the study of a photoelectric effect the graph between the stopping potential  $V$  and frequency  $\nu$  of the incident radiation on two different metals P and Q is shown below:



(i) Which one of the two metals has higher threshold frequency?

(ii) Determine the work function of the metal which has greater value.

(iii) Find the maximum kinetic energy of electron emitted by light of frequency  $8 \times 10^{14}$  Hz for this metal.

12. An electron and a proton, each have de Broglie wavelength of 1.00 nm.

(i) Find the ratio of their momenta.

(ii) Compare the kinetic energy of the proton with that of the electron.

13. The work function of caesium is 2.14 eV. Find (a) the threshold frequency for caesium, and (b) the wavelength of the incident light if the photocurrent is brought to zero by a stopping potential of 0.60 V.

14. A particle is moving three times as fast as an electron. The ratio of the de Broglie wavelength of the particle to that of the electron is  $1.813 \times 10^{-4}$ . Calculate the particle's mass and identify the particle.

15. Given the ground state energy  $E_0 = -13.6 \text{ eV}$  and Bohr radius  $a_0 = 0.53 \text{ \AA}$ . Find out how the de Broglie wavelength associated with the electron orbiting in the ground state would change when it jumps into the first excited state.

### Hints

$$1. K = h(\nu - \nu_0) = hc \left( \frac{1}{\lambda} - \frac{1}{\lambda_0} \right)$$

$$K = hc / \lambda - \phi \text{ on substituting values, Stopping potential is } 0.65 \text{ eV}$$

2.  $P = nh\nu$ ,  $n = 2.0 \times 10^{-3} / h\nu$  on solving  $n = 5.027 \times 10^{15}$  per second

3.  $\lambda_1 = 600 \times 10^{-9} \text{ m}$ ,  $\lambda_2 = 400 \times 10^{-9}$

$hc[2/\lambda_1 - 1/\lambda_2] = \phi_0$  on substituting values,  $\phi_0 = 1.03 \text{ eV}$ .

4.  $E = hc/\lambda \text{ eV}$  on substituting values we get  $E = 4.125 \text{ eV}$

Work function  $\phi_0 = 2.125 \text{ eV}$

For metal B,  $\lambda_0 = 5892 \text{ \AA}$

5.  $eV_{01} = h\nu_1 - \phi$  ----(1)  $eV_{02} = h\nu_2 - \phi$  ----(2)

(1) - (2) gives  $16.6 \text{ V}$

6.  $E = hc/\lambda$  on substituting values we get  $E = 4.9 \text{ eV}$

$E_{k\text{max}} = 1.4 \text{ eV}$

7.  $E = -13.6[1/1^2 - 1/2^2] = 10.2 \text{ eV}$

$h\nu = \phi_0 + E$  on substituting values we get  $\lambda_0 = 5.6 \times 10^{-7} \text{ m}$

8.  $E = hc/\lambda$  on solving we get  $3.01 \text{ eV}$

9.  $\lambda = h/\sqrt{2mk}$  on substituting the values we get  $\lambda = 6.66 \times 10^{-10} \text{ m}$

10.  $V = 100 \text{ volts}$   $\lambda = h/\sqrt{2meV} = 12.27 / \sqrt{V} = 1.227 \text{ \AA}$

11. (i) Metal Q

(ii)  $Q = h\nu_0 = 6.63 \times 10^{-34} \times 6 \times 10^{14} \text{ J}$

$\phi_0 = 2.49 \text{ eV}$

(iii)  $K_{\text{max}} = h\nu - \phi_0 = 3.32 - 2.49 = 0.83 \text{ eV}$

12.  $\lambda_e = \lambda_p = 1.00 \text{ nm}$

(i)  $p = h/\lambda$  hence on substituting we get  $P_e / P_p = 1:1$

(ii)  $E_K = p^2 / 2m$

$E_{Kp} / E_{Ke} = (P_p / P_e)^2 \times (m_e / m_p)$  on solving we get  $E_{Kp} / E_{Ke} = 5.4 \times 10^{-4}$

13 (a).  $\nu_0 = \phi_0 / h = 2.14 \text{ eV} / 6.63 \times 10^{-34} \text{ Js} = 5.16 \times 10^{14} \text{ Hz}$

$eV_0 = hc/\lambda - \phi_0$ ,  $\lambda = hc / (eV_0 + \phi_0) \therefore \lambda = 454 \text{ nm}$

14.  $\lambda = h/mv$

$$\lambda_e = h / m_e v_e \text{ and } \lambda_p = h / m_p \times 3v_e \because m_p = 1838.6 m_e$$

$$15. E_2 = -13.6 / 4 \text{ eV} = -3.4 \text{ eV} . \text{ As K.E, } K_n = -E_n , K_2 = 3.4 \text{ eV}$$

$$\text{In 2}^{\text{nd}} \text{ energy level would be , } \lambda_2 = h / \sqrt{2m_e K_2} = 6.654 \text{ \AA}$$

$$1^{\text{st}} \text{ energy level } \lambda_1 = 3.327 \text{ \AA}$$

## **CASE STUDY QUESTION**

1. According to wave picture, light is an EM wave consisting of electric and magnetic fields with continuous distribution of energy over the region of space of wave. This wave nature didn't explain the photoelectric effect. The needs to be supplied with more energy than work function of material. We know photoelectric emission is an instantaneous process. Photon is called quanta of energy.

1. The kinetic energy of the electron emitted dependson which parameter?

- (a) Frequency of incident light.
- (b) Intensity of incident light.
- (c) Work function of material.
- (d) Potential applied.

2. Does the matterwave picture elegantly incorporated the Heisenberg's uncertainty principle?

- (a) Yes(b) No
- (c) May be(d) Can't say

3. How does amplitude of electric and magnetic fields vary with intensity of radiation ?

- (a) If the intensity increases then amplitude also increases.
- (b) Intensity increases and amplitudedecreases.
- (c) Amplitude doesn't depend on intensity.
- (d) None of the above.

4. Is there any specific region of absorption of electron on wavefront?

- (a) Continuously over the right of wavefront.
- (b) Continuously over the left of wavefront.
- (c) Continuously over the entire wavefront.
- (d) None of the above.

5. Does photon get deflected by electric and magnetic fields?

- (a) Yes (b) No
- (c) May be (d) Depending on situation

### **Solutions**

1. (a) 2. (a) 3. (a) 4.(c) 5. (a)

2. In 1887, German physicist Heinrich Hertz noticed that shining a beam of ultraviolet light onto a metal plate could cause it to shoot sparks. It is due to the emission of negatively charged particles called electrons from the metal surface into the surrounding space. Hallwachs and Lenard also observed that when ultraviolet light fell on the emitter plate, no electrons were emitted at all when the frequency of the incident light was smaller than a certain minimum frequency. Experimental study shows that different metals required different minimum frequencies of light for the emission of electron. When brightness of the incident light increases, more electrons were produced, without increasing their energy, and increasing the frequency of

the light produced electrons with higher energies, but without increasing the number produced. This is known as the photoelectric effect, and it would be understood in 1905 by a young scientist named Albert Einstein.

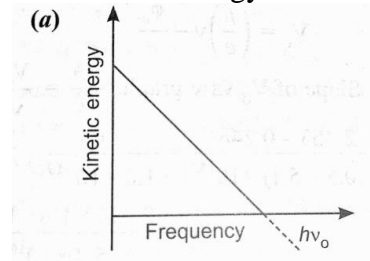
1. In photoelectric effect, the kinetic energy of emitted electrons from the metal surface depends upon

- (a) frequency of incident light
- (b) velocity of incident light
- (c) intensity of light
- (d) angular momentum of emitted electron.

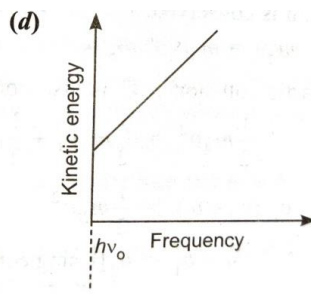
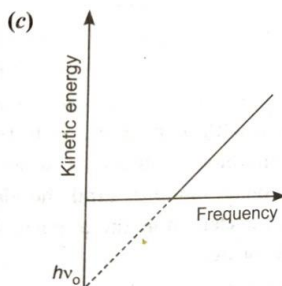
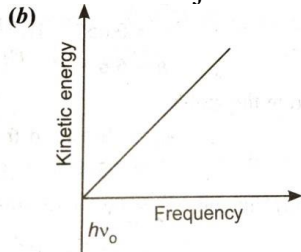
2. When monochromatic radiation of intensity  $I$  falls on a metal surface, the number of photoelectron and their maximum kinetic energy are  $n$  and  $K$  respectively. If the intensity of radiation is  $2I$ , the number of emitted photoelectron and their maximum kinetic energy will be

- (a)  $n$  and  $2K$
- (b)  $2n$  and  $2K$
- (c)  $2n$  and  $K$
- (d)  $n$  and  $K$

3. According to Einstein's photoelectric equation, the graph between the kinetic energy of



photoelectrons ejected and the frequency of incident radiation is



4. If the momentum of an electron is changed by  $P$ , then the de-Broglie wavelength associated with it changes by 0.4%. The initial momentum of electron will be

- (a)  $100 P$
- (b)  $250 P$
- (c)  $300 P$
- (d)  $P/200$

5. Which of the following property does not support wave theory of light?

- (a) Light waves get polarised

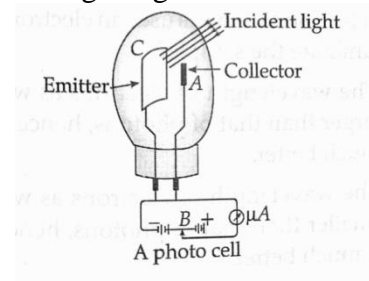
- (b) Light obeys Laws of refraction and reflection
- (c) Light shows phenomenon of diffraction
- (d) Light shows photoelectric effect.

**Solutions**

- 1.(a) 2.(c) 3.(c) 4.(b) 5.(d)

3. Read the following text and answer the following questions on the basis of the same:

**Photocell:** A photocell is a technological application of the photoelectric effect. It is a device whose electrical properties are affected by light. It is also sometimes called an electric eye. A photocell consists of a semi-cylindrical photo-sensitive metal plate C (emitter) and a wire loop A (collector) supported in an evacuated glass or quartz bulb. It is connected to the external circuit having a high-tension battery B and micro ammeter ( $\mu A$ ) as shown in the figure.



Sometimes, instead of the plate C, a thin layer of photosensitive material is pasted on the inside of the bulb. A part of the bulb is left clean for the light to enter it. When light of suitable wavelength falls on the emitter C, photoelectrons are emitted. These photoelectrons are drawn to the collector A. Photocurrent of the order of a few microampere can be normally obtained from a photo cell. A photocell converts a change in intensity of illumination into a change in photocurrent. This current can be used to operate control systems and in light measuring devices.

1. Photocell is an application of

- (a) thermoelectric effect
- (b) photoelectric effect
- (c) photoresistive effect
- (d) None of the above

2. Photosensitive material should be connected to

- (a) -ve terminal of the battery
- (b) +ve terminal of the battery
- (c) any one of (a) or (b)
- (d) connected to ground

3. Which of the following statement is true?

- (a) The photocell is totally painted black.
- (b) A part of the photocell is left clean.
- (c) The photocell is completely transparent.
- (d) A part of the photocell is made black.

4. The photocurrent generated is in the order of

- (a) ampere
- (b) milliampere
- (c) microampere
- (d) None of the above

5. A photocell converts a change in light into a change in of incident

- (a) intensity, photovoltage

- (b) wavelength, photovoltage
- (c) frequency, photocurrent
- (d) intensity, photocurrent

**Solutions**

- 1.(b)    2.(a)    3.(b)    4.(c)    5.(d)

**ASSIGNMENT – 1 ( MCQ QUESTIONS )**

1. A particle is dropped from a height H. The de Broglie wavelength of the particle as a function height is proportional to

- (a) H
- (b)  $H^{1/2}$
- (c)  $H^0$
- (d)  $H^{-1/2}$

2. The wavelength of a photon needed to remove a proton from a nucleus which is bound to the nucleus with 1 MeV energy is nearly

- (a) 1.2nm
- (b)  $1.2 \times 10^{-3}$ nm
- (c)  $1.2 \times 10^{-6}$ nm
- (d)  $1.2 \times 10^1$  nm

3. Consider a beam of electrons (each electron with energy E) incident on a metal surface kept in an evacuated chamber. Then

- (a) no electrons will be emitted as only photons can emit electrons.
- (b) electrons can be emitted but all with an energy,  $E_0$ .
- (c) electrons can be emitted with any energy, with a maximum of  $E_0 - \phi$  ( $\phi$  is the work function).
- (d) electrons can be emitted with any energy, with a maximum of  $E_0$ .

4. The threshold wavelength for photoelectric emission from a material is 5200 Å.

Photoelectrons will be emitted when this material is illuminated with monochromatic radiation from a:

- (a) 50 watt infrared lamp
- (b) 1000 watt infrared lamp
- (c) 1 watt ultraviolet lamp
- (d) 1 watt infrared lamp

5. A photoelectric cell is illuminated by a point source of light 1 m away. The plate emits electrons having stopping potential V. Then:

- (a) V decreases as distance increase
- (b) V increases as distance increase
- (c) V is independent of distance (r)
- (d) V becomes zero when distance increases or decreases

6. In a photoelectric experiment, the stopping-potential for the incident light of wavelength 4000 Å is 2 volt. If the wavelength be changed to 3000 Å, the stopping-potential will be:

- (a) 2 volt
- (b) less than 2 volt
- (c) zero
- (d) more than 2 volt

7. The work-function for a metal is 3 eV. To emit a photoelectron of energy 2 eV from the surface of this metal, the wavelength of the incident light should be:

- (a) 6187 Å
- (b) 4125 Å
- (c) 12375 Å
- (d) 2875 Å

8. In the Davisson and Germer experiment, the velocity of electrons emitted from the electron gun can be increased by

- (a) increasing the potential difference between the anode and filament
- (b) increasing the filament current
- (c) decreasing the filament current
- (d) decreasing the potential difference between the anode and filament

9. The work-function of a surface of a photosensitive material is 6.2 eV. The wavelength of incident radiation for which the stopping potential is 5 V lies in:

- (a) ultraviolet region
- (b) visible region
- (c) infrared region
- (d) X-ray region

10. A proton, a neutron, an electron and an  $\alpha$  -particle have same energy. Then their de Broglie wavelengths compare as

- (a)  $\lambda_p = \lambda_n > \lambda_e > \lambda_\alpha$
- (b)  $\lambda_\alpha < \lambda_p = \lambda_n > \lambda_e$
- (c)  $\lambda_e < \lambda_p = \lambda_n > \lambda_\alpha$
- (d)  $\lambda_e = \lambda_p = \lambda_n = \lambda_\alpha$

11. The number of photoelectrons emitted for light of frequency (higher than the threshold frequency  $\nu_0$ ) is proportional to:

- (a) threshold frequency
- (b) intensity of light
- (c) frequency of light
- (d)  $\nu - \nu_0$

12. Relativistic corrections become necessary when the expression for the kinetic energy  $1/2 mv^2$  becomes comparable with  $mc^2$  where m is the mass of the particle. At what de Broglie wavelength will relativistic corrections become important for an electron?

- (a)  $\lambda = 10\text{nm}$
- (b)  $\lambda = 10^{-1}\text{nm}$
- (c)  $\lambda = 10^{-4}\text{nm}$
- (d)  $\lambda = 10^{-6}\text{nm}$

13. Monochromatic light of wavelength 667 nm is produced by a helium neon laser. The power emitted is 9 mW. The number of photons arriving per second on the average at a target irradiated by this beam is:

- (a)  $3 \times 10^{16}$
- (b)  $9 \times 10^{15}$
- (c)  $3 \times 10^{19}$
- (d)  $9 \times 10^{17}$

14. Electrons used in an electron microscope are accelerated by a voltage of 25 kV. If the voltage is increased to 100 kV then the de-Broglie wavelength associated with the electrons would

- (a) increase by 2 times
- (b) decrease by 2 times
- (c) decrease by 4 times
- (d) increase by 4 times

15. Two particles A1 and A2 of masses  $m_1, m_2$  ( $m_1 > m_2$ ) have the same de Broglie wavelength. Then

- (a) their momenta are the same
- (b) their energies are the same
- (c) energy of A1 is less than the energy of A2
- (d) energy of A1 is more than the energy of A2

16. An electron (mass m) with an initial velocity  $\vec{v} = v_0\hat{i}$  is in an electric field  $\vec{E} = E_0\hat{j}$ . If  $\lambda_0 = h / mv_0$  it's de Broglie wavelength at time t is given by

- (a)  $\lambda_0$

(b)  $\lambda_0 \sqrt{1 + \frac{e^2 E_0^2 t^2}{m^2 v_0^2}}$

(c)  $\frac{\lambda_0}{\sqrt{1 + \frac{e^2 E_0^2 t^2}{m^2 v_0^2}}}$

$$(d) \frac{\lambda_0}{\left(1 + \frac{e^2 E_0^2 t^2}{m^2 v_0^2}\right)}$$

17. The de Broglie wavelength of an electron accelerated through , p .d. Vis directly proportional to V". Then n must be equal to ( n =)

- (a) 1 (b) -1  
(c) 0.5 (d) = -0.5

18. For a given kinetic energy, which of the following has smallest de Broglie wavelength:

- (a) electron (b) proton  
(c) deuteron (d)  $\alpha$  -particle

19. If an electron and a photon propagate in the form of waves having same wavelength, it implies that they have same:

- (a) speed (b) momentum  
(c) energy (d) all the above

20. A particle of mass 1 mg has the same wavelength as an electron moving with a velocity of  $3 \times 10^8 \text{ ms}^{-1}$ . The velocity of the particle is (mass of electron =  $9.1 \times 10^{-31} \text{ kg}$ )

- (a)  $2.7 \times 10^{-18} \text{ ms}^{-1}$   
(b)  $9 \times 10^{-2} \text{ ms}^{-1}$   
(c)  $3 \times 10^{-31} \text{ ms}^{-1}$   
(d)  $2.7 \times 10^{-21} \text{ ms}^{-1}$

### Solutions

- 1.(d) 2.(b) 3.(d) 4.(c) 5.(c) 6.(d) 7.(d) 8.(a) 9.(a) 10.(b)  
11.(b) 12.(c,d) 13.(a) 14.(b) 15.(a,c) 16.(c) 17.(d) 18.(d) 19.(b) 20.(d)

### ASSERTION AND REASON QUESTIONS

In the following questions a statement of assertion followed by a statement of reason is given. Choose the correct answer out of the following choices.

