केन्द्रीय विद्यालय संगठन
KENDRIYA VIDYALAYA SANGATHAN

आज़ादी का अमृत महोत्सव

शिक्षा एवं प्रशिक्षण का आंचलिक संस्थान, चंडीगढ़
ZONAL INSTITUTE OF EDUCATION AND TRAINING, CHANDIGARH

अध्ययन सामग्री / Study Material

शैक्षिक सत्र / Session - 2022-23

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तैयारकर्ता - अनुपम एस प्रकाश, सह-प्रशिक्षक (भौतिकी)
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निदेशक महोदय का संदेश

विद्यार्थियों की शैक्षिक प्रगति को ध्यान में रखते हुए उपयोगी अध्ययन सामग्री उपलब्ध कराना हमारा महत्त्वपूर्ण उद्देश्य है। इससे न केवल उन्हें अपने लक्ष्य को प्राप्त करने में सरलता एवं सुविधा होगी बल्कि वे अपने आंतरिक गुणों एवं अभिरुचियों को पहचानने में सक्षम होंगे। बोर्ड परीक्षा में अधिकतम अंक प्राप्त करना हर एक विद्यार्थी का सपना होता है। इस संबंध में तीन प्रमुख आधार स्तंभों को एक कड़ी के रूप में देखा जाना चाहिए- अवधारणात्मक स्पष्टता, प्रासंगिक परिचितता एवं आनुप्रयोगिक विशेषज्ञता।

राष्ट्रीय शिक्षा नीति 2020 के उद्देश्यों की मूलभूत बातों को गौर करने पर यह तथ्य स्पष्ट है कि विद्यार्थियों की सोच को सकारात्मक दिशा देने के लिए उन्हें तकनीकी आधारित समेकित शिक्षा के समान अवसर उपलब्ध कराए जाएँ। बोर्ड की परीक्षाओं के तनाव और दबाव को कम करने के उद्देश्य को प्रमुखता देना अति आवश्यक है।

यह सर्वमान्य है कि छात्र-छात्राओं का भविष्य उनके द्वारा वर्तमान कक्षा में किए गए प्रदर्शन पर ही निर्भर करता है। इस तथ्य को समझते हुए यह अध्ययन सामग्री तैयार की गई है। उम्मीद है कि प्रस्तुत अध्ययन सामग्री के माध्यम से वे अपनी विषय संबंधी जानकारी को समृद्ध करने में अवश्य सफल होंगे।

शुभकामनाओं सहित।

मुकेश कुमार
(उपायुक्त एवं निदेशक)

विषय-सूची / INDEX

CLASS XII (2022-23)

PHYSICS (THEORY)

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

		No. of Periods	Marks
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	Chapter–2: Electrostatic Potential and Capacitance		
Unit-II	**Current Electricity**	18	
	Chapter–3: Current Electricity		
Unit-III	**Magnetic Effects of Current and Magnetism**	25	17
	Chapter–4: Moving Charges and Magnetism		
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	Chapter–8: Electromagnetic Waves		
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	Chapter–9: Ray Optics and Optical Instruments		
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	Chapter–11: Dual Nature of Radiation and Matter		
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	Chapter–14: Semiconductor Electronics: Materials, Devices and Simple Circuits		
Total		**160**	**70**

CHAPTER 1 ELECTRIC CHARGES AND FIELDS

1. **Charge-** Charge is the property associated with matter due to which it produces and experiences electric and magnetic effect.

2. Conductors and Insulators Those substances which readily allow the passage of electricity through them are called conductors, e.g. metals, the earth and those substances which offer high resistance to the passage of electricity are called insulators, e.g. plastic rod and nylon.

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

4. Additivity of Charges Charges are scalars and they add up like real numbers. It means if a system consists of n charges $q_1, q_2, q_3, \ldots, q_n$, then total charge of the system will be $q_1 + q_2 + \ldots + q_n$.

5. Conservation of Charge The total charge of an isolated system is always conserved, i.e. initial and final charge of the system will be same.

6. Quantisation of Charge Charge exists in discrete amount rather than continuous value and hence, quantised.

Mathematically, charge on an object, $q = \pm ne$

where, n is an integer and e is electronic charge. When any physical quantity exists in discrete packets rather than in continuous amount, the quantity is said to be quantised. Hence, charge is quantised.

7. Units of Charge

(i) SI unit coulomb (C)

(ii) CGS system

(a) electrostatic unit, esu of charge or stat-coulomb (stat-C)

(b) electromagnetic unit, emu of charge or ab-C (ab-coulomb)

1 ab-C = 10 C, 1 C = 3 x 10^9 stat-C

8. Coulomb's Law It states that the electrostatic force of interaction or repulsion acting between two stationary point charges is given by

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

where, q_1 and q_2 are the stationary point charges and r is the separation between them in air or vacuum.

Also, $$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{ N-m}^2/\text{C}^2$$

where, ε_0 = permittivity of free space = 8.85419×10^{-12} C^2/N-m^2

The force between two charges q_1 and q_2 located at a distance r in a medium other than free space may be expressed as

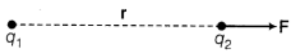
$$F = \frac{1}{4\pi\varepsilon} \cdot \frac{q_1 q_2}{r^2}$$

where, ε is **absolute permittivity** of the medium.

Now, $$\frac{F_{\text{vacuum}}}{F} = \frac{\frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r^2}}{\frac{1}{4\pi\varepsilon} \cdot \frac{q_1 q_2}{r^2}} = \frac{\varepsilon}{\varepsilon_0} = \varepsilon_r$$

where, ε_r is called **relative permittivity** of the medium also called **dielectric constant** of the medium.

In vector form,



$$\mathbf{F} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{|\mathbf{r}|^2}\,\hat{\mathbf{r}} \quad \text{or} \quad |\mathbf{F}| = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r^2}$$

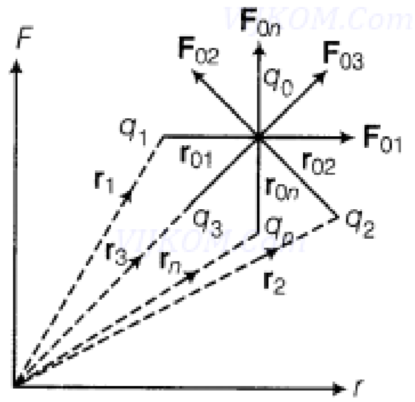
9. Electrostatic forces (Coulombian forces) are conservative forces.

10. Principle of Superposition of Electrostatic Forces This principle states that the net electric force experienced by a given charge particle q_0 due to a system of charged particles is equal to the vector sum of the forces exerted on it due to all the other charged particles of the system.

i.e. $\mathbf{F}_0 = \mathbf{F}_{01} + \mathbf{F}_{02} + \mathbf{F}_{03} + \ldots + \mathbf{F}_{0n}$

$$\mathbf{F}_0 = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1 q_0}{|\mathbf{r}_{01}|^3}\mathbf{r}_{01} + \frac{q_2 q_0}{|\mathbf{r}_{02}|^3}\mathbf{r}_{02} + \ldots + \frac{q_n q_0}{|\mathbf{r}_{0n}|^3}\mathbf{r}_{0n}\right]$$

where, $\mathbf{r}_{01} = \mathbf{r}_0 - \mathbf{r}_1$, $\mathbf{F}_{01}$ = force on q_0 due to q_1.



Superposition of electrostatic forces

Similarly, $\mathbf{r}_{0n} = \mathbf{r}_0 - \mathbf{r}_n$; $\mathbf{F}_{0n}$ = force on q_0 due to q_n

$$\therefore \quad \mathbf{F}_0 = \frac{q_0}{4\pi\varepsilon_0}\left[\sum_{i=1}^{n}\frac{q_i}{|\mathbf{r}_{0i}|^3}\mathbf{r}_{0i}\right]$$

Net force in terms of position vector,

$$\mathbf{F}_0 = \frac{q_0}{4\pi\varepsilon_0}\left[\sum_{i=1}^{n}\frac{q_i}{|\mathbf{r}_0 - \mathbf{r}_i|^3}(\mathbf{r}_0 - \mathbf{r}_i)\right]$$

11. Electrostatic Force due to Continuous Charge Distribution

The region in which charges are closely spaced is said to have continuous distribution of charge. It is of three types given as below:

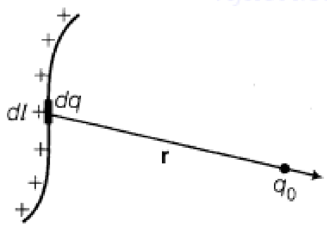
(*i*) **Linear Charge Distribution**

$$dq = \lambda\, dl$$

where, λ = linear charge density

$$d\mathbf{F} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_0\,(dq)}{|\mathbf{r}|^2}\,\hat{\mathbf{r}} \Rightarrow d\mathbf{F} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_0\,(\lambda\, dl)}{|\mathbf{r}|^2}\,\hat{\mathbf{r}}$$