- (a) Assertion and reason both are correct statements and reason is correct explanation for assertion.  
(b) Assertion and reason both are correct statements but reason is not correct explanation for assertion.  
(c) Assertion is correct statement but reason is wrong statement.  
(d) Assertion is wrong statement but reason is correct statement.

**1. Assertion:** Matter has dual nature.

**Reason :** Light has dual nature.

**2. Assertion:** In the process of photoelectric emission, all emitted electrons have the same kinetic energy.

**Reason:** According to Einstein's equation  $E_k = hv - \phi_0$

**3. Assertion :** Photoelectric effect demonstrates the wave nature of light.

**Reason :** The number of photoelectrons is proportional to the wavelength of incident light.

**4. Assertion :** On increasing the frequency of light, the photocurrent remains unchanged.

**Reason :** Photocurrent is independent of frequency but depends only on intensity of incident light.

**5. Assertion :** On increasing the intensity of light the photocurrent increases.



**Reason** : The photocurrent increases with increase of frequency of light.

**6. Assertion** : Photoelectric process is instantaneous process.

**Reason** : When photons of energy ( $h\nu$ ) greater than work function of metal ( $\phi_0$ ) are incident on a metal, the electrons from metal are emitted with no time lag.

**7. Assertion** : Threshold frequency depends on intensity of light.

**Reason** : Greater is the photon frequency, greater is the energy of a photon.

**8. Assertion** : If frequency of incident light is doubled, the kinetic energy of photoelectron is also doubled.

**Reason** : The kinetic energy of photoelectron is directly proportional to frequency of incident light.

**9. Assertion** : An electron and a photon possessing same wavelength, will have the same momentum.

**Reason** : Electron and photon possess same energy.

**10. Assertion** : The electrons and protons having same momentum has same de Broglie wavelength.

**Reason** : de Broglie wavelength  $\lambda = h/P$

### Solutions

1.(b) 2.(d) 3.(d) 4.(a) 5.(c) 6.(a) 7.(d) 8.(d) 9.(a) 10.(a)

## **ASSIGNMENT – 2 ( DESCRIPTIVE QUESTIONS -2M & 3M)**

1. Write the basic features of photon picture of electromagnetic radiation on which Einstein's photoelectric equation is based.

2. In photoelectric effect, why should the photoelectric current increase as the intensity of monochromatic radiation incident on a photosensitive surface is increased? Explain.

3. There are materials which absorb photons of shorter wavelength and emit photons of longer wavelength. Can there be stable substances which absorb photons of larger wavelength and emit light of shorter wavelength?

4. Do all the electrons that absorb a photon come out as photoelectrons?

5. Electrons are emitted from a photosensitive surface when it is illuminated by green light but electron emission does not take place by yellow light. Will the electrons be emitted when the surface is illuminated by (i) red light, and (ii) blue light?

6. In a photoelectric effect, the yellow light is just able to emit electrons, will green light emit photoelectrons? What about red light?

7. Work function of aluminium is 4.2 eV. If two photons, each of energy 2.5 eV, are incident on its surface, will the emission of electrons take place? Justify your answer.

8. Write Einstein's photoelectric equation and point out any two characteristic properties of photons on which this equation is based.

9. Write three characteristic features in photoelectric effect which cannot be explained on the basis of wave theory of light, but can be explained only using Einstein's equation.

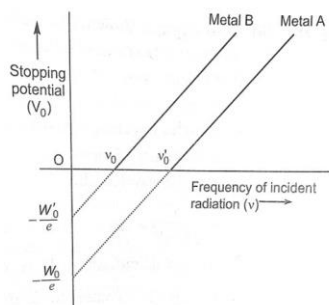
10. A proton and an electron have same velocity. Which one has greater de Broglie wavelength and why?

11. When the electron orbiting in hydrogen atom in its ground state moves to the third excited state, show how the de Broglie wavelength associated with it would be affected.

12. What is meant by work function of a metal? How does the value of work function influence the kinetic energy of electrons liberated during photoelectron emission?

13. Plot a graph showing the variation of stopping potential with the frequency of incident radiation for two different photosensitive materials having work functions  $W_1$  and  $W_2$  ( $W_1 > W_2$ ). On what factors does the (i) slope and (ii) intercept of the lines depend?
14. There are two sources of light, each emitting with a power 100W. One emits X-rays of wavelength 1 nm and the other visible light at 500 nm. Find the ratio of number of photons of X-rays the photons of visible light of the given wavelength.
15. Explain briefly the reasons why wave theory of light is not able to explain the observed features of photo-electric effect.
16. Write Einstein's photoelectric equation. State clearly the three salient features observed in photoelectric effect which can explain on the basis of this equation. The maximum kinetic energy of the photoelectrons gets doubled when the wavelength of light incident on the surface changes from  $\lambda_1$  to  $\lambda_2$ . Derive the expressions for the threshold wavelength and work function for the metal surface.
17. Using photon picture of light, show how Einstein's photoelectric equation can be established. Write two features of photoelectric effect which cannot be explained by wave theory.
18. Define the terms (i) 'cut-off voltage' and (ii) 'threshold frequency' in relation to the phenomenon of photoelectric effect. Using Einstein's photoelectric equation show how the cut-off voltage and threshold frequency for a given photosensitive material can be determined with the help of a suitable plot/graph.
19. Sketch the graphs showing variation of stopping potential with frequency of incident radiations for two photosensitive materials A and B having threshold frequencies  $\nu_A > \nu_B$ .
- (i) In which case is the stopping potential more and why?
- (ii) Does the slope of the graph depend on the nature of the material used? Explain.
20. A proton and a deuteron are accelerated through the same accelerating potential. Which one of the two has
- (i) greater value of de-Broglie wavelength associated with it, and
- (ii) less momentum?
- Give reason and justify your answers.
21. A beam of monochromatic radiation is incident on a photosensitive surface. Answer the following questions giving reasons:
- (i) Do the emitted photoelectrons have the same kinetic energy?
- (ii) Does the kinetic energy of the emitted electrons depend on the intensity of incident radiation?
- (iii) On what factors does the number of emitted photoelectrons depend?
22. (a) Define the term 'intensity of radiation' in terms of photon picture of light.
- (b) Two monochromatic beams, one red and the other blue, have the same intensity. In which case (i) the number of photons per unit area per second is larger, (ii) the maximum kinetic energy of the photoelectrons is more? Justify your answer.
23. 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.
24. Two monochromatic beams A and B of equal intensity  $I$ , hit a screen. The number of photons hitting the screen by beam A is twice that by beam B. Then what inference can you make about their frequencies?
25. A monochromatic light source of power 5mW emits  $8 \times 10^{15}$  photons per second. This light ejects photo electrons from a metal surface. The stopping potential for this set up is 2V. Calculate the work function of the metal.
26. Derive Einstein's photoelectric equation  $\nu^2 = h\nu - h\nu_0$ .

27. The graph shows the variation of stopping potential with frequency of incident radiation for two photosensitive metals A and B. Which one of the two has higher value of work-function? Justify your answer.



### Answers with Marking Scheme

1. i) Photons are particles of light having energy  $E = h\nu$  and momentum  $p = h/\lambda$ . (1M)  
 ii) Intensity of light depends on the number of photons. (1M)

2. The photoelectric current increases proportionally with the increase in intensity of incident radiation. (1M)

Larger the intensity of incident radiation, larger is the number of incident photons and hence larger is the number of electrons. (1M)

3. In the 1st case, energy given out is less than the energy supplied. (1M).

In the 2nd case, the material has to supply the energy as the emitted photon has more energy. This cannot happen for stable substances. (1M)

4. No. (1M). Most electrons get scattered into the metal. Only a few come out of the surface of the metal. (1M)

5. i) No (1M)

ii) Yes (1M)

6. As  $\lambda_{\text{green}} < \lambda_{\text{red}}$  so green light photon has more energy than yellow light photon. (1M)

As  $\lambda_{\text{red}} > \lambda_{\text{green}}$  so red light photon has lesser energy than yellow light photon. (1M)

7. In photoelectric effect, a single photon interacts with a single electron. (1M)

As individual photon has energy (2.5eV) which is less than work function, hence emission of electron will not take place. (1M)

8. Equation –  $K_{\text{max}} = \frac{1}{2} m v_{\text{max}}^2 = h\nu - h\nu_0$  (1M)

Characteristics – i) Energy of photon is directly proportional to the frequency (or inversely proportional to the wavelength). (1M)

ii) In photon-electron collision, total energy and momentum of the system of two constituents remains constant. (1M)

9. i) K.E of emitted electrons is found to be independent of the intensity. (1M)

ii) There is no emission of electrons if frequency of incident light is below a certain frequency. (1M)

iii) Photoelectric effect is an instantaneous process. (1M)

10.  $\lambda = h/mv$ . Given,  $v_p = v_e$ . Since  $m_p > m_e$  (1M)

$\lambda \propto 1/m$ , hence  $\lambda_p < \lambda_e$  (1M)

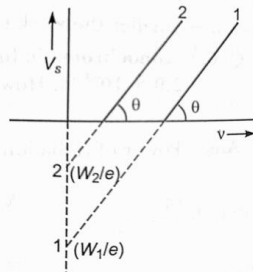
11.  $\lambda = h/p = h/mv = \lambda \propto 1/v$  (1M)

$v \propto 1/n \therefore$  de Broglie wavelength will increase. (1M)

12. The minimum energy required to free an electron from metallic surface is called the work function. (1M)

Smaller the work function, larger the kinetic energy of emitted electron. (1M)

13. i)  $\tan\theta = h/e$  ii) Intercept of lines depends on the work function. (2M)



(1M)

14.  $n_1 E_1 = n_2 E_2$ ,  $n_1 \times hc/\lambda_1 = n_2 \times hc/\lambda_2$  (1M)

$$n_1/n_2 = \lambda_1/\lambda_2, \quad n_1/n_2 = 1/500 \quad (1M)$$

15. According to wave theory, the kinetic energy of photoelectrons must depend on the intensity of incident light. (1M)

The light of any frequency can emit electrons from metallic surface provided the intensity of light be sufficient to provide necessary energy for emission of electrons. (1M)

The energy transferred by light waves will not go to a particular electron, but it will be distributed uniformly to all electrons present in the illuminated surface. (1M)

16. Equation –  $K_{\max} = \frac{1}{2} m v_{\max}^2 = h\nu - h\nu_0$  (1M)

Derivation - For  $\lambda_1$ ,  $hc/\lambda_1 = \phi_0 + K = \phi_0 + eV_0$

For  $\lambda_2$ ,  $hc/\lambda_2 = \phi_0 + 2eV_0$  (1M)

From above equations,

$$\phi_0 = 2hc/\lambda_1 - hc/\lambda_2$$

For threshold wavelength  $\lambda_0$  K.E,  $K = 0$ , and work function  $\phi_0 = hc/\lambda_0$

$$\therefore \text{On solving, } \phi_0 = hc(2\lambda_2 - \lambda_1) / \lambda_1 \lambda_2 \quad (1M)$$

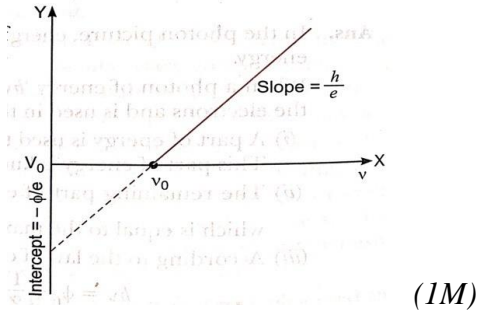
17. According to law of conservation of energy,

$$h\nu = \phi_0 + \frac{1}{2} m v_{\max}^2 \quad (1M)$$

$$\text{On solving } KE_{\max} = h\nu - \phi_0 \quad (1M)$$

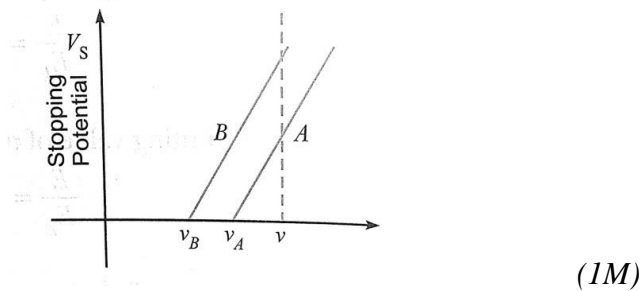
18. i) Cut off or stopping potential is that minimum value of negative potential at anode which just stops the photo electric current. (1M)

ii) For a given material, there is a minimum frequency of light below which no photo electric emission will take place, this is called as threshold frequency. (1M)



19. i) Material B (1M)

ii) No (1M)



20. i)  $\lambda_p > \lambda_d$  (1M)

ii)  $\lambda_p > \lambda_d$  (1M)

21.i) No (1M)

ii) No (1M)

iii) depends on the intensity of the radiations. (1M)

22. a) The number of photons incident normally per unit area per unit time is determined the intensity of radiations. (1M)

(b) i)  $(h\nu)_R < (h\nu)_B$  (1M)

ii)  $(h\nu)_B > (h\nu)_R$  (1M)

23. de Broglie wavelength associated with a moving charge particle having a KE 'K' can be given as.  $\lambda = h / p = h / \sqrt{2mk}$  ----- (1) (1M)

The kinetic energy electron in any orbit of hydrogen atom can be given as,

$$K = 13.6 / n^2 \times eV \text{ ----- (2)} \quad (1M)$$

$n_1 = 1$  and  $n_2 = 4$  and on solving (1) and (2),  $\lambda_1 = \lambda_4 / 4$  (1M)

$$24. I = n_A v_A = n_B v_B \quad (1M)$$

$$n_A / n_B = v_B / v_A \text{ or, } 2n_B / n_B = v_B / v_A \Rightarrow v_B = 2v_A \quad (1M)$$

$$25. P = 5 \times 10^{-3} \text{W}, n = 8 \times 10^{15} \text{ photons per second}$$

$$E = p / n = 6.25 \times 10^{-19} \text{J} / 1.6 \times 10^{-19} \text{eV} \quad (1M)$$

$$E = 3.9 \text{eV}$$

$$\text{Work function, } W_0 = E - V_0 = (3.9 - 2) \text{eV} = 1.9 \text{eV} \quad (1M)$$

26. Light is propagated in the form of bundles of energy. Each bundle of energy is called a quantum or photon. (1M)

$$\text{Derivation - } h\nu = W + E_K$$

$$E_K = h\nu - W \text{-----(1)}$$

$$W = h\nu_0 = hc / \lambda \text{-----(2)} \quad (1M)$$

$$\text{On solving, } 1 / 2mv^2 = h\nu - h\nu_0 \text{-----(3)} \quad (1M)$$

27. Metal A (1M)

Since work function  $W = h\nu_0$  and  $\nu'_0 > \nu_0$  so work function of metal A is more. (1M)

## REVISION QUESTION PAPER

(CHAPTERS 5 AND 6)

(35 MARKS)

Chapter :- E.M Waves and OPTICS

### GENERAL INSTRUCTIONS :Max marks - 35

- (i) There are 18 questions in all. All questions are compulsory
- (ii) This question paper has five sections: Section A, Section B, Section C, Section D and Section
- (iii) All the sections are compulsory.
- (iv) Section A contains nine MCQ of 1 mark each, Section B contains four questions of two marks each, Section C contains three questions of three marks each, section D contains one long question of five marks and Section E contains one case study based questions of 4 mark.
- (v) There is no overall choice. However, an internal choice has been provided in section B, C, D and E. You have to attempt only one of the choices in such questions.

SECTION - A

(9 x 1 = 9)

1.If  $\vec{E}$  and  $\vec{B}$  represent electric and magnetic field vectors of the electromagnetic wave, the direction of propagation of electromagnetic wave is along

- (A)  $\vec{E}$
- (B)  $\vec{B}$
- (C)  $\vec{B} \times \vec{E}$
- (D)  $\vec{E} \times \vec{B}$

2. In electromagnetic waves, the phase difference between magnetic and electric field vectors is

- (A) zero
- (B)  $\pi$
- (C)  $\pi / 2$
- (D)  $\pi / 4$

3. Electromagnetic wave having frequency  $5 \times 10^{11}$  Hz is

- (A) Ultraviolet wave
- (B) Radio wave
- (C) Microwave
- (D) X-ray

4. Convex mirrors are preferred over plane mirrors as rear view mirror in automobile since (A) the image formed is magnified

- (B) the image formed is real
- (C) the field of view is large
- (D) it is light weight

5. A short pulse of white light is incident from air to a glass slab at normal incidence. After travelling through the slab, the first colour to emerge is

- (A) blue
- (B) green
- (C) violet
- (D) red

6. Magnifying power of a microscope depends on

- (A) colour of light
- (B) focal length of objective and colour of light
- (C) focal length of eyepiece and colour of light
- (D) focal length of eyepiece and objective

7. Huygens theory could not explain

- (A) photoelectric effect
- (B) reflection of light

- (C) diffraction of light
- (D) interference of light

8. A Young's Double slit experiment is performed in air and in water. Which of the following relationship is true regarding fringe width ( $\beta$ )?

- (A)  $\beta_{\text{AIR}} > \beta_{\text{WATER}}$
- (B)  $\beta_{\text{WATER}} > \beta_{\text{AIR}}$
- (C)  $\beta_{\text{AIR}} = \beta_{\text{WATER}}$
- (D)  $\beta_{\text{WATER}} = 0$

9. The main condition for diffraction to be observed is

- (A) size of obstacle should be comparable to the wavelength of the wave
- (B) size of obstacle should be much larger than the wavelength of the wave
- (C) size of obstacle should be much smaller than the wavelength of the wave
- (D) for any size of obstacle

SECTION - B

(4 x 2 = 8)

1.(a) Why are infrared waves often called heat waves? Explain.

(b) What do you understand by the statement, "Electromagnetic waves transport momentum"?

2.(a) Name the electromagnetic radiation used to take the photograph of the bones.

(b) How is this radiation produced?

3. Why is objective of a microscope of short aperture and short focal length? Give reason.

(or)

The objective of a telescope is of larger focal length and of larger aperture (compared to the eyepiece). Why? Give reasons.

4. In Young's double slit experiment, two slits are separated by 3 mm distance and illuminated by light of wavelength 480 nm. The screen is at 2 m from the plane of the slits. Calculate the separation between the 8th bright fringe and the 3rd dark fringe observed with respect to the central bright fringe.