Net force on charge q_0, $\mathbf{F} = \dfrac{q_0}{4\pi\varepsilon_0}\displaystyle\int_l \frac{\lambda\, dl}{|\mathbf{r}|^2}\,\hat{\mathbf{r}}$

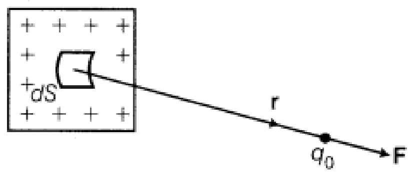


(*ii*) **Surface Charge Distribution**

$$dq = \sigma\, dS$$

where, σ = surface charge density

Net force on charge q_0, $\mathbf{F} = \dfrac{q_0}{4\pi\varepsilon_0}\displaystyle\int_S \frac{\sigma\, dS}{|\mathbf{r}|^2}\,\hat{\mathbf{r}}$

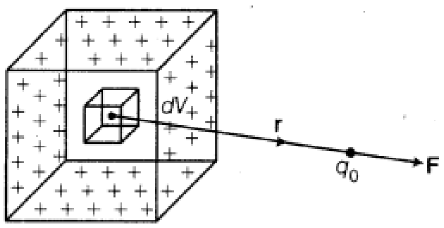


(*iii*) **Volume Charge Distribution**

$$dq = \rho\, dV$$

where, ρ = volume charge density

Net force on charge q_0, $\mathbf{F} = \dfrac{q_0}{4\pi\varepsilon_0}\displaystyle\int_V \frac{\rho\, dV}{|\mathbf{r}|^2}\,\hat{\mathbf{r}}$



12. Electric Field Intensity The electric field intensity at any point due to source charge is defined as the force experienced per unit positive test charge placed at that point without disturbing the source charge. It is expressed as

$$\mathbf{E} = \lim_{q_0 \to 0} \frac{\mathbf{F}}{q_0}$$

Here, $q_0 \to 0$, i.e. the test charge q_0 must be small, so that it does not produce its own electric field.

SI unit of electric field intensity ($\mathbf{E}$) is N/C and it is a vector quantity.

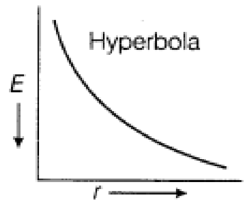
13. Electric Field Intensity (EFI) due to a Point Charge

Electric field intensity at P is, then

$$\mathbf{E} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{|\mathbf{r}|^2}\hat{\mathbf{r}}$$

The magnitude of the electric field at a point P is given by

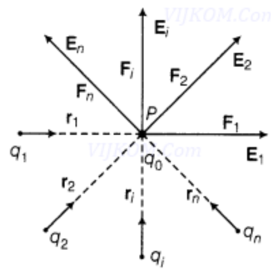
$$|\mathbf{E}| = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2}$$



If $q > 0$, i.e. positive charge, then $\mathbf{E}$ is directed away from source charge. On the other hand if $q < 0$, i.e. negative charge, then $\mathbf{E}$ is directed towards the source charge.

$$\mathbf{E} \propto \frac{1}{r^2}$$

14. Electric Field due to a System of Charges Same as the case of electrostatic force, here we will apply principle of superposition, i.e.



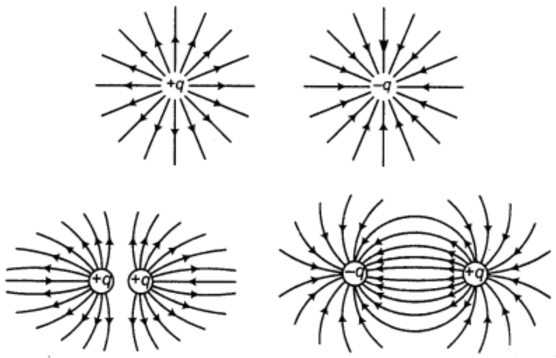
A system of charges

$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2 + \mathbf{E}_3 + \dots + \mathbf{E}_n$$

$$\Rightarrow \quad \mathbf{E} = \frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{n} \frac{q_i}{|\mathbf{r}_i|^2} \hat{\mathbf{r}}_i$$

15. Electric Field Lines Electric field lines are a way of pictorially mapping the electric field around a configuration of charge(s). These lines start on positive charge and end on negative charge. The tangent on these lines at any point gives the direction of field at that point.

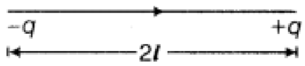
16. Electric field lines due **to positive and negative charge** and their combinations are shown as below:



Different electric field lines

17. Electric Dipole Two-point charges of same magnitude and opposite nature separated by a small distance altogether form an electric dipole.

18. Electric Dipole Moment The strength of an electric dipole is measured by a vector quantity known as electric dipole moment (p) which is the product of the charge (q) and separation between the charges (2l).



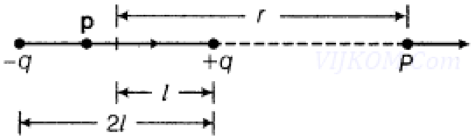
$$\mathbf{p} = q \times 2\mathbf{l}$$

$$\Rightarrow \qquad |\mathbf{p}| = q\,(2l)$$

Direction Its direction is from negative charge $(-q)$ to positive charge $(+q)$.
SI unit Its SI unit is C-m.

NOTE The line joining the two charges $-q$ and $+q$ is called the dipole axis.

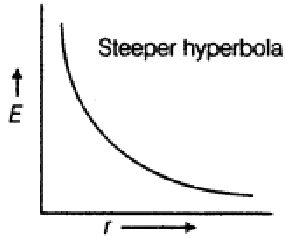
(i) Electric Field at any Point on the Axial Line/End-on Position of Electric Dipole



$$\mathbf{E}_{\text{axial}} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2\mathbf{p}r}{(r^2 - l^2)^2}$$

When $l << r$, $\mathbf{E}_{\text{axial}} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2\,\mathbf{p}}{r^3} \Rightarrow |\mathbf{E}_{\text{axial}}| = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2|\mathbf{p}|}{r^3}$

$$\mathbf{E} \propto \frac{1}{r^3}$$



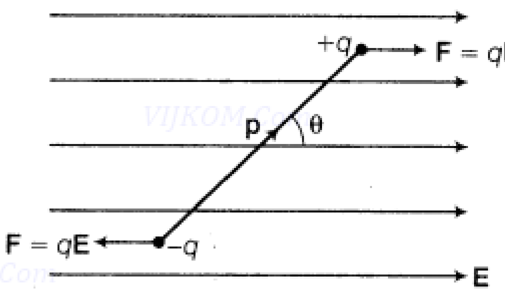
The direction of electric field at any point on axial line is along the direction of electric dipole moment.

19. Electric Field due to a Dipole Electric field of an electric dipole is the space around the dipole in which the electric effect of the dipole can be experienced.

20. When $l << r$, $\frac{|\mathbf{E}_{\text{axial}}|}{|\mathbf{E}_{\text{equatorial}}|} = 2$

21. Torque on an electric dipole placed in a uniform electric field (E) is given by

$\tau = \mathbf{p} \times \mathbf{E} \Rightarrow |\tau| = pE\sin\theta$



22. **Minimum torque** experienced by electric dipole in electric field, when $\theta = 0°$ or π

$$\tau = \tau_{\text{min}} = 0$$

23. **Maximum torque** $\tau = \tau_{\text{max}}$, when $\sin\theta = 1 \Rightarrow \theta = \pi/2$

$$\tau_{\text{max}} = pE$$

24. Dipole is in stable equilibrium in uniform electric field when angle between p and E is 0° and in unstable equilibrium when angle θ= 180°.
25. Net force on electric dipole placed in a uniform electric field is zero.
26. There exists a net force and torque on electric dipole when placed in non-uniform electric field.
27. Work done in rotating the electric dipole from θ_1 to θ_2 is $W = pE(\cos\theta_1 - \cos\theta_2)$

28. Potential energy of electric dipole when it rotates from $\theta_1 = 90°$ to $\theta_2 = 0$

U = pE (cos 90° – cosθ) = -pE cos θ = – p .E

29. Work done in rotating the dipole from the position of stable equilibrium to unstable equilibrium, i.e. when $\theta_1 = 0°$ and $\theta_2 = \pi$.

W = 2 pE

30. Work done in rotating the dipole from the position of stable equilibrium to the position in which dipole experiences maximum torque, i.e. when $\theta_1 = 0°$ and $\theta_2 = 90°$.

W = pE

31. **Electric flux**. The electric flux through a small surface ts defined as the electric lines of force passing through that are when held normally to the lines of force.

Mathematically-- $\varphi = \vec{E}.\overrightarrow{\Delta S}$

where E is the electric field and AS is the area vector representing the elementary surface area.

Unit. In SI, unit of electric flux is newton metre^2 coulomb^{-2} (N m^2 C^{-2}).

32. Gauss' theorem. It states that the total outward electric flux through a closed surface is $\frac{1}{\epsilon_o}$ times the charge enclosed |by the closed surface.

Mathematically**:** $\oint \vec{E}.\overrightarrow{dS} = \frac{q}{\epsilon_0}$

where q is charge enclosed by the closed surface.

33. Gaussian surface. Any closed surface around the charge distribution (may be a point charge, a line charge, a surface charge or a volume charge) so that Gauss' theorem can be conveniently applied to find electrical field due to it is called the gaussian surface.

34.Electric field due to infinitely long straight wire of linear charge density λ

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

where r is perpendicular distance of the observation point from the wire.

35. Electric field due to an infinite plane sheet of charge of surface charge density σ

Electric field between two infinite plane parallel sheets of charge of surface charge density 0 and -o:

$$E = \frac{\sigma}{2\epsilon_0}$$

36. Electric field due to spherical shell of surface charge density o and radius R:

$E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$ **for r>R (outside the shell)**

E=0, for r<R (inside the shell)

$E = \frac{1}{4\pi\epsilon_0}\frac{q}{R^2}$**, for r=R (at the surface)**

Here, q = $4\pi R^2$ **σ**

37. Electric field due to a solid sphere of volume charge density ρ and radius R:

$E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$ **for r>R (outside the sphere)**

$E = \frac{1}{4\pi\epsilon_0}\frac{qr}{R^3}$ **for r<R (inside the sphere)**

$E = \frac{1}{4\pi\epsilon_0}\frac{q}{R^2}$**, for r=R (at the surface)** Here, q = $\frac{4\pi}{3} R^3 \rho$

QUESTIONS WITH ANSWERS

Q. 1 When a polythene piece is rubbed with wool, it acquires negative charge. Is there a transfer of mass from wool to polythene?

Ans. The polythene piece acquires negative charge due to transfer of electrons from wool to it. Since electrons are material particles, there is a transfer of mass from wool to polythene.

Q. 2 A glass rod, when rubbed with silk cloth, acquires a charge 1.6×10^{-8} coulomb. What is the charge on the silk cloth?

Ans. Silk cloth will also acquire a charge 1.6×10^{-8} coulomb. However, it will be negative in nature.

Q. 3 How does the mass of a body changes after charging?

Ans. When a body is charged, either electrons get removed (becomes positively charged) or get added (becomes negatively charged) to it. Since electron is a material particle, the mass of a body decreases on getting positively charged and increases on getting negatively charged.

Q. 4 Ordinary rubber is an insulator. But the special rubber tyres of aircrafts are made slightly conducting. Why is this necessary?

Ans. During landing, the tyres of a space-craft get charged due to friction between the tyres and the ground. In case, the tyres are slightly conducting, the charge developed on the tyres will not stay on them and it will find its way (leak) to the earth.

Q. 5. **'Automobile ignition failure occurs in damp weather.'** Explain, why.

Ans. The insulating porcelain of the spark plugs accumulates a film of dirt. The surface dirt is hygroscopic and picks up moisture from the air. Therefore, in humid weather, the insulating porcelain of the plugs becomes quasi-conductor. This allows an appreciable proportion of the spark to leak across the surface of the plug instead of discharging across the gap.

Q. 6 A bird perches on a bare high-powerline and nothing happens to the bird. A man standing on the ground touches the same line and gets a fatal shock. Why?

Ans. When a bird is perched on a bare high-power line, the circuit does not get completed between the bird and the earth. Therefore, nothing happens to the bird. When a man standing on ground touches the same line, the circuit between the man and the earth gets completed. As a result, he gets a fatal shock.

Q.7 Can a charged body attract another uncharged body? Explain.

Or

Why does a charged glass rod attract a piece of paper?

Ans. Yes, a charged body can attract another uncharged body. It is because, when the charged body is placed in front of an uncharged body, the induced charges of opposite kind are produced on the uncharged body. Due to this, the charged body attracts the uncharged body.

Q. 8 The test charge used to measure electric field at a point should be vanishingly small. Why?

Ans. In case, test charge is not vanishingly small, it will produce its own electric field and the measured value of electric field will be different from the actual value of electric field at that point.

Q. 9 Why do the electric field lines never cross each other?

Ans. The tangent at a point on the line of force gives the direction of electric field at that point. If two lines of force intersect each other at a point, then electric field at that point will have two directions. As the same cannot be true, two lines of force can never intersect each other.

Q. 10 Why do the electrostatic field lines not form closed loops?

Ans. The electrostatic field lines originate from positive charge and end at the negative charge. As the isolated positive and negative charges do exist, the electrostatic field lines do not form closed loops.

Q. 11 Does an electric dipole always experience a torque, when placed in a uniform electric field?

Ans. No. It does not experience a torque, when it is placed along the direction of electric field.

Q. 12. What is the net force on an electric dipole placed in a uniform electric field?

Ans. An electric dipole does not experience any net force in a uniform electric field.

Q. 13 When is the torque acting on an electric dipole maximum, when placed in uniform electric-field?

Ans. The torque is maximum, when the electric dipole is placed perpendicular to the direction of electric field.

Q. 14 What is the angle between the directions of electric dipole moment and electric field at any,
(i) axial point and (ii) equatorial point due to an electric dipole?

Ans. (i) The electric field at a point on the axial line of an electric dipole is same as that of electric dipole moment and hence angle between them is zero.

(ii) The electric field at a point on the equatorial line of an electric dipole is opposite to that of electric dipole moment and hence angle between them is 180°.

Q. 15 An electric dipole of dipole moment 20 x 10-© C mis enclosed by a closed surface. What is the net flux coming out of the surface?

Ans. Since an electric dipole consists of two equal and opposite charges, the net charge on the dipole is zero. Hence, the net electric flux coming out of the closed surface is Zero.

Q.16 Does the strength of electric field due to an infinitely long line charge depend upon the distance of the observation points from the line charge?

Ans. Yes, the electric field due to an infinitely long line charge depends upon the distance of the observation point from the line charge.

Q. 17 Does the strength of electric field due to an infinite plane sheet of charge depend upon the distance of the observation point from the sheet of charge?

Ans. No, the electric field due to an infinite plane sheet of charge does not depend upon the distance of the observation point from the plane sheet of charge.

Q. 18 What is the difference between a sheet of charge and a plane conductor having charge?

Ans. On a sheet of charge, the same charge shows up on its two sides; whereas in case of a charged plane conductor, the charges showing up on the two surfaces are not the same.

Q. 19 How does electric field at a point change with distance r from an infinitely long charged wire?

Ans. The electric field due to a line charge falls off with distance as $\frac{1}{r^2}$.

Q. 20 What is the importance of Gauss's theorem?

Ans. Gauss' theorem is of great importance. Those situations, in which the calculation of electric field by applying Coulomb's law or the principle of superposition of electric fields becomes very difficult, the results can be obtained by applying Gauss' theorem with great ease.

Q.21 A polythene piece rubbed with wool is found to have a negative charge of 3×10^{-7} C.

(a) Estimate the number of electrons transferred (from which to which?).

(b) Is there a transfer of mass from wool to polythene?

Ans. When two neutral bodies are rubbed together, electrons of one body are transferred to the other. The body which gains electrons is negatively charged and the body which loses electrons is positively charged.

(a) From quantisation of charge q = ne

Here, $q = 3 \times 10^{-7}$C and $e = 1.6 \times 10^{-19}$C

∴ Number of electrons transferred, $n = \frac{q}{e} = \frac{3 \times 10^{-7}}{1.6 \times 10^{-19}} = 1.875 \times 10^{12}$

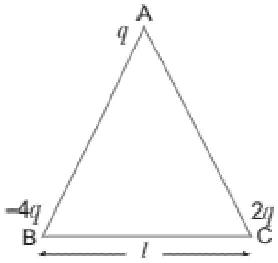
When polythene is rubbed with wool, the polythene becomes negatively charged and wool becomes positively charged. This implies that the electrons are transferred from wool to polythene.

(b) Yes, as electrons have finite mass, the mass is transferred from wool to polythene.

$M = n \times m = 1.875\ 10^{12} \times \times 9.1 \times 10^{-31} = 1.7 \times 10^{-18}$ kg

Q.22 Three-point charges **q, – 4q and 2q** are placed at the vertices of an equilateral triangle ABC of side 'l' as shown in the figure. Obtain the expression for the magnitude of the resultant electric force acting on the charge q.