SECTION - C

(3 x 3 = 9)

1. How are electromagnetic waves produced? What is the source of energy of these waves? Draw a schematic sketch of the electromagnetic waves propagating along the + x-axis. Indicate the directions of the electric and magnetic fields. Write the relation between the velocity of propagation and the magnitudes of electric and magnetic fields.

2. Draw a labelled ray diagram of an astronomical telescope in the near point adjustment position. A giant refracting telescope at an observatory has an objective lens of focal length 15 m and an eyepiece of focal length 1.0 cm. If this telescope is used to view the Moon, find the diameter of the image of the Moon formed by the objective lens. The diameter of the Moon is  $3.48 \times 10^6$  m, and the radius of lunar orbit is  $3.8 \times 10^8$  m.

(or)

Plot a graph to show variation of the angle of deviation as a function of angle of incidence for light passing through a prism. Derive an expression for refractive index of the prism in terms of angle of minimum deviation and angle of prism.

3. (a) Define wavefront. Use Huygens' principle to verify the laws of refraction.

(b) In a double slit experiment using light of wavelength 600 nm, the angular width of the fringe formed on a distant screen is  $0.1^\circ$ . Find the spacing between the two slits.

SECTION - D

(1 X 5 = 5)

1.(a) Derive the mathematical relation between refractive indices  $n_1$  and  $n_2$  of two radii and radius of curvature R for refraction at a convex spherical surface. Consider the object to be a point since lying on the principle axis in rarer medium of refractive index  $n_1$  and a real image formed in the denser medium of refractive index  $n_2$ . Hence, derive lens maker's formula.



(b) Light from a point source in air falls on a convex spherical glass surface of refractive index 1.5 and radius of curvature 20 cm. The distance of light source from the glass surface is 100 cm. At what position is the image formed?

(or)

(a) Draw a ray diagram to show image formation when the concave mirror produces a real, inverted and magnified image of the object.

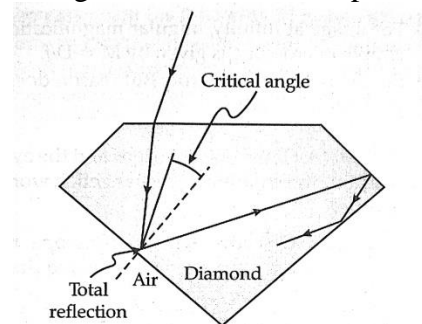
(b) Obtain the mirror formula and write the expression for the linear magnification.

(c) Explain two advantages of a reflecting telescope over a refracting telescope.

SECTION – E

(4 x 1 =4)

Read the following text and answer the following questions on the basis of the same: Sparking Brilliance of Diamond: The total internal reflection of the light is used in polishing diamonds to create a sparking brilliance. By polishing the diamond with specific cuts, it is adjusted the most of the light rays approaching the surface are incident with an angle of incidence more than critical angle. Hence, they suffer multiple reflections and ultimately come out of diamond from the top. This gives the diamond a sparking brilliance.



1. Light cannot easily escape a diamond without multiple internal reflections. This is because:

- (A) its critical angle with reference to air is too large.
- (B) its critical angle with reference to air is too small.
- (C) the diamond is transparent.
- (D) rays always enter at angle greater than critical angle.

2. The critical angle for a diamond is  $24.4^\circ$ . Then its refractive index is:

- (A) 2.42
- (B) 0.413
- (C) 1
- (D) 1.413

3. The basic reason for the extraordinary sparkle of suitably cut diamond is that:

- (A) it has low refractive index.
- (B) it has high transparency.
- (C) it has high refractive index.
- (D) it is very hard.

4. A diamond is immersed in a liquid with a refractive index greater than water. Then the critical angle for total internal reflection will:

- (A) depend on the nature of the liquid
- (B) decrease
- (C) remains the same
- (D) increase

**Marking scheme**

SECTION – A

- 1.(D) 2.(A) 3.(C) 4.(C) 5.(D) 6.(D) 7.(A) 8.(A) 9.(A)

SECTION – B

1.(a) Because the water molecules present in most materials readily absorb infrared waves. (1M)

(b) Electromagnetic waves carry both the energy and the momentum. (1M)

2. (a) X-rays (1M)

(b) By sudden deceleration of high speed electrons at high atomic number target. (1M)

3. Because light rays from the nearby tiny object spread over small aperture and the final image formed is very bright. (2M)

(or)

The focal length of objective must be larger for higher magnification. With the larger aperture of object, light gathering capacity of the telescope increases. Hence, a better resolution is obtained. (2M)

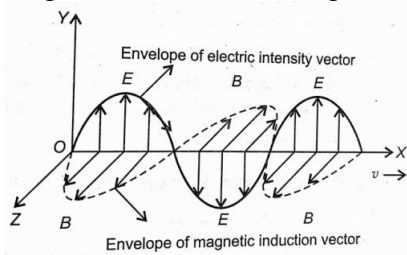
4.  $d = 3 \times 10^{-3} \text{m}$ ,  $\lambda = 480 \times 10^{-9} \text{m}$ ,  $D = 2 \text{m}$

$$\beta = \lambda D / d = 32 \times 10^{-5} \text{ (1M)}$$

Separation between 8<sup>th</sup> bright and 3<sup>rd</sup> dark fringe =  $1.76 \times 10^{-3} \text{m}$ . (1M)

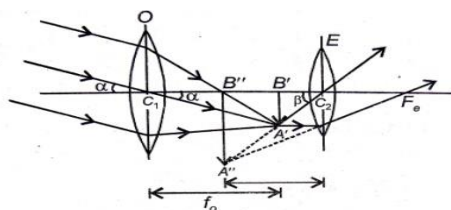
SECTION – C

1. Produced by both electric and magnetic fields. When charge is accelerated, the electric and the magnetic fields will change with space and time, it then produces electromagnetic waves. (1M)



(1M)

Relation :  $c = E / B$  (1M)



2.

(1M)

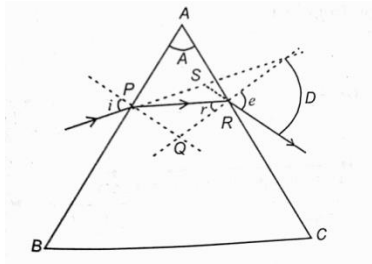
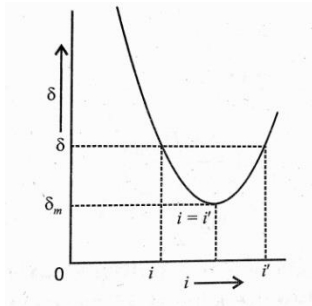
Given  $f_0 = 15 \times 10^2 \text{cm}$ ,  $f_e = 1 \text{cm}$

Angle subtended by image =  $d / f_0$  ..... (1)

Angle subtended by diameter of moon =  $3.48 \times 10^6 / 3.8 \times 10^8$  ..... (2) (1M)

From (1) and (2)  $d = 13.73 \text{cm}$  (1M)

(or)



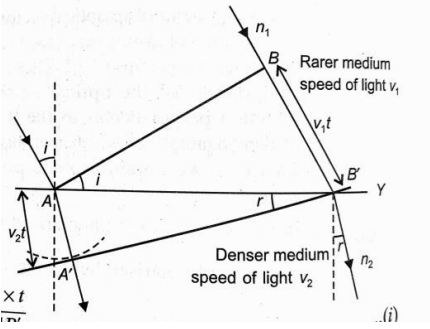
$$(1+1 = 2M)$$

In trapezium APQR,  $\angle A + \angle PQR = 180^\circ$ ----(1)  
 In triangle PQR,  $\angle r + \angle PQR + \angle r' = 180^\circ$ ---- (2)

On solving,

$$\mu = \frac{\sin\left(\frac{A + D_{\min}}{2}\right)}{\sin\frac{A}{2}} \quad (1M)$$

3. (a) A wavefront is the locus of all the points in space which receives the light waves from a source in phase. (1M)

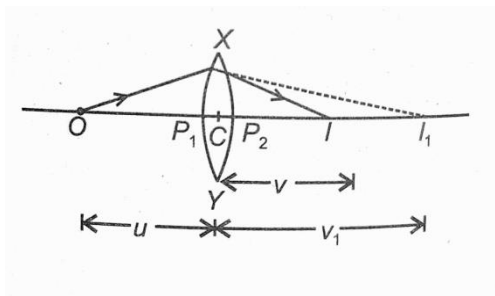


... (i) On solving,  $\sin i / \sin r = v_1 / v_2$  (1M)

(b) Given,  $\lambda = 600 \times 10^{-9} \text{ m}$ ,  $\Delta\theta = 0.1^\circ$   
 $\Delta\theta = \lambda / d$   
 $d = 0.34 \text{ mm}$  (1M)

**SECTION – D**

1.(a) Lens Maker's Formula:  $n = n_2 / n_1$   
 $(n_2 / v_1) - (n_1 / u) = n_2 - n_1 / R_1$  (1M)



(1M)

On solving,  $1/f = (n-1)[1/R_1 - 1/R_2]$

(1M)

(b)  $u = -100$  cm;  $n = 1.5$ ;  $R = 20$  cm

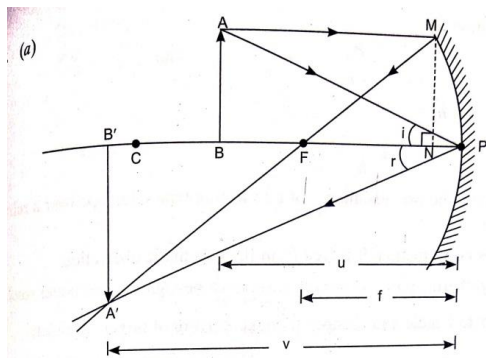
Using lens formula  $1/f = 1/v - 1/u$

(1M)

$v = 25$  cm

(1M)

(or)



(1M)

(b) From the above diagram prove  $m = h_1/h_0 = -v/u$  (3M)

(c) As there is no refraction, it is free from the chromatic aberration.

The light gathering power of the objective must be higher to get better resolution. (2M)

SECTION - E

1.(B) 2.(A) 3.(C) 4.(D)

# Unit - VIII Atoms and Nuclei (Chapter 12 & 13)

## FORMULA CHART

<b>GIST</b>	
<p><b>Thomson's Atom Model:</b> An atom is a positively charged sphere in which electrons are embedded like seeds in the watermelon.</p>	<p><b>Drawbacks:</b> It couldn't explain large angle scattering of <math>\alpha</math>-particles &amp; the origin of line spectra.</p>
<p><b>Rutherford's Atom model:</b> An atom consists of a tiny central core, called the <b>nucleus</b>, in which the entire positive charge and mass of the atom are concentrated. The size of the nucleus(<math>10^{-14}</math> m) is 10000 times smaller than the size of the atom(<math>10^{-10}</math> m) The electrons are spread over the remaining part of the atom, leaving plenty of empty space in the atom. As atom is neutral, the total negative charge of electrons is equal to total positive charge in the nucleus. The electrons are revolving around the nucleus in circular orbits. The necessary centripetal force is provided by the force of attraction between the nucleus and the electrons</p>	<p><b>Drawbacks:</b> It couldn't explain the stability of the atoms and emission of line spectra.</p>
<p><b>Distance of closest approach of <math>\alpha</math> particle in the scattering experiment</b></p>	$r = \frac{KZe(Ze)}{1/2mv^2}$
<p><b>Impact parameter of the <math>\alpha</math>-particle</b></p>	$b = \frac{KZe^2 \cot\theta/2}{\frac{1}{2}mv^2}$
<p><b>Bohr's Atom model: Postulates:</b> 1. An atom consists of a tiny central core, called the <b>nucleus</b>, in which the entire positive charge and mass of the atom are concentrated. The electrons are revolving around the nucleus in circular orbits. The necessary centripetal force is provided by the force of attraction between the nucleus and the electrons. 2. The electron can revolve in those circular orbits in which angular momentum of an electron is integral multiple of <math>h/2\pi</math> then electron can revolve without radiating energy. Angular momentum = <math>mvr = nh/2\pi</math> 3. The energy is radiated, when an electron jumps from higher orbit to lower orbit. <math>h\nu = E_i - E_f</math></p>	<p><b>Limitations:</b> It can be applicable only for hydrogen like atoms &amp; couldn't explain the splitting of spectral lines.</p>

<b>Orbit radius of the electron around the nucleus</b>	$r = 4\pi\epsilon_0 \frac{n^2 h^2}{4\pi^2 m e^2} = 0.53 \text{ \AA} n^2$
<b>Speed of the electron</b>	$v = \frac{1}{4\pi\epsilon_0} \frac{2\pi e^2}{nh} = \frac{1}{137} \frac{c}{n}$
<b>Energy of the electron in the <math>n^{\text{th}}</math> orbit of the hydrogen atom</b>	<p>Kinetic Energy = <math>E_K = \frac{1}{2} m v^2 = \frac{1}{4\pi\epsilon_0} \frac{Z e^2}{2r}</math></p> <p>Potential Energy = <math>E_P = -\frac{1}{4\pi\epsilon_0} \frac{Z e^2}{r}</math></p> <p>Total Energy = <math>E = -\frac{1}{4\pi\epsilon_0} \frac{Z e^2}{2r}</math>  <math>= \frac{-13.6}{n^2} \text{ eV}</math></p>
<b>The wavelength of the radiation emitted</b>	$\frac{1}{\lambda} = R_H \left( \frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$ <p><math>R_H = 1.09678 \times 10^7 \text{ m}^{-1}</math></p> <p>Lyman Series: <math>n_f = 1</math>, <math>n_i = 2, 3, 4, \dots</math> UV region</p> <p>Balmer Series: <math>n_f = 2</math>, <math>n_i = 3, 4, 5, \dots</math> visible region</p> <p>Paschen Series: <math>n_f = 3</math>, <math>n_i = 4, 5, 6, \dots</math> IR region</p> <p>Brackett Series: <math>n_f = 4</math>, <math>n_i = 5, 6, 7, \dots</math> IR region</p> <p>Pfund Series: <math>n_f = 5</math>, <math>n_i = 6, 7, 8, \dots</math> far IR region</p>
<b>Atomic Number (Z)</b>	No. of protons or no. of electrons in the neutral atom
<b>Mass Number (A)</b>	No. of nucleons (protons + neutrons) in a nucleus
<b>Number of neutrons</b>	$A - Z$
<b>Nuclear radius</b>	$R = R_0 A^{1/3}$ Where $R_0 = 1.2 \times 10^{-15} \text{ m}$
<b>Isotopes</b>	Same Z and different A Ex. ${}^1_1\text{H}, {}^2_1\text{H}, {}^3_1\text{H}$
<b>Isobars</b>	Same A and different Z Ex. ${}^{40}_{18}\text{Ar}, {}^{40}_{20}\text{Ca}$
<b>Isotones</b>	Same no. of neutrons Ex. ${}^3_1\text{H}, {}^4_2\text{He}$
<b>Mass Defect (<math>\Delta m</math>) in amu</b>	Total mass of nucleons – mass of nucleus
<b>Binding Energy (BE):</b> <i>It is the energy required to break up a nucleus into its constituent particles (protons and neutrons)</i>	$BE = \Delta m c^2$ $= (\Delta m) \times 931.5 \text{ in eV}$
<b>Packing Fraction</b>	$\Delta m / A$
<b>Energy Equivalence of 1 amu</b>	<b>931.5 MeV</b>
<b>Radioactive decay law</b>	Rate of disintegration $\propto$ no. of atoms present $\frac{dN}{dt} = -\lambda N$ $\lambda =$ disintegration constant Activity = $-\frac{dN}{dt} = \lambda N$ unit : curie
<b>No. of nuclei remain undecayed at any instant</b>	$N = N_0 e^{-\lambda t}$ $N = N(1/2)^n$

	Where $n = t/T_{1/2}$
<b>Half-life</b> ( $T_{1/2}$ ) -time required to disintegrate half of the nuclei in the radioactive sample.	$T_{1/2} = \frac{0.693}{\lambda}$
<b>Mean life</b> ( $T_a$ )-average time for which the nuclei of the atoms of the radioactive substance exist.	$T_a = \frac{1}{\lambda}$
<b>Nuclear Fission</b>	Spitting of a heavy nucleus into lighter nuclei It takes place in nuclear reactor, atom bomb
<b>Nuclear Fusion</b>	Fusing of lighter nuclei into a heavy nucleus It takes place in Stars and Hydrogen bomb.

## NUMERICALS FOR PRACTICE WITH SOLUTIONS

1. The wavelength of the second line of the Balmer series in the hydrogen spectrum is 4861 Å. Calculate the wavelength of the first line.

**Ans:**  $\lambda_1$  and  $\lambda_2$  are the wavelengths of the first and second lines of the Balmer Series are given by

$$\frac{1}{\lambda_1} = R_H \left( \frac{1}{2^2} - \frac{1}{3^2} \right) = \frac{5}{36} R_H$$

$$\frac{1}{\lambda_2} = R_H \left( \frac{1}{2^2} - \frac{1}{4^2} \right) = \frac{3}{16} R_H$$

$$\frac{\lambda_1}{\lambda_2} = \frac{3}{16} \times \frac{36}{5} = \frac{27}{20}$$

$$\lambda_1 = \frac{27}{20} \times \lambda_2 = \frac{27}{20} \times 4861 = 6562 \text{ Å}$$

2. The ground state energy of hydrogen atom is -13.6 eV. What is the KE and PE of the electron in this state?

**Ans:** Kinetic Energy =  $E_K = \frac{1}{2}mv^2 = \frac{1}{4\pi\epsilon_0} \frac{Ze^2}{2r} E_K = -E$

Potential Energy =  $E_P = -\frac{1}{4\pi\epsilon_0} \frac{Ze^2}{r} E_P = 2E$

Total Energy =  $E = -\frac{1}{4\pi\epsilon_0} \frac{Ze^2}{2r} \quad E = -13.6 \text{ eV (given)}$

KE = 13.6 eV, PE = 2 X -13.6 = -27.2 eV

3. Derive the Bohr's quantization condition for angular momentum of the orbiting electron in the hydrogen atom using de Broglie's hypothesis.

**Ans:** By de Broglie's hypothesis,

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

Using de Broglie's condition of stationary orbits,

$$2\pi r = n\lambda \quad \text{or} \quad 2\pi r = n \times \frac{h}{mv}$$

$$mvr = L = \frac{nh}{2\pi} \quad \text{This is Bohr's quantization condition for angular momentum of}$$

orbiting electron in hydrogen atom.

4. The photon emitted during the de-excitation from the first excited level to the ground state of hydrogen atom is used to irradiate a photocathode of a photocell, in which stopping potential of 5 V is used. Calculate the work function of the cathode used.

**Ans:** Energy of incident photon =  $E_2 - E_1 = -3.4 - (-13.6) = 10.2 \text{ eV}$

KE of the photo electron =  $eV_0 = 5 \text{ eV}$

By conservation of energy,

Energy of incident photon = KE of photo electron + work function

$$10.2 \text{ eV} = 5 \text{ eV} + W_0$$

$$W_0 = 5.2 \text{ eV}$$

5. Calculate the shortest and longest wavelength of the Bracket series.

**Ans: For shortest Wavelength:**

Correspond to the transition of electrons from  $n_i = \infty$  to  $n_f = 4$

$$\frac{1}{\lambda} = R_H \left( \frac{1}{n_f^2} - \frac{1}{n_i^2} \right) = R_H \left( \frac{1}{4^2} - \frac{1}{\infty^2} \right) = \frac{R}{16}$$

$$\lambda_s = 16/R = \frac{16}{1.097 \times 10^7} = 1458.5 \text{ nm}$$

**For longest Wavelength:**

Correspond to the transition of electrons from  $n_i = 5$  to  $n_f = 4$

$$\frac{1}{\lambda} = R_H \left( \frac{1}{n_f^2} - \frac{1}{n_i^2} \right) = R_H \left( \frac{1}{4^2} - \frac{1}{5^2} \right) = \frac{9R}{400}$$

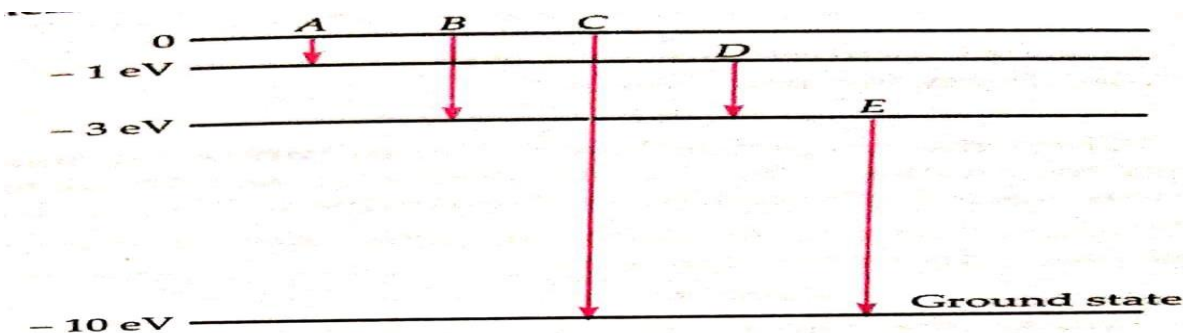
$$\lambda_s = \frac{400}{9R} = \frac{400}{9 \times 1.097 \times 10^7} = 4051 \text{ nm}$$

6. A hydrogen atom is in its third excited state. How many spectral lines can be emitted by it before coming to the ground state? In which of the transitions will the spectral line of shortest wavelength be emitted?

**Ans:** Here  $n = 4$ . The total number of spectral lines emitted =  $\frac{n(n-1)}{2} = \frac{4 \times 3}{2} = 6$  spectral lines

The spectral line of shortest wavelength will be emitted in the transition  $n = 4 \rightarrow n = 1$  as it corresponds to the photon of maximum energy

7. The energy levels of an atom of element X are shown in the diagram. Which one of the level transition will result in the emission of photon of wavelength 620 nm? Support your answer with mathematical calculations.



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$$\begin{aligned} \text{Ans: } E &= h\nu = \frac{hc}{\lambda} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{620 \times 10^{-9}} = 3.2 \times 10^{-19} \text{ J} \\ &= \frac{3.2 \times 10^{-19}}{1.6 \times 10^{-19}} = 2 \text{ eV} \end{aligned}$$

This corresponds to the transition 'D'. Hence transition D will result in emission of wavelength 620 nm.



8. A hydrogen atom initially in its ground state absorbs a photon of energy 12.5 eV. Calculate the longest wavelength of the radiation emitted and identify the series to which it belongs.

**Ans:** Energy of electron in ground state = -13.6 eV

Energy of the incident photon = 12.5 eV

Energy of the electron after absorption of the photon = -13.6 - (12.5) = -1.1 eV

This means that electron can go to the excited state  $n_i = 3$ . It emits photon of longest wavelength on going to  $n_f = 2$

$$\frac{1}{\lambda_L} = R_H \left( \frac{1}{2^2} - \frac{1}{3^2} \right) = \frac{5}{36} R_H$$

$$\lambda_L = \frac{36}{5R} = \frac{36}{5 \times 1.1 \times 10^7} = 6555 \text{ \AA}$$

It belongs to visible region and hence belongs to Balmer series.

9. Calculate the binding energy per nucleon of  ${}^{40}_{20}\text{Ca}$ . Given;  $m({}^{40}_{20}\text{Ca}) = 39.962589 \text{ amu}$   
 $M_n = 1.008665 \text{ amu}$ ,  $m_p = 1.007825 \text{ amu}$ .

**Ans:** mass of 20 protons = 20 X 1.007825 = 20.1565 amu

Mass of 20 neutrons = 20 X 1.008665 = 20.1733 amu

Total mass = 40.3298 amu

Mass of  ${}^{40}_{20}\text{Ca}$  nucleus = 39.962589 amu

Mass defect = 0.367211 amu

B.E = 0.367211 X 931.5 = 341.87 MeV

B.E per nucleon =  $\frac{341.87}{40} = 8.547 \text{ MeV}$

10. Prove that the instantaneous rate of change in activity of a radioactivity substance is inversely proportional to the square of its half-life.

**Ans:**  $R = \frac{dN}{dt} = -\lambda N$

$\frac{dR}{dt} = \lambda \frac{dN}{dt}$  (ignoring the negative sign)

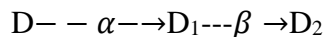
$$= \lambda \cdot \lambda N = \lambda^2 N$$

$$\text{we know } T = \frac{\log_e 2}{\lambda}$$

$$= \frac{\log_e 2 \lambda^2 N}{T^2}$$

$$\frac{dR}{dt} \propto \frac{1}{T^2}$$

10. The radioactive isotope D decays according to the sequence



If the mass number and atomic number of  $D_2$  are 176 and 71 respectively, What is the

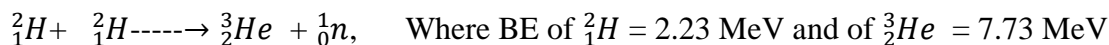
(i) mass number (ii) atomic number of D ?

**Ans:** The sequence is represented as  ${}^A_Z D \xrightarrow{\alpha} {}^{A-4}_{Z-2} D_1 \xrightarrow{\beta} {}^{A-4}_{Z-1} D_2$

(i) **Given**  $A-4 = 176 \rightarrow$  Mass number of D,  $A = 180$

(ii) **Z-1 = 71**  $\rightarrow$  Atomic number of D,  $Z = 72$

11. Calculate the energy released in fusion reaction:



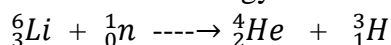
**Ans:**

Initial Binding Energy  $\text{BE}_1 = (2.23 + 2.23) = 4.46 \text{ MeV}$

Final Binding Energy  $\text{BE}_2 = 7.73 \text{ MeV}$

Energy Released =  $(7.73 - 4.46) = 3.27 \text{ MeV}$

**12.** Calculate the energy released in the reaction:



Given that mass of  ${}^6_3\text{Li} = 6.015126 \text{ amu}$ ; mass of  ${}^4_2\text{He} = 4.002603 \text{ amu}$ , mass of  ${}^3_1\text{H} = 3.016049 \text{ amu}$ ; mass of  ${}^1_0\text{n} = 1.008665 \text{ amu}$  and  $1 \text{ amu} = 931 \text{ MeV}$

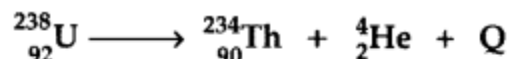
**Ans:** Total mass of the reactants =  $6.015126 + 1.008665 = 7.023791 \text{ amu}$

Total mass of the products =  $4.002603 + 3.016049 = 7.018652 \text{ amu}$

Loss in mass or decrease in mass =  $7.023791 - 7.018652 = 0.005139 \text{ amu}$

Energy released =  $0.005139 \times 931 = 4.78 \text{ MeV}$

**13.** Calculate the energy released in MeV in the following nuclear reaction:



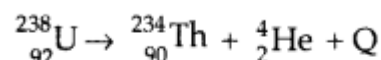
[Mass of  ${}^{238}_{92}\text{U} = 238.05079 \text{ u}$ ,

Mass of  ${}^{234}_{90}\text{Th} = 234.043630 \text{ u}$ ,

Mass of  ${}^4_2\text{He} = 4.002600 \text{ u}$ ,  $1 \text{ u} = 931.5 \text{ MeV}/c^2$ ]

Answer:

Nuclear reaction



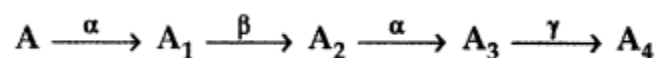
Energy released,  $\text{Q} = \Delta m c^2$

$$= (M_{\text{U}} - M_{\text{Th}} - M_{\text{He}}) c^2$$

$$= 0.00456 \times 931.5 \text{ MeV}$$

$$= 4.25 \text{ MeV}$$

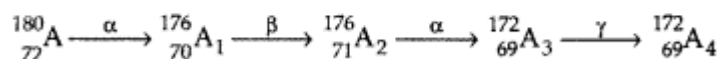
**14.** A radioactive nucleus 'A' undergoes a series of decays according to the following scheme:



The mass number and atomic number of A are 190 and 75 respectively. What are these numbers for  $\text{A}_4$ ?

Answer:

The series can be shown as below :



So, the Mass number of  $\text{A}_4 \rightarrow 182$

and Atomic number of  $\text{A}_4 \rightarrow 72$

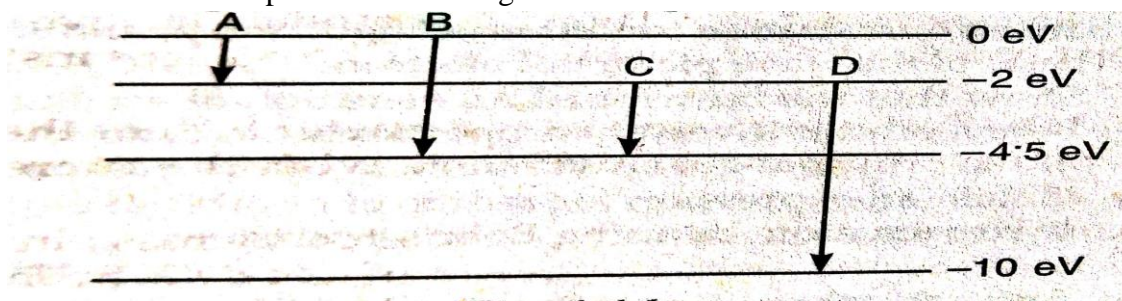
## **NUMERICALS FOR PRACTICE**

1. What is the shortest wavelength present in the Paschen series of hydrogen spectrum?  
**Hint:**  $n_f = 3$ ,  $n_i = \text{infinity}$ ,  $\lambda = 9/R = 8204 \text{ \AA}$
2. The ground state energy of hydrogen atom is  $-13.6 \text{ eV}$ . What is the K.E & P.E of the electron in this state?
3. Find the ratio of maximum wavelength of Lyman series in hydrogen spectrum to the maximum wavelength in Paschen series? **Ans:** 7 : 108
4. Calculate the frequency of the photon which can excite an electron to  $-3.4 \text{ eV}$  from  $-13.6 \text{ eV}$ . **Ans:**  $2.5 \times 10^{15} \text{ Hz}$
5. The wavelength of the first member of Balmer series in the hydrogen spectrum is  $6563 \text{ \AA}$ . Calculate the wavelength of the first member of Lyman series in the same spectrum.  
**Ans:**  $1215.4 \text{ \AA}$
6. What is the energy possessed by an electron for  $n = \alpha$  ? **Ans:**  $E = 0$
7. Calculate the ratio of wavelength of photon emitted due to transition of electrons of hydrogen atom from
  - (i) Second permitted level to first level
  - (ii) Highest permitted level to second level
8. The radius of inner most electron orbit of hydrogen atom is  $5.3 \times 10^{-11} \text{ m}$ . What are radii for  $n = 2, 3, 4$  ?
9. By what factor must the mass number change for the nuclear radius to become twice?
10. If 70% of a given radioactive sample is left undecayed after 20 days, What is the percentage of original sample will get decayed in 60 days?
11. Tritium has a half life of 12.5 years against beta decay. What fraction of a sample of pure tritium will remain undecayed after 25 years?
12. What percentage of a given mass of a radioactive substance will be left undecayed after 5 half life periods?
13. Two nuclei P & Q have equal number of atoms at  $t = 0$ . Their half lives are 3 & 9 hours respectively. Compare the rates of disintegration after 18 hours from the start.  
**Ans: 3:16**
14. One gram of radium is reduced by 2.1 mg in 5 years by decay. Calculate the half-life of radium. **Ans:** 1672 years
15. At a given instant there are 25% undecayed radioactive nuclei in a sample. After 10 seconds the number of undecayed nuclei reduces to 12.5%. Calculate the (i) mean life of the nuclei (ii) the time in which the number of the undecayed nuclei will further reduce to 6.25% of the reduced number.
16. Half lives of two substances A and B are 20 min and 40 min respectively. Initially the sample had equal number of nuclei. Find the ratio of the remaining number of nuclei of A and B after 80min.  
**Ans: 1:4**

17. If 200MeV energy is released in the fission of single nucleus of  $^{235}_{92}\text{U}$  , how much fission must occur to produce a power of 1 KW.
18. From the given data, write the nuclear reaction for  $\alpha$ -decay of  $^{238}_{92}\text{U}$  and hence calculate the energy released. Mass of  $^{238}_{92}\text{U} = 238.05079$  amu, mass of  $^4_2\text{He} = 4.00260$  amu, mass of  $^{234}_{90}\text{Th} = 234.04363$  amu.
19. Binding energy of  $^{16}_8\text{O}$  &  $^{35}_{17}\text{Cl}$  are 127.35 MeV and 289.3 MeV respectively. Which of the two nuclei is more stable?
20. Plutonium decays with half life of 24000 years. If plutonium is stored for 72000 years, what fraction of it remains?

**Ans:1/8**

21. The energy levels of an atom are as shown in fig. Which one of these transitions will result in the emission of a photon of wavelength 275 nm?

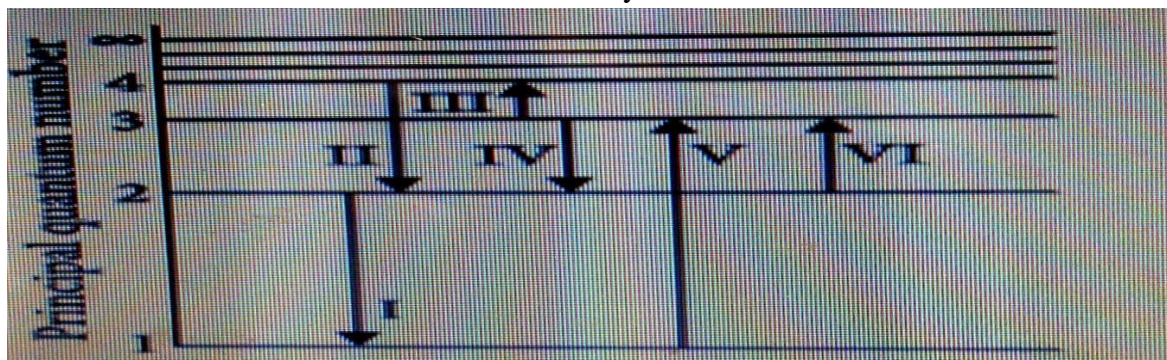


**Ans: transition B**

## CASE STUDY QUESTIONS

### 1. Electron Transitions for the Hydrogen Atom

Bohr's model explains the spectral lines of hydrogen atomic emission spectrum. While the electron of the atom remains in the ground state, its energy is unchanged. When the atom absorbs one or more quanta of energy, the electrons move from the ground state orbit to the excited state orbit that is further away.



The given figure shows an energy level diagram of the hydrogen atom. Several transitions are marked as I,II,III and so on. The diagram is only indicative and to scale.

- (i) In which transition is Balmer series photon absorbed?
- (a) II                      (b) III                      (c) IV                      (d) VI

- (ii) The wavelength of the radiation involved in transition II is  
 (a) 291 nm      (b) 364 nm      (c) 487 nm      (d) 652 nm
- (iii) Which transition will occur when a hydrogen atom is irradiated with radiation of wavelength 103 nm?  
 (a) I      (b) II      (c) IV      (d) V
- (iv) The electron in a hydrogen atom makes a transition from  $n = n_1$  to  $n = n_2$  state. The time period of the electron in the initial state is eight times that in the final state. The possible values of  $n_1$  and  $n_2$  are  
 (a)  $n_1 = 4$  and  $n_2 = 2$       (b)  $n_1 = 8$  and  $n_2 = 2$       (c)  $n_1 = 8$  and  $n_2 = 3$   
 (d)  $n_1 = 6$  and  $n_2 = 2$
- (v) The Balmer series for the H-atom can be observed  
 (a) If we measure the frequencies of light emitted when an excited atom falls to the ground state  
 (b) If we measure the frequencies of light emitted due to transitions between excited states and the first excited state.  
 (c) In any transition in a H-atom  
 (d) None of these.

**Ans:**

- (i) (d): For Balmer series  $n_1 = 2$ (lower);  $n_2 = 3, 4, \dots$ (higher)  
 Therefore, in transition (VI), photon of Balmer series is absorbed.