Ans-



Force on charge q due to the charge $-4q$

$$F_1 = \frac{1}{4\pi\varepsilon_0}\left(\frac{4q^2}{l^2}\right), \text{ along } AB$$

Force on the charge q, due to the charge $2q$

$$F_2 = \frac{1}{4\pi\varepsilon_0}\left(\frac{2q^2}{l^2}\right), \text{ along CA}$$

The forces F_1 and F_2 are inclined to each other at an angle of 120°

Hence, resultant electric force on charge q

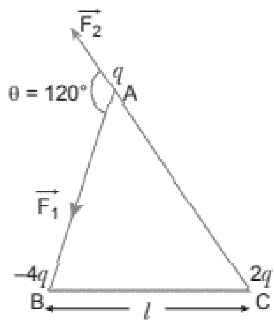
$$F = \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos\theta}$$

$$= \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos 120^\circ}$$

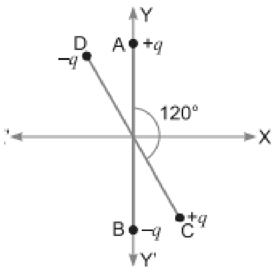
$$= \sqrt{F_1^2 + F_2^2 - F_1F_2}$$

$$= \left(\frac{1}{4\pi\varepsilon_0}\frac{q^2}{l^2}\right)\sqrt{16+4-8}$$

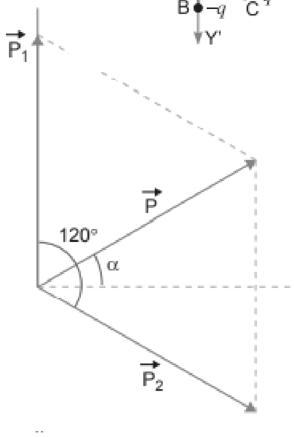
$$= \frac{1}{4\pi\varepsilon_0}\left(\frac{2\sqrt{3}q^2}{l^2}\right)$$



Q.23 Two small identical electrical dipoles AB and CD, each of dipole moment 'p' are kept at an angle of 120° as shown in the figure. What is the resultant dipole moment of this combination? If this system is subjected to electric field $(\vec{E})$ directed along + X direction, what will be the magnitude and direction of the torque acting on this?



Ans-



Resultant dipole moment

$$\vec{p}_r = \sqrt{p_1^2 + p_2^2 + 2p_1p_2\cos 120°}$$

$$= \sqrt{2p^2 + 2p^2\cos 120°} \qquad (\because p_1 = p_2 = p)$$

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

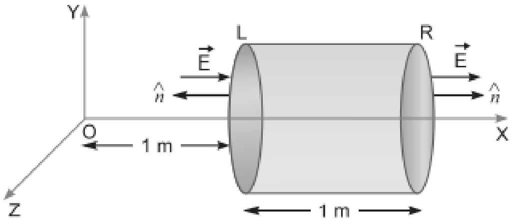
Using law of addition of vectors, we can see that the resultant dipole makes an angle of 60° with the y axis or 30° with x - axis.

Torque, $\vec{\tau} = \vec{p}\times\vec{E}$ ($\vec{\tau}$ is perpendicular to both $\vec{p}$ and $\vec{E}$)

$$= pE\sin 30° = \frac{1}{2}pE.$$

Direction of torque is into the plane of paper or along positive Z-direction.

Q.24 A hollow cylindrical box of length 1m and area of cross-section 25 cm2 is placed in a three-dimensional coordinate system as shown in the figure. The electric field in the region is given by $\vec{E} = 50xi$, t where E is in NC^{-1} and x is in metres. Find (i) net flux through the cylinder.



(ii) charge enclosed by the cylinder

Ans-

(i) Electric flux through a surface, $\phi = \vec{E}.\vec{S}$

Flux through the left surface, $\phi_L = ES\cos 180° = -ES = (-50x)S$

Since $x = 1$ m, $\phi_L = -50 \times 1 \times 25 \times 10^{-4}$

$= -1250 \times 10^{-4} = -0.125 \text{ N m}^2 \text{ C}^{-1}$

Flux through the right surface,

$\phi_R = ES\cos 0°$

$= ES = (50x)S$

Since $x = 2$ m, $\phi_R = 50 \times 2 \times 25 \times 10^{-4} = 2500 \times 10^{-4} = 0.250 \text{ N m}^2 \text{ C}^{-1}$

Net flux through the cylinder, $\phi_{net} = \phi_R + \phi_L$

$= 0.250 - 0.125 = \mathbf{0.125\ N\ m^2\ C^{-1}}$

(ii) Charge inside the cylinder, by Gauss's Theorem

$$\phi_{net} = \frac{q}{\varepsilon_0} \Rightarrow q = \varepsilon_0\phi_{Net}$$

$$= 8.854\times10^{-12}\times0.125 = 8.854\times10^{-12}\times\frac{1}{8} = \mathbf{1.107\times10^{-12}C}$$

Q. 25 Two charges q and –3q are placed fixed on x-axis separated by distance 'd'. Where should a third charge 2q be placed such that, it will not experience any force?

Ans-

Let the charge $2q$ be placed at point P as shown. The force due to q is to the left and that due to $-3q$ is to the right.

$$\therefore \qquad \frac{2q^2}{4\pi\varepsilon_0 x^2} = \frac{6q^2}{4\pi\varepsilon_0(d+x)^2} \Rightarrow (d+x)^2 = 3x^2$$

$$\therefore \qquad 2x^2 - 2dx - d^2 = 0 \quad \Rightarrow \quad x = \frac{d}{2} \pm \frac{\sqrt{3}\,d}{2}$$

(–ve sign shows charge $2q$ at p would be lie between q and $-3q$ and hence is unacceptable.)

$$\Rightarrow \qquad x = \frac{d}{2} + \frac{\sqrt{3}\,d}{2} = \frac{d}{2}(1+\sqrt{3}) \text{ to the left of } q.$$

CHAPTER 2 ELECTRIC POTENTIAL AND CAPACITANCE

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

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

   $$V_B - V_A = \frac{W_{AB}}{q_O} = = \frac{q}{4\pi\epsilon_O}\left(\frac{1}{r_B} - \frac{1}{r_A}\right)$$

   Here, r_A and r_B are distances of points A and B from the source charge q.

   Unit. Its unit in SI is volt (V)

   1 volt (V) = 1 joule coulomb! (J C1)

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

   Mathematically - If W is work done in moving a small positive test charge from infinity to point A in the electrostatic field of charge q, then potential at point A,

   $$V = \frac{W_{AB}}{q_O} = \frac{1}{4\pi\epsilon_O}\frac{q}{r}$$

   Here, r is the distance of the point A from the source charge q.

   Unit. Its unit is also volt.

   1V=1J/s

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

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

4. **Potential gradient.** The rate of change of potential with distance at a point is called potential gradient at that point.

   The electric field at a point is equal to the negative potential gradient at that point.

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

   Unit. Its unit in SI is volt /metre (V/m).

5. **Equipotential surface**. The surface at every point of which, the electric potential is same, is called equipotential surface.

   Two equipotential surfaces can never intersect each other.

6. **Electrostatic potential energy of a system of charges**. It is defined as the work done to put the charges constituting the system at their respective locations after having been removed to infinity.

   Mathematically- **A. Potential energy of the system of two charges q_1 and q_2**

   $$U = \frac{1}{4\pi\epsilon_O}\frac{q_1 q_2}{r}$$

   B. Potential energy of the system of three charges q_1, q_2 and q_3

   $$U = \frac{1}{4\pi\epsilon_O}\left(\frac{q_1 q_2}{r_{12}} + \frac{q_2 q_3}{r_{23}} + \frac{q_3 q_1}{r_{31}}\right)$$

   Unit. Its unit in SI is joule (J) or electron volt (eV).

   1 eV =1.6 x 10^{-19} J

7. **Potential energy of an electric dipole in a uniform electric field.**

1. If the electric dipole is rotated from initial orientation making angle 6, with the electric field to the final orientation making angle ϑ , with the field, then

U = pE ($\cos\vartheta_2$ — $\cos\vartheta_1$)

2. If the electric dipole is rotated from its initial orientation perpendicular to the field to the final orientation so as to make an angle ϑ with the field, then

U = -pEcos ϑ $= -\vec{p}.\vec{E}$

8. Behaviour of a charged conductor

A. Charges reside only at the surface of the charged conductor.

B. The electric potential is constant at the surface and inside the conductor.

C. The electric field is zero inside the conductor and just outside it, the electric field is normal to the surface.

9. Electrical capacitance. The ability of a conductor to store charge is called its electrical capacitance.

Mathematically- C = $\frac{q}{V}$

Unit. Its unit in SI is farad (F).

1 farad (F) = 1 coulomb /volt (C/ V)

Capacitance of a spherical conductor. C = $4\pi \in_0$ r , r is radius (in metre) of the spherical conductor.

10. Capacitor. It is an arrangement for storing a very large amount of charge.

11. Principle. The capacitance of a conductor gets increased greatly, when an earth connected conductor is placed near it.

12. Parallel plate capacitor C= $\frac{\in_0 A}{d}$ (when air is between the plates)

C= $\frac{K \in_0 A}{d}$ (when dielectric is between the plates)

Here, A is area of each plate and d is separation between the two plates.

13. Energy stored in a capacitor. Work done in charging a capacitor gets stored in the capacitor in the form of its electrostatic potential energy.

Mathematically : U = $\frac{1}{2}$ CV^2 = $\frac{1}{2}$ qV = = $\frac{1}{2}$ $\frac{Q^2}{C}$

14. Dielectric constant. The ratio of the strength of the applied electric field to the strength of reduced value of electric field

on inserting the dielectric slab between the plates of a capacitor is called the dielectric constant of the slab.

15. Dielectric strength. The maximum value of electric field (or potential gradient) that can be applied to the dielectric without its electric breakdown is called dielectric strength of the dielectric.

Unit. Its unit in V/m (same as that of electric field).

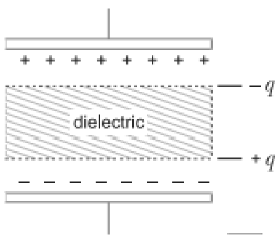
16. Effect of dielectric slab on the capacitance of a parallel plate capacitor.

1. When a dielectric slab of dielectric constant K and thickness t (t < d) is introduced between the plates, then

$$C = \frac{\in_0 A}{d - t(1 - \frac{t}{K})}$$

2. When a conducting slab of thickness t (f < d) is introduced, then

$$C = \frac{\in_0 A}{d(1 - \frac{t}{K})}$$

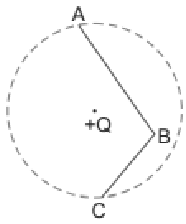


QUESTIONS WITH ANSWERS

Q.1 Name the physical quantity whose SI unit is JC^{-1}. Is it a scalar or a vector quantity?

Ans. Electric potential. It is a scalar quantity.

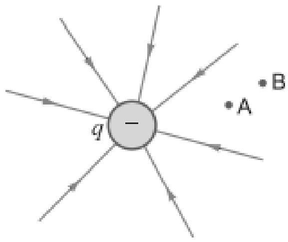
Q.2 In the given figure, charge +Q is placed at the centre of a dotted circle. Work done in taking another charge +q from A to B is W_1 and from B to C is W_2. Which one of the following is correct: $W_1 > W_2$, $W_1 = W_2$ and $W_1 < W_2$?



Ans- The points A and C are at same distance from the charge +Q at the centre, so $V_A = V_C$ Therefore, $V_A - V_B = V_C - V_B$

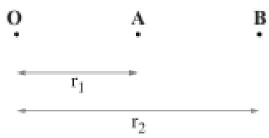
Hence, the magnitude of work done in taking charge +q from A to B or from B to C will be the same i.e., $W_1 = W_2$

Q.3 The field lines of a negative point charge are as shown in the figure. Does the kinetic energy of a small negative charge increase or decrease in going from B to A?



Ans-The kinetic energy of a negative charge decreases while going from point B to point A, against the movement of force of repulsion.

Q. 4 A point charge Q is placed at point 'O' as shown in figure. Is the potential at point A, i.e., VA, greater, smaller or equal to potential, VB, at point B, when Q is (i) positive, and (ii) negative charge?



Ans-

(i) If Q is positive,

$$V_A = \frac{KQ}{r_1} \quad \text{and} \quad V_B = \frac{KQ}{r_2}$$

Clearly, $V_A > V_B$

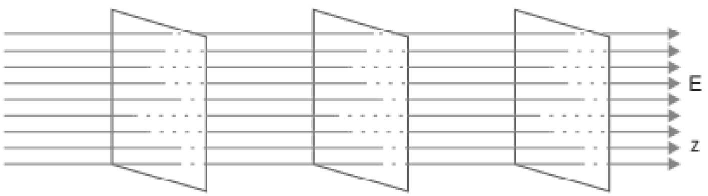
(ii) If Q is negative,

$$V_A = -\frac{KQ}{r_1} \quad \text{and} \quad V_B = -\frac{KQ}{r_2}$$

Clearly, $V_A < V_B$

Q.5 Draw the equipotential surfaces corresponding to a uniform electric field in the z-direction

Ans- The equipotential surfaces are the equidistant planes normal to the z-axis, i.e., planes parallel to the X–Y plane.



Q.6 Why do the equipotential surfaces due to a uniform electric field not intersect each other?

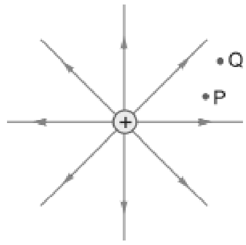
Ans. This is because at the point of intersection there will be two values of electric potential, which is not possible.

Q.7 Why is there no work done in moving a charge from one point to another on an equipotential surface?

Ans. The potential difference between any two points of equipotential surface is zero.

We have $V_1 - V_2 = \frac{W}{q} = 0 \Rightarrow W = 0$

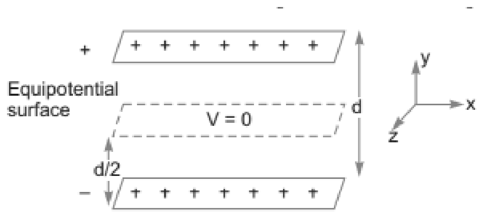
Q.8 The figure shows the field lines of a positive point charge. What will be the sign of the potential energy difference of a small negative charge between the points Q and P? Justify your answer.



Ans-The sign of the potential energy difference of a small negative charge will be positive. This is because negative charge moves from a point at a lower potential energy to a point at a higher potential energy.

Q.9 Two uniformly large parallel thin plates having charge densities +σ and – σ are kept in the X-Z plane at a distance 'd' apart. Sketch an equipotential surface due to electric field between the plates. If a particle of mass m and charge '–q' remains stationary between the plates, what is the magnitude and direction of this field?

Ans- 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.

So, mg = qE

$E = \frac{mg}{q}$ vertically downward, i.e., along (–)Y-axis.

Q.10 (a) A parallel plate capacitor (C_1) having charge Q is connected, to an identical uncharged capacitor C_2 in series. What would be the charge accumulated on the capacitor C_2?

(b) Three identical capacitors each of capacitance 3 µF are connected, in turn, in series and in parallel combination to the common source of V volt. Find out the ratio of the energies stored in two configurations.

Ans-

(a) Since the capacitor C_2 is uncharged so when connected to an identical capacitor C_1 charged to Q then charge Q is equally shared and charge acquired by capacitor C_2 is $\frac{Q}{2}$.

(b) We have $C_{series} = \frac{3\mu F}{3} = 1\mu F$

Also, $C_{parallel} = (3 + 3 + 3) = 9\ \mu F$

Energy stored $= \frac{1}{2}CV^2$

∴ Energy in series combination $= \frac{1}{2} \times 1 \times 10^{-6} \times V^2 \Rightarrow U_{Series} = \frac{10^{-6}}{2} V^2$

∴ Energy in parallel combination $= \frac{1}{2} \times 9 \times 10^{-6} \times V^2 \Rightarrow U_{parallel} = \frac{10^{-6} \times 9}{2} V^2$

∴ $U_{series} : U_{parallel} = \mathbf{1 : 9}$

Q.11 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?

Ans. Potential at centre of sphere = 10 V. Potential at all points inside the hollow metal sphere (or any surface) is always equal to the potential at its surface.

Q.12 Net capacitance of three identical capacitors in series is 1 μF. 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.

Ans-

Let C be the capacitance of each capacitor, then in series

$$\frac{1}{C_S} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C} = \frac{3}{C}$$

or $C = 3C_s = 3 \times 1\ \mu F = 3\ \mu F$

When these capacitors are connected in parallel, net capacitance, $C_p = 3\,C = 3 \times 3 = 9\ \mu F$

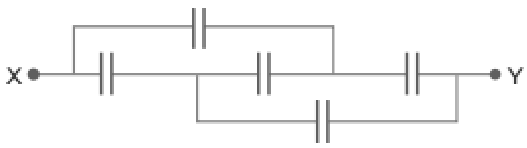
When these two combinations are connected to same source the potential difference across each combination is same.