(ii)(c): in transition II

$$E_2 = -3.4 \text{ eV}, E_4 = -0.85 \text{ eV} \quad \Delta E = 2.55 \text{ eV} = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{\Delta E} = 487 \text{ nm}$$

(iii)(d) Wavelength of radiation = 1030 Å

$$\Delta E = \frac{12400}{1030 \text{ Å}} = 12.0 \text{ eV}$$

$$\text{Hence for } n_1 = 1 \text{ to } n_2 = 3 \quad E_{n_3} - E_{n_1} = -1.51 - (-13.6) = 12.09 = 12 \text{ eV}$$

Therefore, transition V will occur.

$$(iv) \quad (a) T^2 \propto r^3 \text{ and } r \propto n^2 \quad T^2 \propto n^6 \quad T \propto n^3$$

$$\frac{T_1}{T_2} = (n_1/n_2)^3 = 8 \quad \frac{n_1}{n_2} = 2$$

(v)(b)

## 2. Alpha Scattering Experiment;

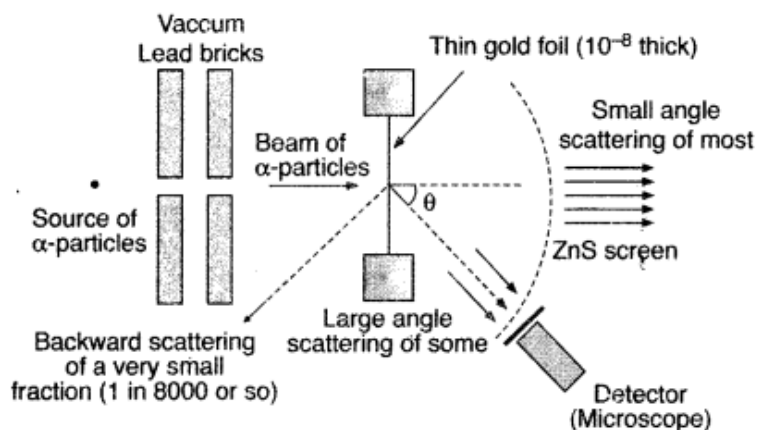
In 1911, Rutherford, along with his assistants, H. Geiger and E. Marsden, performed the alpha particle scattering experiment. They took radioactive source Bi-214 for  $\alpha$ -particles. A collimated beam of  $\alpha$ -particles of energy 5.5 MeV was allowed to fall on  $2.1 \times 10^{-7}$  m thick gold foil. The  $\alpha$ -particles were observed through a rotatable detector consisting of a zinc sulphide screen and microscope. He found that  $\alpha$ -particles got scattered. These

scattered  $\alpha$ -particles produced scintillations on the zinc sulphide screen. Observations of this experiment are as follows

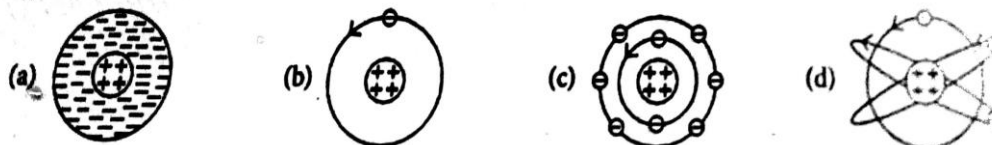
- (i) Most of the  $\alpha$ -particles passed through the foil without deflection.
- (ii) Only about 0.14% of the incident  $\alpha$ -particles scattered by more than  $1^\circ$
- (iii) Only about one  $\alpha$ -particle in every 8000  $\alpha$ -particles deflected by more than  $90^\circ$

These observations led to many arguments and conclusions which laid down the structure of the nuclear model of an atom.

(a) (i) **Geiger-Marsden experiment**



- (i) Rutherford's atomic model can be visualized as



Scanned with CamScanner

- (ii) In Geiger-Marsden scattering experiment, the trajectory traced by an  $\alpha$ -particle depends on
  - (a) Number of collision
  - (b) number of scattered  $\alpha$ -particles
  - (c) impact parameter
  - (d) None of these.
- (iii) Gold foil used in Geiger-Marsden experiment is about  $10^{-8}$ m thick. This ensures that
  - (a) Gold foil's gravitational pull is small or possible.
  - (b) Gold foil is deflected when  $\alpha$ -particle stream is not incident centrally over it
  - (c) Gold foil provides no resistance to passage of  $\alpha$ -particles
  - (d) Most  $\alpha$ -particles will not suffer more than  $1^\circ$  scattering during passage through gold foil
- (iv) In the Geiger-Marsden scattering experiment, in case of head-on collision, the impact parameter should be
  - (a) Maximum
  - (b) minimum
  - (c) infinite
  - (d) zero

- (v) The fact only a small fraction of the number of incident particles rebound back in Rutherford Scattering indicates that
- (a) Number of  $\alpha$ -particles undergoing head-on-collision is small
  - (b) Mass of the atom is concentrated in a small volume
  - (c) Mass of the atom is concentrated in a large volume
  - (d) Both (a) and (b)

**Ans: (i) (d)      (ii)(c)      (iii)(d)      (iv)(b)      (v)(d)**

### 3. DISCOVERY OF NUCLEUS

The nucleus was first discovered in 1911 by Rutherford and his team by experiments on scattering of  $\alpha$ -particles by atoms. He found that the scattering result could be explained if atom consists of small, central, massive and positively charged core surrounded by orbiting electrons. The experimental results indicated that the size of the nucleus is of the order of  $10^{-14}$  m and is thus 10000 times smaller than the size of the atom.

- (i) Ratio of mass of nucleus with mass of the atom is approximately  
(a) 1      (b) 10      (c)  $10^3$       (d)  $10^{10}$
- (ii) Masses of hydrogen, deuterium and tritium are in the ratio  
(a) 1:2:3      (b) 1:1:1      (c) 1:1:2      (d) 1:2:4
- (iii) Nuclides with same neutron number but different atomic number are  
(a) isobars      (b) isotopes      (c) isotones      (d) none of these
- (iv) If R is the radius and A is the mass number, then log R versus log A graph will be  
(a) A straight line      (b) a parabola      (c) an ellipse      (d) none of these
- (iv) The ratio of the nuclear radii of the gold isotope  $^{197}_{79}\text{Au}$  and silver isotope  $^{107}_{47}\text{Ag}$   
(a) 1.23      (b) 0.226      (c) 2.13      (d) 3.46

**Ans: (i) (a)      (ii) (a)      (iii) (c)      (iv) (a)      (v) (a)**

### ASSIGNMENT 1

When a  $\beta$ -particle is emitted from a nucleus then its neutron-proton ratio

- (a) increases      (b) decreases
- (c) remains unchanged.      (d) may increase or decrease depending upon the nucleus.

**Answer: b**

Explanation:

(b) In  $\beta$ -decay neutron converts to proton with emission of electron and neutrino.

The quantity which is not conserved in a nuclear reaction is

- (a) momentum.      (b) charge.      (c) mass.      (d) none of these.

**Answer: c**

Explanation: (c) Energy equivalent to mass defect is released.

A radioactive element has half-life period 1600 years. After 6400 years what amount will remain?

- (a)  $\frac{1}{2}$       (b)  $\frac{1}{16}$       (c)  $\frac{1}{8}$       (d)  $\frac{1}{4}$

**Answer: b**

Ratio of the radii of the nuclei with mass numbers 8 and 27 would be

- (a)  $\frac{27}{8}$       (b)  $\frac{8}{27}$       (c)  $\frac{2}{3}$       (d)  $\frac{3}{2}$

**Answer: c**

A radioactive nucleus emits a beta particle. The parent and daughter nuclei are

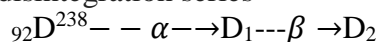
- (a) isotopes    (b) isotones    (c) isomers    (d) isobars

**Answer: d**

Explanation:

(d) Isobars have the same atomic mass but 1 different atomic number.

In the disintegration series



the values of Z and A of  $\text{D}_2$  respectively will be

- (a) 92, 236    (b) 88, 230    (c) 90, 234    (d) 91, 234

**Answer: d**

A nucleus  ${}^A_Z\text{X}$  emits an  $\alpha$ -particle. The resultant nucleus emits a  $\beta$ -particle. The respective atomic and mass numbers of the daughter nucleus will be

- (a)  $Z - 3, A - 4$     (b)  $Z - 1, A - 4$     (c)  $Z - 2, A - 4$     (d)  $Z, A - 2$

**Answer: b**

The radius of a spherical nucleus as measured by electron scattering is 3.6 fm. What is the mass number of the nucleus most likely to be?

- (a) 27    (b) 40    (c) 56    (d) 120

**Answer: a**

If 13.6 eV energy is required to ionise the hydrogen atom, then energy required to remove an electron from  $n = 2$  is

- (a) 10.2 eV  
 (b) 0 eV  
 (c) 3.4 eV  
 (d) 6.8 eV.

**Answer: c**

In Bohr's model, the atomic radius of the first orbit is  $r_0$ . Then, the radius of the third orbit is

- (a)  $r_0/9$   
 (b)  $r_0$   
 (c)  $9r_0$   
 (d)  $3r_0$

**Answer: c**

The ratio between Bohr radii is

- (a) 1 : 2 : 3  
 (b) 2 : 4 : 6  
 (c) 1 : 4 : 9  
 (d) 1 : 3 : 5

**Answer: c**



The longest wavelength in Balmer series of hydrogen spectrum will be

- (a) 6557 Å (b) 1216 Å (c) 4800 Å (d) 5600 Å

**Answer: a**

In terms of Rydberg constant R, the wave number of the first Balmer line is

- (a) R (b) 3R (c) 5R/36 (d) 8R/9

**Answer: c**

The ionisation energy of hydrogen atom is 13.6 eV. Following Bohr's theory the energy corresponding to a transition between 3rd and 4th orbits is

- (a) 3.40 eV (b) 1.51 eV (c) 0.85 eV (d) 0.66 eV

**Answer: d**

The transition of electron from  $n = 4, 5, 6, \dots$  to  $n = 3$  corresponds to

- (a) Lyman series (b) Balmer series (c) Paschen series (d) Brackett series

**Answer: c**

Which of the following spectral series in hydrogen atom gives spectral line of 4860 Å?

- (a) Lyman (b) Balmer (c) Paschen (d) Brackett

**Answer: b**

In Geiger-Marsden scattering experiment, the trajectory traced by an  $\alpha$ -particle depends on

- (a) number of collision (b) number of scattered  $\alpha$ -particles  
(c) impact parameter (d) none of these

**Answer: c**

In the Geiger-Marsden scattering experiment the number of scattered particles detected are maximum and minimum at the scattering angles respectively at

- (a)  $0^\circ$  and  $180^\circ$   
(b)  $180^\circ$  and  $0^\circ$   
(c)  $90^\circ$  and  $180^\circ$   
(d)  $45^\circ$  and  $90^\circ$

**Answer: a**

In the Geiger-Marsden scattering experiment, in case of head-on collision the impact parameter should be

- (a) maximum (b) minimum (c) infinite (d) zero

**Answer: d**

Which of the following spectral series falls within the visible range of electromagnetic radiation?

- (a) Lyman series (b) Balmer series (c) Paschen series (d) Pfund series

**Answer: b**

The transition from the state  $n = 5$  to  $n = 1$  in a hydrogen atom results in UV radiation. Infrared radiation will be obtained in the transition

- (a)  $2 \rightarrow 1$   
(b)  $3 \rightarrow 2$   
(c)  $4 \rightarrow 3$   
(d)  $6 \rightarrow 2$

**Answer: c**

The spectral lines in the Brackett series arise due to transition of electron in hydrogen atom from higher orbits to the orbit with

- (a)  $n = 1$  (b)  $n = 2$  (c)  $n = 3$  (d)  $n = 4$

**Answer: d**

the Balmer series for the H-atom can be observed

- (a) if we measure the frequencies of light emitted when an excited atom falls to the ground state.
- (b) if we measure the frequencies of light emitted due to transitions between excited states and the first excited state.
- (c) in any transition in a H-atom.
- (d) as a sequence of frequencies with the lower frequencies getting closely packed.

**Answer: b**

The hydrogen atom can give spectral lines in the Lyman, Balmer and Paschen series. Which of the following statement is correct?

- (a) Lyman series is in the infrared region.
- (b) Balmer series is in the visible region.
- (c) Paschen series is in the visible region.
- (d) Balmer series is in the ultraviolet region.

**Answer: b**

### ASSERTIONS AND REASONS QUESTIONS-ATOMS AND 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.**

**Assertion :** Hydrogen atom consists of only one electron but its emission spectrum has many lines.

**Reason :** Only Lyman series is found in the absorption spectrum of hydrogen atom whereas in the emission spectrum, all the series are found.

**Answer(b)** When the atom gets appropriate energy from outside, then this electron rises to some higher energy level. Now it can return either directly to the lower energy level or come to the lowest energy level after passing through other lower energy levels hence all possible transitions take place in the source and many lines are seen in the spectrum.

**Assertion :** In Lyman series, the ratio of minimum and maximum wavelength is  $3/4$

**Reason :** Lyman series constitute spectral lines corresponding to transition from higher energy to groundstate of hydrogen atom.

**Answer: b**

**Assertion :** The force of repulsion between atomic nucleus and  $\alpha$ -particle varies with distance according to inverse square law.

**Reason :** Rutherford did  $\alpha$ -particle scattering experiment.

**Answer(b)** Rutherford confirmed that the repulsive force of  $\alpha$ - particle due to nucleus varies with distance according to inverse square law and that the positive charges are concentrated at the centre and not distributed throughout the atom.

**Assertion :** Bohr had to postulate that the electrons in stationary orbits around the nucleus do not radiate.

**Reason:** According to classical physics all moving electrons radiate.

**Answer(b)** Bohr postulated that electrons in stationary orbits around the nucleus do not radiate. This is the one of Bohr's postulate, According to this the moving electrons radiates only when they go from one orbit to the next lower orbit.

**Assertion :** Electrons in the atom are held due to coulomb forces.

**Reason :** The atom is stable only because the centripetal force due to Coulomb's law is balanced by the centrifugal force.

**Answer(c)** According to postulates of Bohr's atom model the electron revolves around the nucleus in fixed orbit of definite radii. As long as the electron is in a certain orbit it does not radiate any energy.

**Assertion (A) :** Total energy of revolving electron in any stationary orbit is negative.

**Reason (R) :** Energy is a scalar quantity. It can have positive or negative value.

**Answer: (b)** Both A and R are true but R is not the correct explanation of A.

**Assertion :** Density of all the nuclei is same.

**Reason :** Radius of nucleus is directly proportional to the cube root of mass number.

**Answer: (a)**

**Assertion :** The mass number of a nucleus is always less than its atomic number.

**Reason :** Mass number of a nucleus may be equal to its atomic number.

**Answer(d)** In case of hydrogen atom mass number and atomic number are equal.

**Assertion :** The binding energy per nucleon, for nuclei with atomic mass number  $A > 100$ , decrease with A.

**Reason :** The forces are weak for heavier nuclei.

**Answer(c)** Nuclear force is nearly same for all nucleus.

Neutrons penetrate matter more readily as compared to protons.

**Reason :** Neutrons are slightly more massive than protons.

**Answer(b)** Both statements are separately correct.

**Assertion :** The mass number of a nucleus is always less than its atomic number.

**Reason :** Mass number of a nucleus may be equal to its atomic number.

**Answer(d)** In case of hydrogen atom mass number and atomic number are equal.

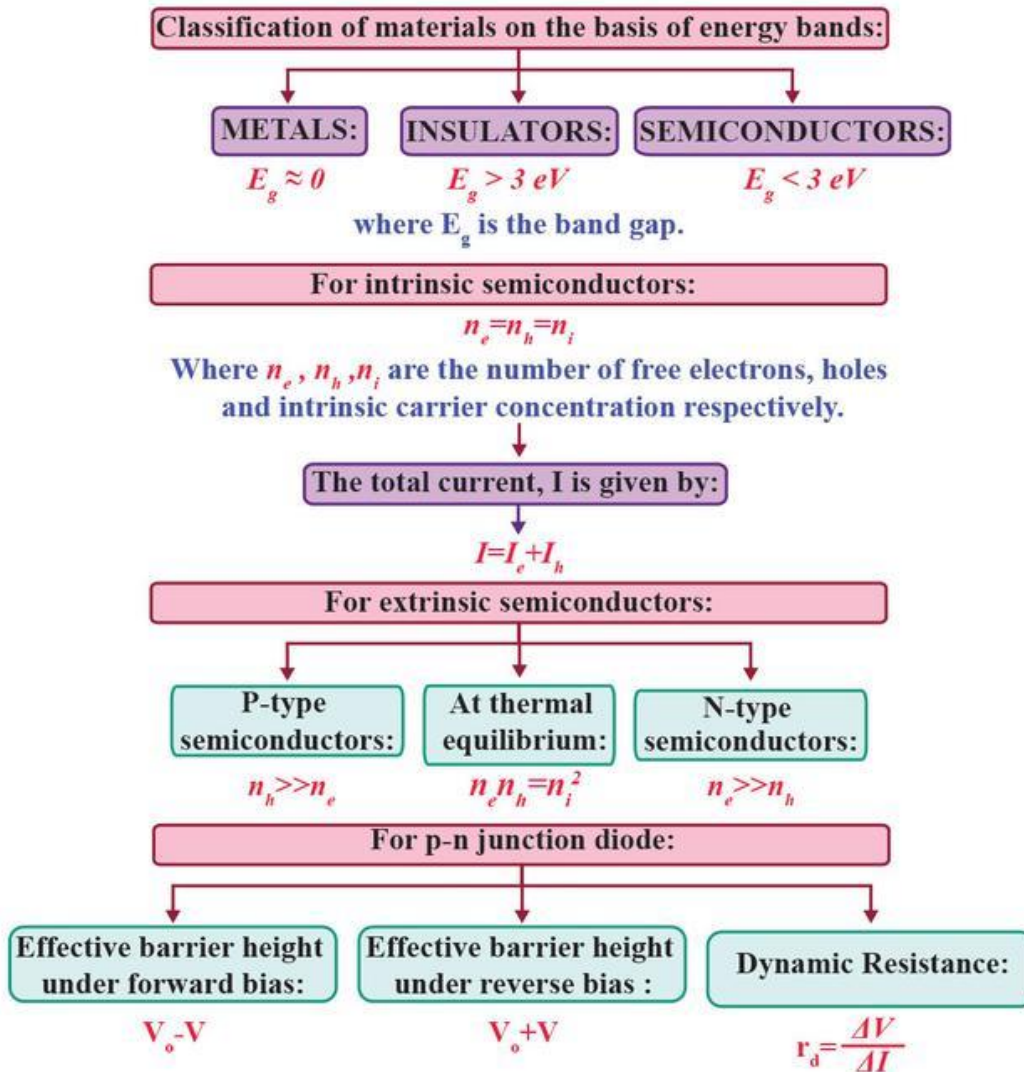
## **ASSIGNMENT 2**

- 1 Using Bohr's postulates of the atom model, derive the expression for radius of nth electron orbit. Hence obtain the expression for Bohr's radius
- 2 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?
- 3 Draw the trajectory traced by alpha particles in the coulomb field of target nucleus and explain how this led to estimate the size of the nucleus
- 4 Write two important limitations of Rutherford nuclear model of the atom

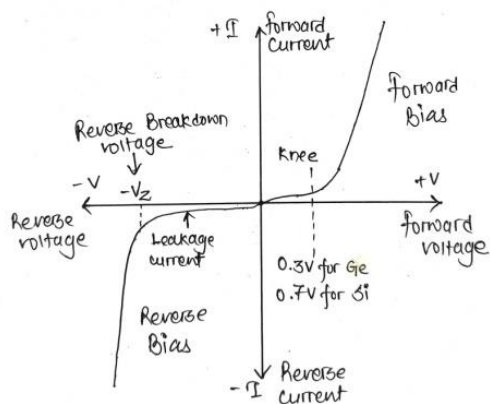
- 5 (a) Using Bohr's second postulate of quantization of orbital angular momentum show that the circumference of the electron in the  $n$ -th orbital state in hydrogen atom is  $n$  times the de-Broglie wavelength associated with it.
- 6 Using Bohr's postulates, derive the expression for the frequency of radiation emitted when electron in hydrogen atom undergoes transition from higher energy state (quantum number  $n_i$ ) to the lower state ( $n_f$ ).  
When electron in hydrogen atom jumps from energy state  $n_i = 4$  to  $n_f = 3, 2, 1$ , identify the spectral series to which the emission lines belong.
- 7 (a) Draw a schematic arrangement of Geiger- Marsden experiment showing the scattering of  $\alpha$ -particles by a thin foil of gold. Why is it that most of the alpha-particles go right through the foil and only a small fraction gets scattered at large angles?  
Draw the trajectory of the alpha-particle in the coulomb field of a nucleus. What is the significance of impact parameter and what information can be obtained regarding the size of the nucleus?
- 8 State characteristic properties of nuclear force.
- 9 Two nuclei have mass numbers in the ratio 1: 2. What is the ratio of their nuclear densities?
- 10 Two nuclei have mass numbers in the ratio 8:125. What is the ratio of their nuclear radii?
- 11 Define the activity of a given radioactive substance. Write its S.I. unit.
- 12 Draw a plot of the binding energy per nucleon as a function of mass number for a large number of nuclei,  $2 \leq A \leq 240$ . How do you explain the constancy of binding energy per nucleon in the range  $30 < A < 170$  using the property that nuclear force is short-ranged?
- 13 (a) The mass of a nucleus in its ground state is always less than the total mass of its constituents – neutrons and protons. Explain.  
(b) Plot a graph showing the variation of potential energy of a pair of nucleons as a function of their separation.
- 14 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.
- 15 Write the relation between half life and decay constant of a radioactive nucleus.
- 16 Distinguish between nuclear fission and fusion. Explain how the energy is released in both the processes.
- 17 State the law of radioactive decay.  
Plot a graph showing the number ( $N$ ) of undecayed nuclei as a function of time ( $t$ ) for a given radioactive sample having half life  $T_{1/2}$ . Depict in the plot the number of undecayed nuclei at  
(i)  $t = 3 T_{1/2}$  and(ii)  $t = 5 T_{1/2}$  .
- 18 Obtain the relation  $N=N_0e^{-\lambda t}$  for a sample of radioactive material having decay constant  $\lambda$ , where  $N$  is the number of nuclei present at constant  $\lambda$ . Hence obtain the relation between decay constant  $\lambda$  and half life  $T_{1/2}$  of the sample.

# Unit - IX Electronic Devices (Chapter 14)

## MIND MAP

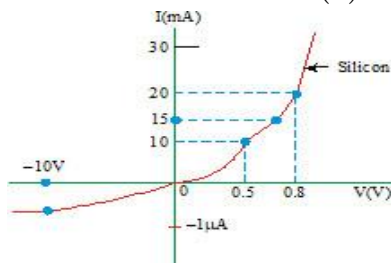


### V-I Characteristics of p-n Junction diode

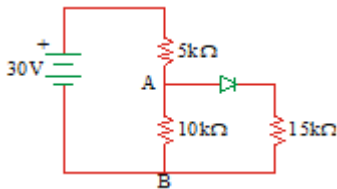


## NUMERICALS FOR PRACTICE WITH SOLUTIONS

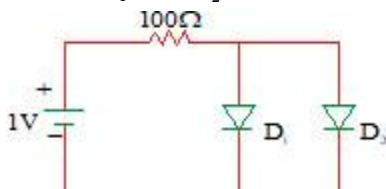
- The number of silicon atoms per  $m^3$  is  $5 \times 10^{28}$ . This is doped simultaneously with  $5 \times 10^{22}$  atoms per  $m^3$  of Arsenic and  $5 \times 10^{20}$  per  $m^3$  atoms of Indium. Calculate the number of electrons and holes. Given that .Is the material - n type or p-type?
- A semiconductor has an electron concentration of  $0.45 \times 10^{12} m^{-3}$  and a hole concentration of  $5.0 \times 10^{20} m^{-3}$ . Calculate its conductivity . Given electron mobility  $= 0.135 m^2 V^{-1} s^{-1}$ ; hole mobility  $= 0.048 m^2 V^{-1} s^{-1}$ ,
- An N-type silicon sample of width thickness and length  $6 \times 10^{-2} m$  carries a current of 4.8mA when the voltage is applied across the length of the sample. What is the current density? If the free electron density is  $10^{22} m^{-3}$ , then find how much time it takes for the electrons to travel the full length of the sample .
- The energy gap of pure Si is 1.1 eV. The mobilities of electrons and holes are respectively  $0.135 m^2 V^{-1} s^{-1}$  and  $0.048 m^2 V^{-1} s^{-1}$  and can be taken as independent of temperature. The intrinsic carrier concentration is given by  $n_i = n_0 e^{-E_g/2kT}$ . Where  $n_0$  is a constant,  $E_g$  The gap width and  $k$  The Boltzmann's constant whose value is  $1.38 \times 10^{-23} JK^{-1}$ . The ratio of the electrical conductivities of  $Si$  at 600K and 300K is.
- The V-I characteristic of a silicon diode is shown in the Fig. Calculate the resistance of the diode at (a)  $I_D = 15mA$  and (b)  $V_D = -10V$



- Find maximum voltage across AB in the circuit shown in Fig. Assume that diode is ideal



- Considering the circuit and data given in the diagram, calculate the currents flowing in the diodes  $D_1$  and  $D_2$ . Forward resistance of  $D_1$  and  $D_2$  is  $20\Omega$

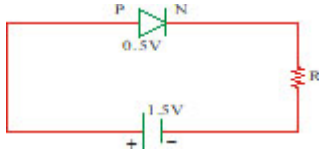


- A potential barrier of 0.50V exists across a p-n junction

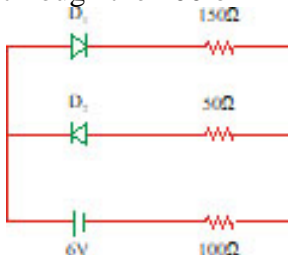
a) If the depletion region is  $5.0 \times 10^{-7} \text{ m}$  wide, what is the intensity of the electric field in this region?

b) An electron with a speed of  $5.0 \times 10^5 \text{ m/s}$  approaches the p-n junction from the n-side. With what speed will it enter the p-side ?

9. A PN junction diode when forward biased has a drop of 0.5V which is assumed to be independent of current. The current in excess of 10mA through the diode produces large joule heating which damages the diode. If we want to use a 1.5V battery to forward bias the diode, what is the resistor used in series with the diode so that the maximum current does not exceed 5mA.



10. The circuit shown in figure Contains two diodes each with a forward resistance of 50 ohm and with infinite reverse resistance. If the battery voltage is 6 V, then what is the current through the 100 ohm resistance.



11. A Ge specimen is doped with Al. The concentration of acceptor atoms is  $10^{21} \text{ atoms / m}^3$ . Given that the intrinsic concentration of electron-hole pairs is  $10^{19} / \text{m}^3$ , then what is the concentration of electrons in the specimen.

## Solutions

1.Sol. Arsenic is donor impurity No. of donor atoms added,  $N_D = 5 \times 10^{22} \text{ m}^{-3}$ ,

Indium is acceptor impurity, no. of acceptor atoms added  $N_A = 5 \times 10^{20} \text{ m}^{-3}$

Therefore, no. of free electrons created  $n_e = N_D = 5 \times 10^{22}$

Now,  $n_e > n_h$ , therefore, net no. of free electrons created,

$$n_e^1 = n_e - n_h = 5 \times 10^{22} - 5 \times 10^{20} = 4.95 \times 10^{22} \text{ m}^{-3}$$

Also net no. of holes created

$$n_h^1 = \frac{n_i^2}{n_e^1} = \frac{(1.5 \times 10^{16})^2}{4.95 \times 10^{22}} = 4.55 \times 10^9 \text{ m}^{-3}$$

As,  $n_e^1 > n_h^1$  the resulting material is n-type semiconductor.

2.Sol. The conductivity of a semiconductor is the sum of the conductivities due to electrons and holes and is given by

$$\sigma = \sigma_e + \sigma_h = n_e e \mu_e + n_h e \mu_h = e(n_e \mu_e + n_h \mu_h)$$

As per given data,  $n_e$  is negligible as compared to  $n_h$ , so that we can write

$$\sigma = en_h\mu_h = (1.6 \times 10^{-19} C)(5.0 \times 10^{20} m^{-3})(0.048 m^2 V^{-1} s^{-1}) = 3.84 \Omega^{-1} m^{-1} = 3.84 S m^{-1}$$

3.Sol.

The current density J is given by

$$J = \frac{I}{A} = \frac{4.8 \times 10^{-3}}{(4 \times 10^{-3})(25 \times 10^{-5})} = \frac{4.8 \times 10^{-3}}{10^{-6}}$$

The drift velocity  $v_d$  given by

$$v_d = \frac{J}{ne} = \frac{4800}{10^{22} \times 1.6 \times 10^{-19}} = 3 m/s$$

The time taken 't' is given by

$$t = \frac{L}{v_d} = \frac{6 \times 10^{-2}}{3} = 0.02 \text{ sec}$$

4. Sol. The total electrical conductivity of a semiconductor is given by  $\sigma = e(n_e\mu_e + n_h\mu_h)$

For an intrinsic semiconductor,  $n_e = n_h = n_i$

We can thus write for the conductivity  $\sigma = e(\mu_e + \mu_h)n_i$  or  $\sigma = e(\mu_e + \mu_h)n_0 e^{E_g/2kT}$

As the mobilities,  $\mu_e, \mu_h$  are independent of temperature, they can be regarded as constant. The ratio of the conductivities at 600 K and 300 K is then,

$$\frac{\sigma_{600}}{\sigma_{300}} = \frac{e(\mu_e + \mu_h)n_0 e^{-E_g/2k \times 600}}{e(\mu_e + \mu_h)n_0 e^{-E_g/2k \times 300}} = e^{-E_g/1200k}$$

As per given data  $E_g = 1.1 eV$

$$k = 1.38 \times 10^{-23} JK^{-1} \text{ or } \left( \frac{1.38 \times 10^{-23}}{1.6 \times 10^{-19}} \right) eVK^{-1} \therefore k = 8.625 \times 10^{-5} eVK^{-1}$$

Solving we get the ratio of electrical conductivities is  $4 \times 10^4$

5.Sol.

Considering the diode characteristics as a straight line between  $I=10mA$  to  $I=20mA$  passing through the origin, we can calculate the resistance using Ohm's law

a) From the curve at  $I=20mA, V=0.8V$

$I=10mA, V=0.7V$

$$r_{fb} = \Delta V / \Delta I = 0.1V / 10mA = 10\Omega$$

b) From the curve at  $V = -10V, I = -1\mu A$

Therefore,

$$r_{rb} = 10V / 1\mu A = 1.0 \times 10^7 \Omega$$

6.Sol. As the diode is treated ideal, its forward resistance  $R_f = zero$ . It acts as short circuit.

So  $10k\Omega$  is in parallel with  $15k\Omega$  and the effective resistance across AB is



$$R_{AB} = \frac{10 \times 15}{10 + 15} = \frac{10 \times 15}{25} = 6k\Omega$$

$6k\Omega$  is in series with  $5k\Omega$

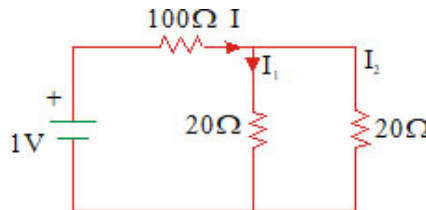
Total resistance  $R_T = 6k\Omega + 5k\Omega = 11k\Omega$ , =

$V = 30V$ . Current drawn from the battery is

$$I = \frac{V}{R_T} = \frac{30V}{11k\Omega} = 2.72mA$$

$$V_{AB} = IR_{AB} = 2.72mA \times 6k\Omega = 16.32V$$

7.Sol. Since the positive terminal of battery is connected to P-type of both diodes  $D_1$  and  $D_2$ , they are forward biased. These diodes are replaced by with their forward resistance as shown is Fig:



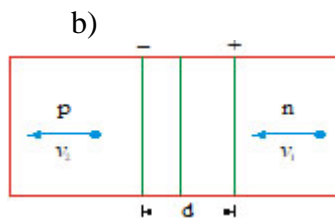
The resistance of  $20\Omega$  and  $20\Omega$  are in parallel,

$$\frac{1}{R} = \frac{1}{20} + \frac{1}{20} \text{ (or) } R = \frac{20}{2} = 10\Omega$$

Therefore, total current I in the circuit  $I = \frac{1}{100 + 10} = \frac{1}{110}$  amp

and  $I_1 = I_2 = \frac{1}{2} \times \frac{1}{110} = \frac{1}{220}$  amp

8.Sol. a) The electric field is  $E = V/d = \frac{0.50V}{5.0 \times 10^{-7}m} = 1.0 \times 10^6 V/m$



Let the electron has a speed  $v_1$  when it enters the depletion layer and  $v_2$  when it comes out of it. As the potential energy increases by  $e \times 0.50V$ . From the principle of conservation of energy

$$\frac{1}{2}mv_1^2 = e \times 0.50 + \frac{1}{2}mv_2^2$$

$$\frac{1}{2}(9.1 \times 10^{-31})(5 \times 10^5)^2 = 1.6 \times 10^{-19} \times 0.5 + \frac{1}{2} \times 9.1 \times 10^{-31} \times v_2^2$$

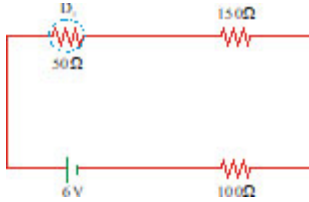
Solving this.  $v_2 = 2.7 \times 10^5 m/s$

9. Sol.

$$R = \frac{E - V_b}{i} = \frac{1.5 - 0.5}{5 \times 10^{-3}} = \frac{1}{5 \times 10^{-3}}$$

10.Sol. As per given circuit, diode  $D_1$  is forward biased and offers a resistance of 50 ohm. Diode  $D_2$  is reverse biased and as its corresponding resistance is infinite, no current flows through it. Thus the equivalent circuit is as shown in Figure. As all the three resistances are in series, the current through then is

$$I = \frac{6V}{(50 + 150 + 100)\Omega} = \frac{6}{300} A = 0.02A$$



11.Sol. When Ge specimen is doped with Al, then concentration of acceptor atoms is also called concentration of holes. Using formula  $n_i^2 = n_0 p_0$ , where

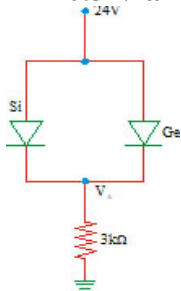
$$n_i = \text{concentration of electron hole pair} = 10^{19} m^{-3}$$

$$n_0 = \text{concentration of electron}$$

$$p_0 = \text{concentration of holes} = 10^{21} atom m^{-3} \Rightarrow (10^{19})^2 = 10^{21} \times n_0 \Rightarrow n_0 = 10^{17} m^{-3}$$

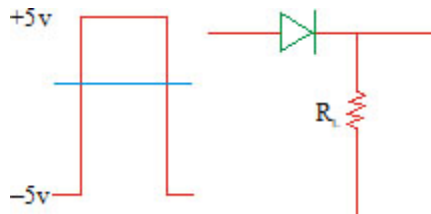
## NUMERICALS FOR PRACTICE

1. Find the voltage  $V_A$  in the circuit shown in figure. The potential barrier for Ge is 0.3 V and for Si is 0.7 V



- A p-n diode is used in a half wave rectifier with a load resistance of  $1000\Omega$ . If the forward resistance ( $r_f$ ) of diode is  $10\Omega$ , calculate the efficiency of this half wave rectifier.
- A full wave rectifier uses two diodes with a load resistance of  $100\Omega$ . Each diode is having negligible forward resistance. Find the efficiency of this full wave rectifier.
- If a p-n junction diode, a square input signal of 10V is applied as shown

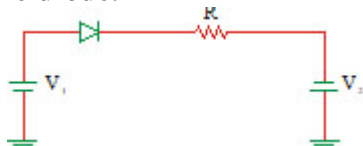
Then what will be the output signal across  $R_L$



5. The electrical conductivity of a semi conductor increases when electromagnetic radiation of wavelength shorter than 1240 nm is incident on it. Then what is the forbidden band energy for the semi conductor (in eV)
6. A semiconductor is known to have an electron concentration of  $5 \times 10^{13} / \text{cm}^3$  and hole concentration of  $8 \times 10^{12} / \text{cm}^3$  . Then what is the nature of semiconductor.
7. A potential barrier of 0.5V exists across a p-n junction. If the width of depletion layer is  $10^{-6}\text{m}$ , then what is the intensity of electric field in this region.
8. A p - n junction diode has breakdown voltage of 28V. If applied external voltage in reverse bias is 40V then what is the current through it.
9. What is the value of current in the following diagrams is (diode assumed to be ideal one)



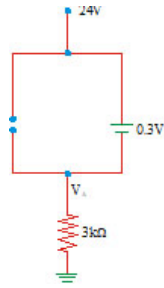
10. A half -wave rectifier is used to convert 50Hz A.C. to D.C. voltage. Then what are the number of pulses per second in the rectified voltage.
11. If a full wave rectifier circuit is operating from 50Hz mains, Then what is the fundamental frequency in the ripple.
12. Motilities of electrons and holes in a sample of intrinsic germanium at room temperature are  $0.36\text{m}^2 / \text{Vs}$  and  $0.17\text{m}^2 / \text{Vs}$  .The electron and hole densities are each equal to  $2.5 \times 10^{19} \text{m}^{-3}$  .Then what is the electrical conductivity of germanium.
13. In a p-n junction diode the thickness of depletion layer is  $2 \times 10^{-6} \text{m}$  and barrier potential is 0.3V. Then what is the intensity of the electrical field at the junction.
14. A potential barrier V volts exists across a P-N junction. The thickness of the depletion region is 'd'. An electron with velocity 'v' approaches P-N junction from N-side. Then what is the velocity of the electron crossing the junction.
15. If  $V_1 > V_2$ , r is resistance offered by diode in forward bias then what is the current through the diode.