Ratio of energy stored,

$$\frac{U_s}{U_p} = \frac{\frac{1}{2}C_s V^2}{\frac{1}{2}C_p V^2} = \frac{C_s}{C_p} = \frac{1\,\mu F}{9\,\mu F} = \frac{1}{9}$$

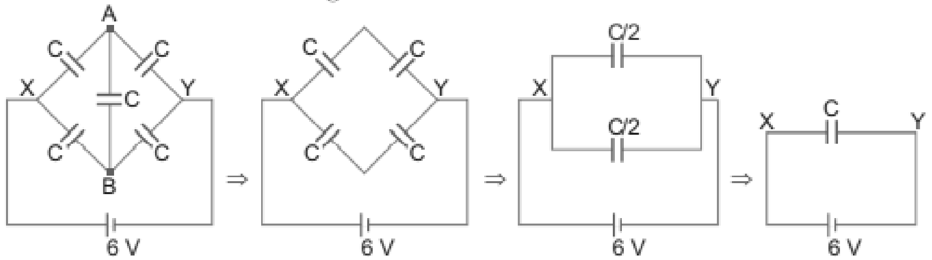
$U_s : U_p = \mathbf{1 : 9}$

Q.13 Find the equivalent capacitance of the network shown in the figure, when each capacitor is of 1 μF. When the ends X and Y are connected to a 6 V battery, find out (i) the charge and (ii) the energy stored in the network.



Ans-

The given circuit can be rearranged as



It is known as wheatstone bridge of the capacitor.

Since $V_A = V_B$, so the bridge capacitor between points A and B can be removed.

(*i*) The equivalent capacitor of the network

$$C_{eq} = \frac{C \times C}{C + C} + \frac{C \times C}{C + C}$$

$$= \frac{C}{2} + \frac{C}{2}$$

$$= C = 1\mu F$$

Charge in the network, $Q = C_{eq} V$

$$= C \times V$$

$$= 1\,\mu F \times 6\,V = \mathbf{6\,\mu C}$$

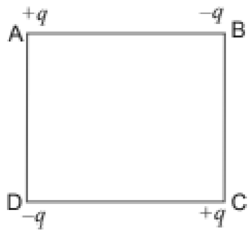
(*ii*) Energy stored in the capacitor,

$$U = \frac{1}{2} C_{eq} V^2 = \frac{1}{2} \times 1\,\mu F \times (6)^2$$

$$= \mathbf{18\,\mu J}$$

Q.14 Four charges +q, – q, + q and – q 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 q_0 is brought to the centre of the square, the four charges being held fixed. How much extra work is needed to do this?

Ans-



(*a*) Work done in bringing charge $+q$ at point A

$$W_A = 0$$

Work done in bringing charge $-q$ to the point B

$$W_B = W_{AB} = -q \times \frac{1}{4\pi\varepsilon_0}\frac{q}{a} = -\frac{1}{4\pi\varepsilon_0}\frac{q^2}{a}$$

Work done in bring the charge $+q$ to the point C

$$W_C = W_{AC} + W_{BC}$$

$$= q \times \frac{1}{4\pi\varepsilon_0}\frac{q}{a\sqrt{2}} + q \times \left(-\frac{1}{4\pi\varepsilon_0}\frac{q}{a}\right) = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a\sqrt{2}} - \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a}$$

Work done in bringing a charge $-q$ to the point D

$$W_D = W_{AD} + W_{BD} + W_{CD}$$

$$= -q \times \frac{1}{4\pi\varepsilon_0}\frac{q}{a} + (-q)\left(\frac{1}{4\pi\varepsilon_0}\frac{-q}{a\sqrt{2}}\right) + (-q) \times \frac{1}{4\pi\varepsilon_0}.\frac{q}{a}$$

Total work done $W = W_A + W_B + W_C + W_D$

$$= 2 \times \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a\sqrt{2}} - 4 \times \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a} = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a}(\sqrt{2} - 4)$$

(*b*) Work done in bringing a charge from infinity to a point is given by

$W = q_0 V_p$ (V_p = Electric potential at the point)

Electric potential at the centre of the square is

$$V_C = \frac{1}{4\pi\varepsilon_0}\left(\frac{+q}{s}\right) + \frac{1}{4\pi\varepsilon_0}\left(\frac{-q}{s}\right) + \frac{1}{4\pi\varepsilon_0}\left(\frac{+q}{s}\right) + \frac{1}{4\pi\varepsilon_0}\left(\frac{-q}{s}\right) = 0$$

and electric potential at infinity is always zero.

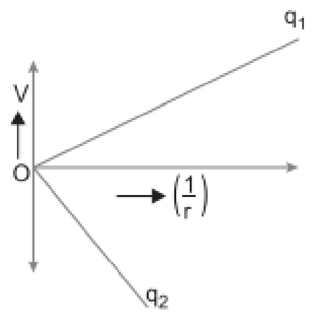
Hence, work done $W = 0$.

Q.15 The two graphs are drawn below, show the variations of electrostatic potential (V) with 1/r (r being the distance of field point from the point charge) for two-point charges q_1 and q_2.

(i) What are the signs of the two charges?

(ii) Which of the two charges has the larger magnitude and why?

Ans-



(i)The potential due to positive charge is positive and due to negative charge, it is negative, so, q_1 is positive and q_2 is negative.

(ii) $V = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$

The graph between V and 1/r is a straight line passing through the origin with slope $\frac{q}{4\pi\epsilon_0}$.

As the magnitude of slope of the line due to charge q_2 is greater than that due to q_1, q_2 has larger magnitude.

Q.16 Two identical capacitors of 12 pF each are connected in series across a 50 V battery. Calculate the electrostatic energy stored in the combination. If these were connected in parallel across the same battery, find out the value of the energy stored in this combination.

Ans-

Net capacitance in series combination is given by

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} \quad \Rightarrow \quad \frac{1}{C_s} = \frac{1}{12} + \frac{1}{12}$$

$$\Rightarrow \quad C_s = 6 \text{ pF}$$

$$E_s = \frac{1}{2} C_s V^2$$

$$E_s = \frac{1}{2} \times 6 \times 10^{-12} \times 50 \times 50$$

$$= 7500 \times 10^{-12} \text{ J}$$

$$= \mathbf{7.5 \times 10^{-9} \text{ J}}$$

Net capacitance in parallel combination is given by

$$C_p = 12 \text{ pF} + 12 \text{ pF}$$

$$= 24 \text{ pF}$$

$$E_p = \frac{1}{2} C_p V^2$$

$$E_p = \frac{1}{2} \times 24 \times 10^{-12} \times 50 \times 50$$

$$= \mathbf{3 \times 10^{-8} \text{ J}}$$

Q.17 A parallel plate capacitor each with plate area A and separation 'd' is charged to a potential difference V. The battery used to charge it is then disconnected. A dielectric slab of thickness d and dielectric constant K is now placed between the plates. What change if any, will take place in

(i) charge on the plates,

(ii) electric field intensity between the plates, (iii) capacitance of the capacitor? Justify your answer in each case.

Ans-

Initial capacitance $C_0 = \frac{\varepsilon_0 A}{d}$, Potential difference $= V$

(*i*) Initial charge, $q_0 = C_0 V = \frac{\varepsilon_0 A}{d} V$

∴ When battery is disconnected the charge on the capacitor remains unchanged and equal to

$$q = q_0 = \frac{\varepsilon_0 A}{d} V.$$

(*ii*) Initial electric field between the plates, $E_0 = \frac{\sigma}{\varepsilon_0} = \frac{q / A}{\varepsilon_0} = \frac{q}{A \varepsilon_0}$

After introduction of dielectric; the permittivity of medium becomes $K\varepsilon_0$;

so final electric field between the plates, $E = \frac{q}{AK\varepsilon_0} = \frac{E_0}{K}$ *i.e.*, electric field reduces to $\frac{1}{K}$ times.

(*iii*) After introduction of dielectric, the capacitance becomes KC_0.

Q. 18 A parallel plate capacitor is charged by a battery, which is then disconnected. A dielectric slab is then inserted in the space between the plates. Explain what changes, if any, occur in the values of

(i) capacitance

(ii) potential difference between the plates

(iii) electric field between the plates, and

(iv) the energy stored in the capacitor.

Ans-

(*i*) The capacitance of capacitor increases to K times (since $C = \frac{K\varepsilon_0 A}{d} \propto K$)

(*ii*) The potential difference between the plates becomes $\frac{1}{K}$ times.

Reason: $V = \frac{Q}{C}$; Q same, C increases to K times; $V' = \frac{V}{K}$

(*iii*) As $E = \frac{V}{d}$ and V is decreased; therefore, electric field decreases to $\frac{1}{K}$ times.

(*iv*) Energy stored will be decreased. The energy becomes, $U = \frac{Q_0^2}{2C} = \frac{Q_0^2}{2KC_0} = \frac{U_0}{K}$

Thus, energy is reduced to $\frac{1}{K}$ times the initial energy.

Q.19 A parallel plate is charged by a battery. When the battery remains connected, a dielectric slab is inserted in the space between the plates. Explain what changes if any, occur in the values of

(i) potential difference between the plates

(ii) electric field strength between the plates

(iii) capacitance

(iv) charge on the plates

(v) energy stored in the capacitor

Ans- (i) When battery remains connected, the potential difference remains the same.