16. A cell of emf 4.5V is connected to a junction diode whose barrier potential is 0.7V. If the external resistance in the circuit is 190 ohm, then what is the current in the circuit.

### Hints

1.Sol. In the situation given, germanium diode will turn on first because potential barrier for germanium is smaller. The silicon diode will not get the opportunity to flow the current and so remains in open circuit. The equivalent circuit is as in figure



$$V_A = 24 - 0.3 = 23.7V$$

**2.Sol.** Load resistance  $R_L = 1000\Omega$

Forward resistance of the diode  $= r_f = 10\Omega$

$$\text{Efficiency of half wave rectifier} \left[ \frac{0.406R_L}{r_f + R_L} \right] = \frac{0.406 \times 1000}{1010} = 0.4019$$

The percentage efficiency of the half wave rectifier  $\eta = 40.19\%$

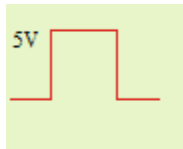
**3.Sol.** Forward resistance of the diode  $r_f = 0$  ,

; Load resistance,  $R_L = 100\Omega; \eta = ?$

$$\text{efficiency of full wave rectifier} = \frac{0.812 \times 100}{100} = 0.812$$

The percentage efficiency of the full wave rectifier = **81.2%**

**4.Sol.** The junction diode will conduct when it is forward biased. Therefore, the output voltage will be obtained during positive half cycle only



**5.Sol.**

$$E = \frac{hc}{\lambda} = \frac{12000}{12400A^0} (e_v)$$

**6.Sol.** As  $n_e > n_h$ , the nature of semiconductor is n-type

**7.Sol.**

$$E = \frac{V}{d} = \frac{10^{24}}{10^{18}} = 10^6$$

**8.Sol.**

Since  $V_a > V_b$

**9.Sol.**

Diode does not conduct in reverse bias as

**10.Sol.** Rectifiers produce unidirectional and pulsating voltage from A.C. source, the number of pulses per second in the rectified voltage remains same as that of input voltage, i.e., here it is 50 Hz.

11.Sol. In full wave rectifier, we get the output for the positive and negative cycle of input a.c. Hence the frequency of the ripple of the output is twice than that of input a.c. i.e. 100Hz

$$12.\text{Sol. } \sigma = \frac{1}{\rho} = e(\mu_e n_e + \mu_h n_h)$$

$$13.\text{Sol. } E = \frac{v}{d} = \frac{0.3}{2 \times 10^{-6}} = 1.5 \times 10^5 \text{Vm}^{-1} \text{ Its direction from n to p side.}$$

$$14.\text{Sol. } v^2 - u^2 = 2as$$

$$15.\text{Sol. } i = \frac{\text{total P.D}}{\text{total resistance}}$$

$$16.\text{Sol. } V = 4.5 - 0.7 = 3.8\text{V}$$

$$R = 190\Omega$$

$$i = \frac{V}{R}$$

## CASE STUDY QUESTIONS

### CASE STUDY-1

In a p-n junction diode, the current I can expressed as  $I = I_0 \exp\left(\frac{eV}{2k_B T} - 1\right)$  where  $I_0$  is called the reverse saturation current, V is the voltage across the diode and is positive for forward bias and negative for reverse bias, and I is the current through the diode,  $K_B$  is the Boltzmann constant ( $8.6 \times 10^{-5} \text{eV/K}$ ) and T is the absolute temperature. If for a given diode  $I_0 = 5 \times 10^{-12} \text{A}$  and  $T = 300\text{K}$ , then

- What will be the forward current at a forward voltage of 0.6V?
- What will be the increase in the current if the voltage across the diode is increased to 0.7V?
- What is the dynamic resistance?
- What will be current if reverse bias voltage changes from 1V to 2V?

### CASE STUDY-2

The minimum energy E required to push an electron from the valence band into the conduction band is band gap of a semiconducting material. The energy of a photon of sodium light ( $\lambda = 589\text{nm}$ ) equal to the band gap of a semiconducting material.

- Find the minimum energy E required to create a hole-electron pair
- Find the value of E/kT at a temperature of 300K
- Can the thermal energy create the hole-electron pair?

### CASE STUDY-3

A block of pure silicon at 300K has a length of 10cm and an area of  $1.0\text{cm}^2$ . A battery of emf 2V is connected across it. The mobility of electron is  $0.14 \text{m}^2 \text{v}^{-1} \text{S}^{-1}$  and their number density is  $1.5 \times 10^{16} \text{m}^{-3}$ . The mobility of holes is  $0.05 \text{m}^2 \text{v}^{-1} \text{S}^{-1}$

- Then what is the electron current.

- b) Then what is the hole current.  
 c) Then what is the total current in the block.

### CASE STUDY-1-Sol.

$$I_o = 5 \times 10^{-12} \text{ A}, k = 8.6 \times 10^{-5} \text{ eV/K}$$

$$= 8.6 \times 10^{-5} \times 1.6 \times 10^{-19} \text{ J/K}$$

a) ,  $I = I_o \left( e^{eV/2kT} - 1 \right)$

For  $V=0.6\text{V}$ ,

$$I = 5 \times 10^{-12} \left( e^{\frac{1.6 \times 10^{-19} \times 0.6}{2 \times 8.6 \times 10^{-5} \times 1.6 \times 10^{-19} \times 300}} - 1 \right)$$

$$= 5 \times 10^{-12} (e^{23.52} - 1)$$

$$= 5 \times 10^{-12} (1.256 \times 10^{10} - 1) = 0.0628 \text{ A}$$

b) For  $v=0.7\text{v}$ , we have

$$I = 5 \times 10^{-12} \left( e^{\frac{1.6 \times 10^{-19} \times 0.7}{2 \times 8.6 \times 10^{-5} \times 1.6 \times 10^{-19} \times 300}} - 1 \right)$$

$$I = 5 \times 10^{-12} (e^{27.32} - 1)$$

$$= 5 \times 10^{-12} (6.054 \times 10^{11} - 1) = 3.0271 \text{ A}$$

$$\therefore \Delta I = 3.271 - 0.0628 = 2.9643 \text{ A}$$

c)  $\Delta I = 2.9643, \Delta v = 0.7 - 0.6 = 0.1 \text{ V}$

$$\text{Dynamic resistance} = \frac{\Delta v}{\Delta I} = \frac{0.1}{2.9643} = 0.0337 \Omega$$

d) For change in voltage from 1 to 2v, the current will remain equal to  $I_o = 5 \times 10^{-12} \text{ A}$ . It shows that the diode possesses practically infinite resistance in reverse biasing

### CASE STUDY-2

(a) The energy of the photon in  $eV = \frac{12400}{\lambda} = \frac{12400}{5890} = 2.1 \text{ eV}$

(Wavelength of photon = 589nm = 5890)

Thus the band gap is 2.1eV . This is also the minimum energy E required to push an electron from the valence band into the conduction band. Hence the minimum energy required to create a hole-electron pair is 2.1eV

(b) At  $T=300\text{K}, kT = (8.62 \times 10^{-5} \text{ eV / K})(300\text{K}) = 25.86 \times 10^{-3} \text{ eV}$

Thus ,  $\frac{E}{kT} = \frac{2.1 \text{ eV}}{25.86 \times 10^{-3} \text{ eV}} = 81$

(c) The available thermal energy is nearly 81 times less than that of the required energy to create electron hole pair. So it is difficult for the thermal energy to create the hole-electron pair but a photon of light can do it easily

### CASE STUDY-3

a) 
$$E = \frac{V}{l} = \frac{2}{0.1} = 20V / m$$

$$A = 1.0cm^2, v_e = \mu_e E = 0.14 \times 20 = 2.8ms^{-1}$$

$$I_e = n_e A e v_e = 6.72 \times 10^{-7} A$$

b) In a pure semi conductor

$$n_e = n_h = 1.5 \times 10^{16} m^{-3}$$

$$V_h = \mu_h E = 0.05 \times 20 = 1.0m / s$$

$$I_h = n_h A e v_h = 2.4 \times 10^{-7} A$$

c) Total current is

$$I = I_e + I_h$$

$$= 9.12 \times 10^{-7} A$$

### ASSIGNMENT 1

1. A strip of copper and another of germanium are cooled from room temperature to 80K. The resistance of:

- 1) Each of these decreases
- 2) copper strip decreases and that of germanium decreases
- 3) copper strip decreases and that of germanium increases
- 4) Each of these increases

2. To a germanium sample, traces of gallium are added as an impurity. The resultant sample would behave like :

- |                           |                           |
|---------------------------|---------------------------|
| 1) A conductor            | 2) A p-type semiconductor |
| 3) A n-type semiconductor | 4) An insulator           |

3. Identify the property which is not characteristic for a semiconductor?

- 1) At a very low temperatures, it behaves like an insulator
- 2) At higher temperatures two types of charge carriers will cause conductivity
- 3) The charge carriers are electrons and holes in the valence band at higher temperatures
- 4) The semiconductor is electrically neutral.

4. In semiconductors the forbidden energy gap between V.B. and C.B. is of the order of

- |        |        |          |         |
|--------|--------|----------|---------|
| 1) 1eV | 2) 5eV | 3) 1 keV | 4) 1MeV |
|--------|--------|----------|---------|

5. On increasing temperature, the conductivity of pure semiconductors

- |              |              |                      |                 |
|--------------|--------------|----------------------|-----------------|
| 1) decreases | 2) increases | 3) remains unchanged | 4) becomes zero |
|--------------|--------------|----------------------|-----------------|

6. An n-type and p-type silicon can be obtained by doping pure silicon with







25. When a p-n junction diode is forward-biased, energy is released at the junction due to the recombination of electrons and holes. This energy is in

- 1) Visible region      2) Infrared region
- 3) UV region          4) X-ray region

26. Assertion : Semiconductors do not obey Ohm's law.

Reason : Electric current is determined by the rate of flow of charge carries

- 1) Both Assertion and Reason are true and Reason is the correct explanation of Assertion
- 2) Both Assertion and Reason are true and Reason not the correct explanation of Assertion
- 3) Assertion is true but Reason is false
- 4) Assertion is false but Reason is true

27. Assertion : Germanium is preferred over silicon for making semiconductor devices.

Reason : Energy gap for Ge is more than that of Si.

28. Assertion : A p-n junction cannot be used at ultra high frequencies.

Reason : Capacitive reactance of a p-n junction increases with increasing frequency.

29. Assertion: I-V characteristic of P-N junction diode is same as that of any other conductor.

Reason: P-N junction diode behave as conductor at room temperature.

30. Assertion (A) : When a donor electrons excited to the conduction band no hole is created

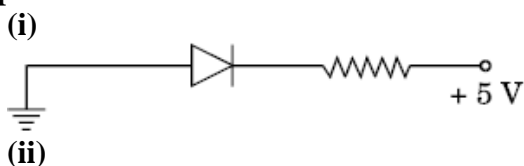
Reason (R) : Donor energy level does not exist in valence band

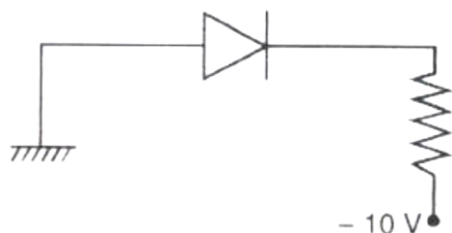
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- |       |       |       |       |       |       |       |       |       |       |       |       |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1. 3  | 2. 2  | 3. 3  | 4. 1  | 5. 2  | 6. 3  | 7. 1  | 8. 1  | 9. 2  | 10. 2 | 11. 3 | 12. 1 |
| 13. 1 | 14. 4 | 15. 3 | 16. 3 | 17. 3 | 18. 1 | 19. 1 | 20. 4 | 21. 1 | 22. 3 | 23. 2 | 24. 4 |
| 25. 2 | 26. 4 | 27. 3 | 28. 3 | 29. 4 | 30. 1 |       |       |       |       |       |       |

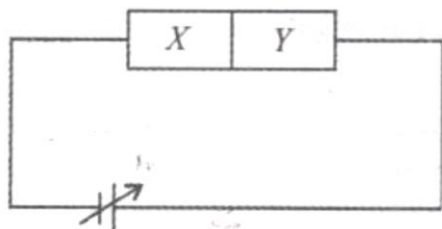
## ASSIGNMENT 2

1. What are energy bands ? How are these formed ?
2. Draw the energy band diagram of an intrinsic semiconductor.
3. Draw the energy band diagram of p-type & n-type semiconductor
4. Name the two important processes that occur during the formation of a p-n junction
5. Explain how the width of depletion region in a p-n junction diode change, when the junction is- (i) forward biased (ii) reverse biased.
6. Distinguish between intrinsic and extrinsic semiconductors
7. Distinguish between n-type and a p-type semiconductor
8. In the following circuit diagram, is the junction diode forward biased or reverse biased ? Explain.

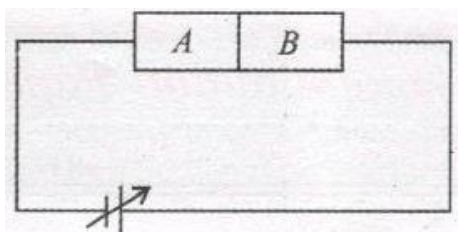




9. Two semiconductor materials X and Y shown in given figure are made by doping germanium crystal with Indium and Arsenic respectively. The two are joined end to end and connected to a battery as shown (i) Will the junction be forward biased or reverse biased ? (ii) sketch V-I graph for this arrangement



10. Two semiconductor materials A and B shown in given figure are made by doping germanium crystal with Arsenic and Indium respectively. The two are joined end to end and connected to a battery as shown. (i) Will the junction be forward biased or reverse biased ? (ii) sketch V-I graph for this arrangement.



11. How are the V-I characteristics of a p-n junction diode made use of in rectification?

12. What is p-n junction ? Explain briefly, with the help of suitable diagram, how a p-n junction is formed. Define the term Potential barrier and depletion region.

13. Distinguish between a conductor, an insulator and a semiconductor on the basis of energy band diagrams.

14. What is meant by forward and reverse biasing of a p-n junction ? Draw the circuit diagram of a forward and reverse biasing of a p-n junction.

15. Draw the circuit diagram for studying the V-I characteristics of a p-n junction diode in (i) forward bias and (ii) reverse bias. Draw the typical V-I characteristics of a silicon diode.

16. Explain with the help of a circuit diagram, the working of p-n junction diode as half wave rectifier.

17. Draw a labeled circuit diagram of a junction diode as a full wave rectifier. Explain its underlying principle and working. Depict the input and output wave forms.

### Marking Scheme

1. What are energy bands ? How are these formed ?

1. Ans.

**Energy bands : – 1 mark**

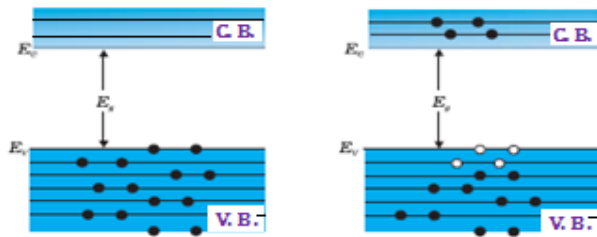
A group of large number of closely spaced energy levels spread in a very short energy range, is called an energy band

**Formation of energy bands : – 1 mark**

Due to interaction of electrons in outermost orbits of atoms in a crystal, different energy levels with continuous energy variation splits and energy bands are formed.