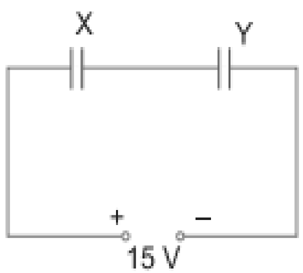
(ii) As electric field, $\mathbf{E} = \frac{\boldsymbol{V}}{\boldsymbol{d}}$, V = constant and d = constant;

therefore, electric field strength remains the same.

(iii) The capacitance of capacitor increases as K > 1.

(iv) The charge Q = CV, V = same, C = increases; therefore, charge on plates increases.

(v) Energy stored by capacitor U = $\frac{1}{2} CV^2$, also increases.



Q.20 Two parallel plate capacitors X and Y have the same area of plates and same separation between them. X has air between the plates while Y contains a dielectric medium K = 4.

(i) Calculate the capacitance of each capacitor if equivalent capacitance of the combination is 4 μF.

(ii) Calculate the potential difference between the plates of X and Y.

(iii) Estimate the ratio of electrostatic energy stored in X and Y.

Ans-

(*i*) Capacitance of X, $C_X = \frac{\varepsilon_0 A}{d}$

Capacitance of Y, $C_Y = \frac{\varepsilon_r \varepsilon_0 A}{d} = 4\frac{\varepsilon_0 A}{d}$

$\therefore \quad \frac{C_Y}{C_X} = 4 \Rightarrow C_Y = 4C_X$

As X and Y are in series, so

$$C_{eq} = \frac{C_X C_Y}{C_X + C_Y} \Rightarrow 4\,\mu\text{F} = \frac{C_X . 4C_X}{C_X + 4C_X}$$

$\Rightarrow \quad C_X = \mathbf{5\,\mu F}$ and $C_Y = 4C_X = \mathbf{20\,\mu F}$

(*ii*) In series charge on each capacitor is same, so

$$\text{P.d. } V = \frac{Q}{C} \Rightarrow V \propto \frac{1}{C}$$

$\therefore \quad \frac{V_X}{V_Y} = \frac{C_Y}{C_X} = 4 \Rightarrow V_X = 4V_Y$

Also $\quad V_X + V_Y = 15$

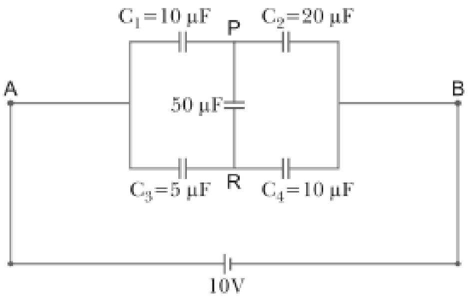
From (*ii*) and (*iii*),

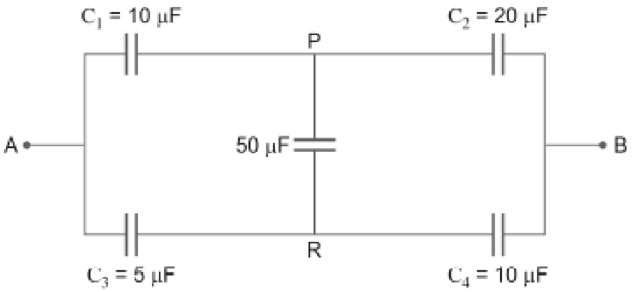
$$4V_Y + V_Y = 15 \Rightarrow V_Y = 3\text{ V}$$
$$V_X = 15 - 3 = 12\text{ V}$$

Thus potential difference across X, $\mathbf{V_X = 12\ V}$, P.d. across Y, $\mathbf{V_Y = 3\ V}$

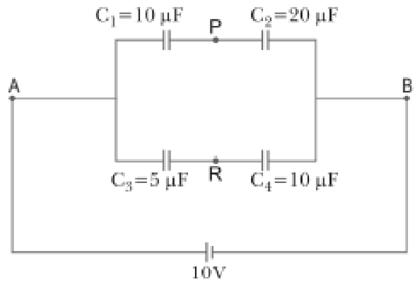
(*iii*) $\frac{\text{Energy stored in } X}{\text{Energy stored in } Y} = \frac{Q^2/2C_X}{Q^2/2C_Y} = \frac{C_Y}{C_X} = \frac{4}{1} \Rightarrow \frac{U_X}{U_Y} = \mathbf{\frac{4}{1}}$

Q.21 Calculate the equivalent capacitance between points A and B in the circuit below. If a battery of 10 V is connected across A and B, calculate the charge drawn from the battery by the circuit.





Ans-



$\therefore \quad \frac{C_1}{C_2} = \frac{C_3}{C_4}$

This is the condition of balance so there will be no current across PR (50 μF capacitor)

Now C_1 and C_2 are in series

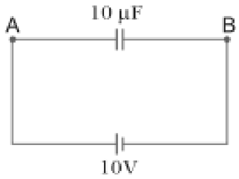
$$C_{12} = \frac{C_1 C_2}{C_1 + C_2} = \frac{10 \times 20}{10 + 20} = \frac{200}{30} = \frac{20}{3}\ \mu\text{F}$$

$\because \quad C_3$ and C_4 are in series

$$C_{34} = \frac{C_3 C_4}{C_3 + C_4} = \frac{5 \times 10}{5 + 10} = \frac{50}{15} = \frac{10}{3}\ \mu\text{F}$$

Equivalent capacitance between A and B is

$$C_{AB} = C_{12} + C_{34} = \frac{20}{3} + \frac{10}{3} = 10\ \mu\text{F}$$

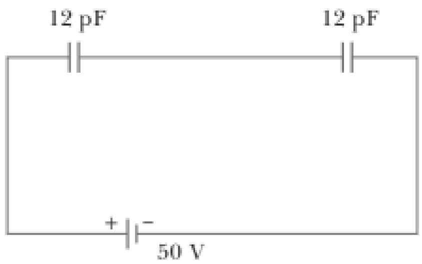


Hence, charge drawn from battery (Q) = CV = 10 × 10 mC

= 100 mC = 10^{-4} C

Q.22 Two identical capacitors of 12 pF each are connected in series across a battery of 50 V. How much electrostatic energy is stored in the combination? If these were connected in parallel across the same battery, how much energy will be stored in the combination now? Also find the charge drawn from the battery in each case.

Ans



In series combination: $\frac{1}{C_S} = \left(\frac{1}{12} + \frac{1}{12}\right) \Rightarrow \frac{1}{C_S} = \frac{1}{6}$

$\therefore \quad C_s = 6 \times 10^{-12}$ F

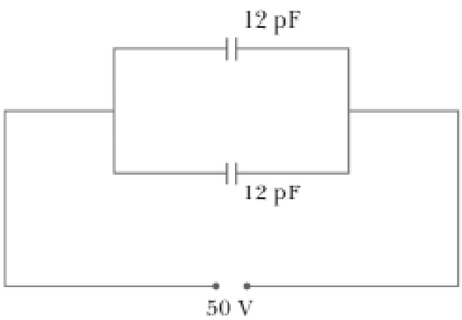
$U_s = \frac{1}{2}CV^2$

$U_s = \frac{1}{2} \times 6 \times 10^{-12} \times 50 \times 50$ J

$\therefore \quad U_s = \mathbf{75 \times 10^{-10}}$ **J**

$Q_s = C_s V = 6 \times 10^{-12} \times 50$

$= 300 \times 10^{-12}$ C $= \mathbf{3 \times 10^{-10}}$ **C**



In parallel combination: $C_p = (12 + 12)$ pF

$\therefore \quad C_p = 24 \times 10^{-12}$ F

$U_s = \frac{1}{2} \times 24 \times 10^{-12} \times 2500$ J

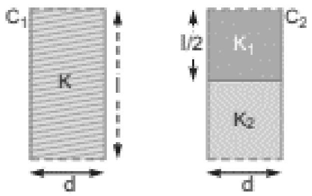
$= \mathbf{3 \times 10^{-8}}$ **J**

$Q_p = C_p V$

$Q_p = 24 \times 10^{-12} \times 50$ C

$Q_p = \mathbf{1.2 \times 10^{-9}}$ **C**

Q.23 Two identical parallel plate (air) capacitors C_1 and C_2 have capacitances C each. The space between their plates is now filled with dielectrics as shown. If the two capacitors still have equal capacitance, obtain the relation between dielectric constants K, K_1 and K_2.



Ans-

Let $A \rightarrow$ area of each plate.