**2. Draw the energy band diagram of an intrinsic semiconductor.**

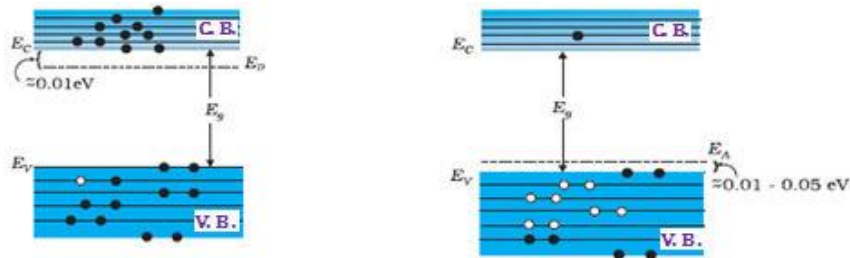
**Ans. Energy band diagrams of an intrinsic semiconductor – 2 marks**



**3. Draw the energy band diagram of p-type & n-type semiconductor**

**Ans. n-type semiconductor – 1 mark**

**p-type semiconductor – 1 mark**



**4. Name the two important processes that occur during the formation of a p-n junction**

**Ans.**

(i) Diffusion – 1 mark

(ii) drift – 1 mark

**5. Explain how the width of depletion region in a p-n junction diode change, when the junction is- (i) forward biased (ii) reverse biased.**

**Ans.**

(i) decreases – 1 mark

(ii) increases – 1 mark

**6. Distinguish between intrinsic and extrinsic semiconductors**

**Ans.**

**Intrinsic Semiconductor -  $1\frac{1}{2}$  marks**

1. It is a pure semiconductor

2.  $n_e = n_h$

3. Low conductivity at room temperature

4. Its electrical conductivity depends on temperature only.

**Extrinsic Semiconductor-1 $\frac{1}{2}$ marks**

**1.It is a semiconductor with added impurity**

**2. $n_e \neq n_h$**

**3. High conductivity at room temperature**

**4. Its electrical conductivity depends on temperature and the amount of doping.**

**7. Distinguish between n-type and a p-type semiconductor**

**Ans. n-type semiconductor-1 $\frac{1}{2}$ marks**

**1.It is obtained by adding controlled amount of pentavalent impurity to a pure semiconductor**

**2. $n_e \gg n_h$**

**3. Its electrical conductivity is due to free electrons**

**p-type semiconductor-1 $\frac{1}{2}$ marks**

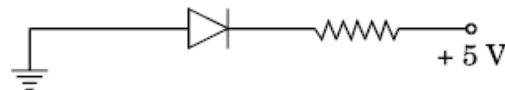
**1.It It is obtained by adding controlled amount of trivalent impurity to a pure semiconductor**

**2. $n_h \gg n_e$**

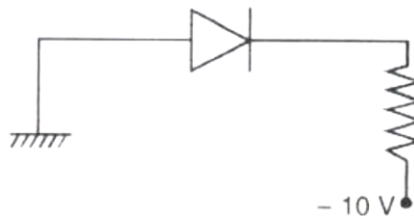
**3. Its electrical conductivity is due to holes**

**8. In the following circuit diagram, is the junction diode forward biased or reverse biased ? Explain.**

**(i)**



**(ii)**

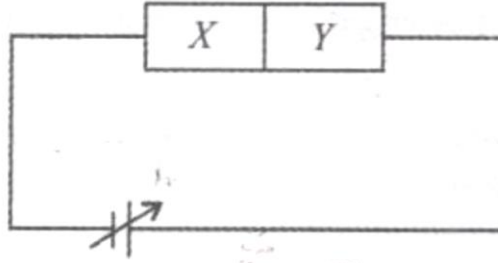


**Ans.**

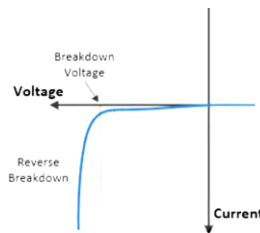
**(i) Reverse bias and Explanation-1 $\frac{1}{2}$ marks**

**(ii) Forward bias and Explanation -1 $\frac{1}{2}$ marks**

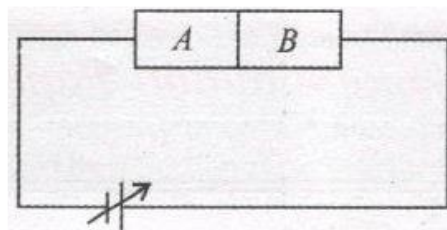
**9. Two semiconductor materials X and Y shown in given figure are made by doping germanium crystal with Indium and Arsenic respectively. The two are joined end to end and connected to a battery as shown (i) Will the junction be forward biased or reverse biased ? (ii) sketch V-I graph for this arrangement**



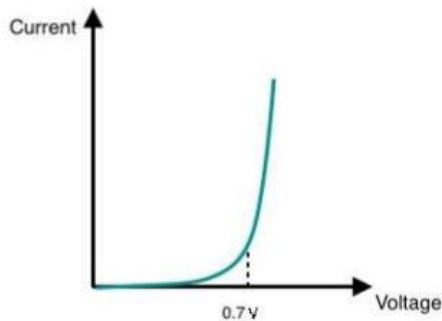
Ans. Reverse bias – 1 mark  
Graph-2 marks



10. Two semiconductor materials A and B shown in given figure are made by doping germanium crystal with Arsenic and Indium respectively. The two are joined end to end and connected to a battery as shown. (i) Will the junction be forward biased or reverse biased? (ii) sketch V-I graph for this arrangement.



Ans. Reverse bias – 1 mark  
Graph-2 marks



11. How are the V-I characteristics of a p-n junction diode made use of in rectification?

Ans. It is obvious from V-I characteristics that diode allows the current to pass only when it is forward biased. So, when an alternating voltage is applied across a junction diode, the current will flow only in that part of the cycle when diode is forward biased. This property is used to rectify the alternating voltages

12. What is p-n junction? Explain briefly, with the help of suitable diagram, how a p-n junction is formed. Define the term Potential barrier and depletion region.

**Ans. p-n junction – 1 mark**

**Formation of p-n junction with diagram -- 2 mark**

**potential barrier – 1 mark**

**depletion region– 1 mark**

**13. Distinguish between a conductor, an insulator and a semiconductor on the basis of energy band diagrams.**

**Ans.**

**a conductor– 1 mark**

**an insulator– 1 mark**

**a semiconductor– 2 mark**

**energy band diagrams– 1 mark**

**14. What is meant by forward and reverse biasing of a p-n junction ? Draw the circuit diagram of a forward and reverse biasing of a p-n junction.**

**Ans.**

**forward biasing– 1 mark**

**reverse biasing– 1 mark**

**Draw the circuit diagram of a forward biasing- $1\frac{1}{2}$ marks**

**Draw the circuit diagram of a reverse biasing- $1\frac{1}{2}$ marks**

**15. Draw the circuit diagram for studying the V-I characteristics of a p-n junction diode in (i) forward bias and (ii) reverse bias. Draw the typical V-I characteristics of a silicon diode.**

**Ans.**

**p-n junction diode in (i) forward bias – 1 mark**

**p-n junction diode in(ii) reverse bias– 1 mark**

**The typical V-I characteristics of a silicon diode with explanation- 3 marks**

**16. Explain with the help of a circuit diagram, the working of p-n junction diode as half wave rectifier.**

**Ans. Circuit diagram-2 marks**

**Wave form- $1\frac{1}{2}$ marks**

**Explanation- $1\frac{1}{2}$ marks**

**17. Draw a labelled circuit diagram of a junction diode as a full wave rectifier. Explain its underlying principle and working. Depict the input and output wave forms.**

**Ans.**

**Circuit diagram-2 marks**

**Wave form- $1\frac{1}{2}$ marks**

**Explanation- $1\frac{1}{2}$ marks**

## REVISION QUESTION PAPER

(CHAPTERS 7, 8 AND 9)

(35 MARKS)

General Instructions:

- (i) There are 18 questions in all. All questions are compulsory
- (ii) This question paper has five sections: Section A, Section B, Section C, Section D and Section E
- (iii) All the sections are compulsory.
- (iv) Section A contains nine MCQ of 1 mark each, Section B contains four questions of two marks each, Section C contains three questions of three marks each, Section D contains one long question of five marks and Section E contains one case study based questions of 4 mark.
- (v) There is no overall choice. However, an internal choice has been provided in section B, C, D and E. You have to attempt only one of the choices in such questions.

### Section A

**1. Emission of electrons in photoelectric effect is possible, if**

- 1) metal surface is highly polished
- 2) the incident light is of sufficiently high intensity
- 3) the light is incident at right angles to the surface
- 4) the incident light is of sufficiently low wavelength

**2. Assertion (A) : For a fixed incident photon energy, photoelectrons have a wide range of energies ranging from zero to the maximum value  $max K$**

**Reason (R) : Initially, the electrons in the metal are at different energy level.**

- 1) If both Assertion and Reason are true and Reason is correct explanation of Assertion.
- 2) If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.
- 3) If Assertion is true but Reason is false.
- 4) If both Assertion and Reason are false.

**3. A point source of light is used in a photoelectric effect. If the source is removed farther from the emitting metal, the stopping potential**

- 1) will increase
- 2) will decrease
- 3) will remain constant
- 4) will either increase or decrease



4. For electron moving in  $n$ th orbit of the atom, the angular velocity is proportional to:

- 1)  $n$       2)  $\frac{1}{n}$       3)  $n^3$       4)  $\frac{1}{n^3}$

5. Hydrogen atom will be in its ground state, if its electron is in

- 1) any energy level  
2) the lowest energy state  
3) the highest energy state  
4) the intermediate state

6. The difference between the mass of a nucleus and the combined mass of its nucleons is

- 1) zero      2) positive      3) negative      4) zero, positive or negative

7. Maximum value of binding energy per nucleon for most stable nuclei is

- 1) 8MeV      2) 8.8MeV      3) 7.6MeV      4) 1.1MeV

8. A strip of copper and another of germanium are cooled from room temperature to 80K. The resistance of:

- 1) Each of these decreases  
2) copper strip decreases and that of germanium decreases  
3) copper strip decreases and that of germanium increases  
4) Each of these increases

9. Assertion (A) : When a donor electron is excited to the conduction band no hole is created

Reason (R) : Donor energy level does not exist in valence band

- 1) Both Assertion and Reason are true and Reason is the correct explanation of Assertion  
2) Both Assertion and Reason are true and Reason not the correct explanation of Assertion  
3) Assertion is true but Reason is false  
4) Assertion is false but Reason is true

#### Section B

10. State de-Broglie hypothesis and write the expression for Wavelength

11. The ground state energy of hydrogen atom is -13.6 eV. What are the kinetic and potential energies of electron in this state ?

12. Define the term mass defect and binding energy of a nucleus.

OR

(i) Write the relation between mass number and radius of a nucleus.

(ii) Show that nuclear density in a given nucleus is independent of mass number .

13. Draw the energy band diagram of an intrinsic semiconductor

#### Section C

14.(i) Plot a graph showing the variation of photoelectric current with intensity of light.

(ii) Show the variation of photocurrent with collector plate potential for different intensity but same frequency of incident radiation

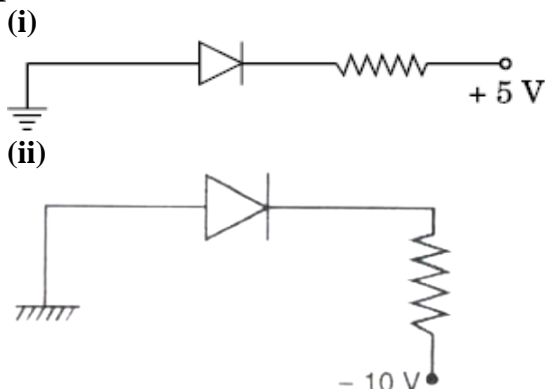
(iii) Show the variation of photocurrent with collector plate potential for different frequency but same intensity of incident radiation

15. (a) Write two important limitations of Rutherford nuclear model of the atom.  
 (b) How these were explained in Bohr's model of hydrogen atom ?

OR

Use de-Broglie's hypothesis to write the relation for the radius of Bohr orbit in terms of Bohr's quantization condition of orbital angular momentum.

16. In the following circuit diagram, is the junction diode forward biased or reverse biased ? Explain.



#### Section D

17. What is p-n junction? Explain briefly, with the help of suitable diagram, how a p-n junction is formed. Define the term Potential barrier and depletion region.

OR

Draw a plot of binding energy per nucleon (B.E/A) as a function of mass number A.

- (a) Write salient features of this curve.  
 (b) Write two important conclusions that can be drawn regarding the nature of nuclear force.

#### Section E

#### CASE STUDY

When an electromagnetic radiation (such as U.V rays, x-rays etc.) of suitable frequency is incident on a metal surface, electrons are emitted from the surface. This phenomenon is called photoelectric effect. The minimum energy required to by an electron to just eject out from the metallic surface is called work function of that surface

A 40 W ultra violet light source of wavelength  $2280 \text{ \AA}$  illuminates a small magnesium (Mg) surface placed 2 m away from the source. The photoelectric work function for Mg is 3.68 eV.

- (a) What are the number of photons incident on unit area of Mg surface per second.  
 (b) What is The kinetic energy of the fastest electrons ejected from the surface.  
 (c) Find The maximum wavelength for which the photoelectric effect can be observed with a Mg-surface (approximately).

OR

Find minimum frequency for which the photoelectric effect can be observed with a Mg-surface

#### MARKING SCHEME

## Section A

**1. Emission of electrons in photoelectric effect is possible, if**

- 1) metal surface is highly polished
- 2) the incident light is of sufficiently high intensity
- 3) the light is incident at right angles to the surface
- 4) the incident light is of sufficiently low wavelength

1.Key:4

**2. Assertion (A) : For a fixed incident photon energy, photoelectrons have a wide range of energies ranging from zero to the maximum value  $\max K$**

**Reason (R) : Initially, the electrons in the metal are at different energy level.**

- 1) If both Assertion and Reason are true and Reason is correct explanation of Assertion.
- 2) If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.
- 3) If Assertion is true but Reason is false.
- 4) If both Assertion and Reason are false.

2.Key:1

**3. A point source of light is used in a photoelectric effect. If the source is removed farther from the emitting metal, the stopping potential**

- 1) will increase
- 2) will decrease
- 3) will remain constant
- 4) will either increase or decrease

3.Key:3

**4. For electron moving in  $n$ th orbit of the atom, the angular velocity is proportional to:**

- 1)  $n$                       2)  $\frac{1}{n}$                       3)  $n^3$                       4)  $\frac{1}{n^3}$

4.Key:4

**5. Hydrogen atom will be in its ground state, if its electron is in**

- 1) any energy level
- 2) the lowest energy state
- 3) the highest energy state
- 4) the intermediate state

5.Key:2

**6. The difference between the mass of a nucleus and the combined mass of its nucleons is**

- 1) zero                      2) positive                      3) negative                      4) zero, positive or negative

6.Key:3

**7. Maximum value of binding energy per nucleon for most stable nuclei is**

- 1) 8MeV                      2) 8.8MeV                      3) 7.6MeV                      4) 1.1MeV

7.Key:3

8. A strip of copper and another of germanium are cooled from room temperature to 80K. The resistance of:

- 1) Each of these decreases
- 2) copper strip decreases and that of germanium decreases
- 3) copper strip decreases and that of germanium increases
- 4) Each of these increases

8.Key:3

9.Assertion (A) : When a donor electrons is excited to the conduction band no hole is created

**Reason (R) : Donor energy level does not exist in valence band**

- 5) Both Assertion and Reason are true and Reason is the correct explanation of Assertion
- 6) Both Assertion and Reason are true and Reason not the correct explanation of Assertion
- 7) Assertion is true but Reason is false
- 8) Assertion is false but Reason is true

9.Key:1

### Section B

10. State de-Broglie hypothesis and write the expression for Wavelength

10. Ans. de-Broglie hypothesis– 1 mark

the expression for Wavelength- – 1 mark

11. The ground state energy of hydrogen atom is -13.6 eV. What are the kinetic and potential energies of electron in this state ?

11. Ans. Kinetic Energy– 1 mark

Potential Energy– 1 mark

12. Define the term mass defect and binding energy of a nucleus.

**OR**

(iii) Write the relation between mass number and radius of a nucleus.

(iv) Show that nuclear density in a given nucleus is independent of mass number .

12. Ans. mass defect– 1 mark

binding energy of a nucleus– 1 mark

**OR**

Relation between mass number and radius of a nucleus– 1 mark

Nuclear density expression– 1 mark

13. Draw the energy band diagram of an intrinsic semiconductor

13. Ans. energy band diagram with labelling – 2 mark

### Section C

14.(i) Plot a graph showing the variation of photoelectric current with intensity of light.

(ii) Show the variation of photocurrent with collector plate potential for different intensity but same frequency of incident radiation

(iii) Show the variation of photocurrent with collector plate potential for different frequency but same intensity of incident radiation

14. Ans. Graph showing the variation of photoelectric current with intensity of light.– 1 mark

The variation of photocurrent with collector plate potential for different intensity– 1 mark

The variation of photocurrent with collector plate potential for different frequency– 1 mark

15. (a) Write two important limitations of Rutherford nuclear model of the atom.

(b) How these were explained in Bohr's model of hydrogen atom ?

OR

Use de-Broglie's hypothesis to write the relation for the radius of Bohr orbit in terms of Bohr's quantization condition of orbital angular momentum.

15. Ans. limitations of Rutherford nuclear model-1 mark

Bohr's model of hydrogen atom– 2 mark

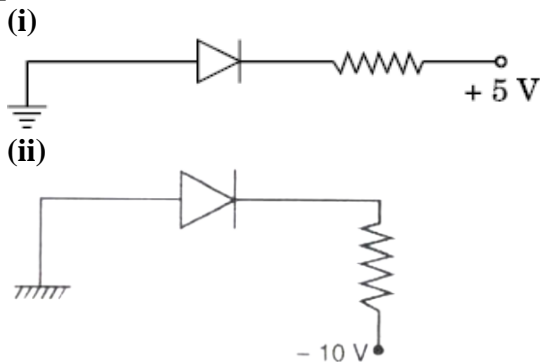
OR

For de Broglie Wavelength associated with electron in its orbit -1 mark

Explanation -2 marks

16. In the following circuit diagram, is the junction diode forward biased or reverse biased ?

Explain.



16. Ans.

(iii) Reverse bias and Explanation- $1\frac{1}{2}$ marks

(iv) Forward bias and Explanation - $1\frac{1}{2}$ marks

### Section D

17. What is p-n junction? Explain briefly, with the help of suitable diagram, how a p-n junction is formed. Define the term Potential barrier and depletion region.

OR

Draw a plot of binding energy per nucleon (B.E/A) as a function of mass number A.

(a) Write salient features of this curve.

(b) Write two important conclusions that can be drawn regarding the nature of nuclear force.

17. Ans. p-n junction – 1 mark

Formation of p-n junction with diagram -- 2 marks

potential barrier – 1 mark

depletion region– 1 mark

OR

Graph with proper labelling-- 2 marks  
salient features of this curve-- 2 marks  
two important conclusions-- 1 mark

**Section E**  
**CASE STUDY**

When an electromagnetic radiation (such as U.V rays, x-rays etc.) of suitable frequency is incident on a metal surface, electrons are emitted from the surface. This phenomenon is called photoelectric effect. The minimum energy required to by an electron to just eject out from the metallic surface is called work function of that surface

A 40 W ultra violet light source of wavelength  $2280 \text{ \AA}$  illuminates a small magnesium (Mg) surface placed 2 m away from the source. The photoelectric work function for Mg is 3.68 eV.

- (c) What are the number of photons incident on unit area of Mg surface per second.
- (d) What is The kinetic energy of the fastest electrons ejected from the surface.
- (c) Find The maximum wavelength for which the photoelectric effect can be observed with a Mg-surface (approximately).

**OR**

Find The minimum frequency for which the photoelectric effect can be observed with a Mg-surface

18. Ans. Energy of each photon  $E = \frac{hc}{\lambda}$

No. of photons emitted per second  $N = P/E$

No. of photons incident per unit area per second =  $\frac{N}{4\pi r^2} = 9.1 \times 10^{17} - 2 \text{ mark}$

Kinetic energy of the fastest electrons ejected from the Surface = 1.74 eV -- 1 mark

Maximum wavelength =  $3365 \text{ \AA}$  -- 1 mark