Let initially $C_1 = C = \frac{\varepsilon_0 A}{d} = C_2$

After inserting respective dielectric slabs:

$$C'_1 = KC \qquad \ldots(i)$$

and $$C'_2 = K_1 \frac{\varepsilon_0 (A/2)}{d} + \frac{K_2 \varepsilon_0 (A/2)}{d} = \frac{\varepsilon_0 A}{2d}(K_1 + K_2)$$

$$C'_2 = \frac{C}{2}(K_1 + K_2) \qquad \ldots(ii)$$

From (i) and (ii)

$$C'_1 = C'_2 \Rightarrow KC = \frac{C}{2}(K_1 + K_2) \Rightarrow K = \frac{1}{2}(K_1 + K_2)$$

Q.24 If N drops of same size each having the same charge, coalesce to form a bigger drop. How will the following vary with respect to single small drop?

(i) Total charge on bigger drop (ii) Potential on the bigger drop (iii) Capacitance.

Ans-

Let r, q and v be the radius, charge and potential of the small drop.

The total charge on bigger drop is sum of all charge on small drops.

(*i*) $\therefore \quad Q = Nq$ (where Q is charge on bigger drop)

(*ii*) The volume of N small drops $= N\frac{4}{3}\pi r^3$

Volume of the bigger drop $\frac{4}{3}\pi R^3$

Hence, $\quad N\frac{4}{3}\pi r^3 = \frac{4}{3}\pi R^3 \quad \Rightarrow \quad R = N^{1/3} r$

Potential on bigger drop, $V = \frac{1}{4\pi\varepsilon_0} \times \frac{Q}{R}$

$$= \frac{1}{4\pi\varepsilon_0}\frac{Nq}{N^{1/3}r} = \frac{1}{4\pi\varepsilon_0}\frac{N^{2/3}.q}{r}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q}{r}.N^{2/3} = \mathbf{N^{2/3}v} \quad \left[\therefore v = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}\right]$$

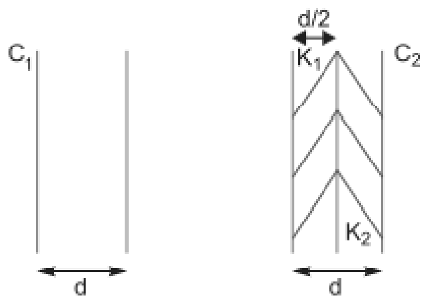
(*iii*) Capacitance $= 4\pi\varepsilon_0 R$

$$= 4\pi\varepsilon_0 N^{1/3} r$$

$$= N^{1/3}(4\pi\varepsilon_0 r)$$

$$= \mathbf{N^{1/3}C} \qquad \text{[where } C \text{ is capacitance of the small drop]}$$

Q. 25 You are given an air-filled parallel plate capacitor C_1. The space between its plates is now filled with slabs of dielectric constants K_1 and K_2 as shown in C_2. Find the capacitances of the capacitor C_2. if area of the plates is A and distance between the plates is d.



Ans-

$$C_1 = \frac{\varepsilon_0 A}{d}$$

$$\frac{1}{C_2} = \frac{1}{K_1\frac{\varepsilon_0 A}{d/2}} + \frac{1}{K_2\frac{\varepsilon_0 A}{d/2}}$$

$$= \frac{d}{2.K_1\varepsilon_0 A} + \frac{d}{2.K_2\varepsilon_0 A}$$

$$\frac{1}{C_2} = \frac{d}{2\varepsilon_0 A}\left[\frac{1}{K_1} + \frac{1}{K_2}\right] \Rightarrow C_2 = \frac{2.\varepsilon_0 A}{d}\left[\frac{K_1 K_2}{K_1 + K_2}\right]$$

$$C_2 = 2C_1\left[\frac{K_1 K_2}{K_1 + K_2}\right] \quad \Rightarrow \quad C_2 = C_1\left[\frac{2K_1 K_2}{K_1 + K_2}\right]$$

CHAPTER 3 CURRENT ELECTRICITY

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

Mathematically - I= a

Unit. In SI, the unit of electric current is ampere (A).

1 ampere (A) = 1 coulomb second™! (C s~})

Ohm's law. It states that physical conditions remaining unchanged, the current flowing through a conductor is always directly proportional to the potential difference across its two ends.

Mathematically - Val or V=RI

Here, R is called resistance of the conductor.

Unit. The unit of resistance is ohm (Ω)

1 ohm (Ω) = 1 volt/ampere (V/A)

Resistance of a conductor. The resistance of a conductor of length / and area of cross-section A is given by

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

Here, ρ is resistivity of the material of the conductor.

Resistivity. The resistivity of the material of a conductor is the resistance offered by a wire of this material of unit length and unit area of cross-section. It is also known as specific resistance of the material of the conductor.

Unit. The SI unit of resistivity is ohm metre (Ω m)

Conductance. The reciprocal of the resistance of a conductor is called its conductance (G). Thus,

$$G = \frac{1}{R}$$

Unit. The SI unit of conductance is ohm=! (Ω^{-1}) or siemen (S). ohm^{-1} is also written as mho.

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

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

Unit. The SI unit of conductivity is ohm/ metre (Ω/m) or siemen /metre (S/m). ohm^{-1} $metre^{-1}$ is also written as mho metre'.

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

Mathematically - $\boldsymbol{v_d = \frac{eE}{m}\tau = \frac{I}{neA}}$

Here, τ t is average relaxation time and n is number of free electrons per unit volume in the conductor. The other symbols have their usual meanings.

Temperature coefficient of resistance. It is defined as the change in resistance per unit resistance per degree rise in temperature.

If resistance increases linearly up to temperature θ, then temperature coefficient,

$$\alpha = \frac{R_t - R_O}{R_O\theta}$$

Unit. The unit of temperature coefficient is $°C^{-1}$.

E.M.F. The work done per unit charge by the source in taking the charge from its one terminal to the other is called the electromotive force or e.m.f. of the source.

It is equal to the potential difference between the two terminals of the source, when no current is drawn from it.

Internal resistance. The resistance offered by the electrolyte of the cell, when the electric current flows through it, is known as internal resistance of the cell.

If V is potential difference across the two terminals of a cell, when a current I is drawn from it, then

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

Here, E is e.m.f. of the cell and R, the external resistance in the circuit.

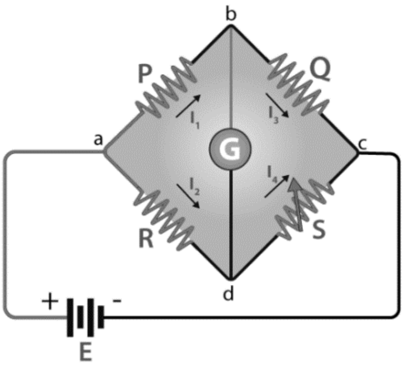
Mathematically- $r = R\left(\frac{E}{V} - 1\right)$

Kirchhoff's Laws. These laws are used to analyse electric circuits.

First law, It states that the algebraic sum of the currents meeting at a point in an electrical circuit is always zero.

Second law. It states that in any closed part of an electrical circuit, the algebraic sum of the e.m.fs. is equal to the algebraic sum of the products of the resistances and the currents flowing through them.

Wheatstone bridge. It is an arrangement of four resistances used to determine an unknown resistance.



In a balanced Wheatstone bridge,

$$\frac{P}{Q} = \frac{R}{S}$$

where P, Q, R and S are resistances in the four arms of the Wheatstone bridge.

QUESTIONS WITH ANSWERS

Q.1 How does the mobility of electrons in a conductor change, if the potential difference applied across the conductor is doubled, keeping the length and temperature of the conductor constant?

Ans-

Mobility is defined as the magnitude of drift velocity per unit electric field.

$$\mu = \frac{v_d}{E} = \frac{eE\tau}{mE} = \frac{e\tau}{m}$$

$$\mu \, \alpha \, \tau$$

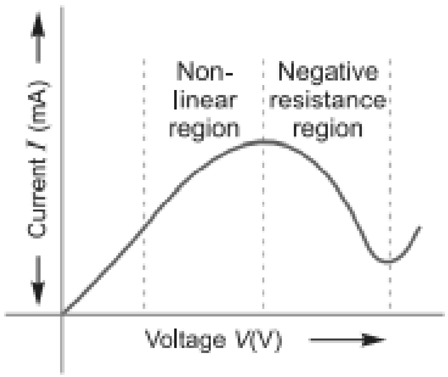
At constant temperature and length, there is no change in relaxation time i.e., $t \propto \frac{1}{T}$.

Also, it does not depend on potential difference.

Hence, on changing the potential difference, there is no change in mobility of electrons.

Q.2 Plot a graph showing variation of current versus voltage for the material GaAs

Ans- The variation of electric current with applied voltage for GaAs is as shown



Q.3 Two wires, one of copper and the other of manganin, have same resistance and equal thickness.

Which wire is longer? Justify your answer

Ans- 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 $R = \frac{\rho_2 l_2}{A}$

$\Rightarrow \quad \rho_1 l_1 = \rho_2 l_2$ (As ρl = constant)

Since $\rho_1 <<< \rho_2$

So, $l_1 >>> l_2$

i.e., copper wire would be longer.

Q.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

Ans

Nichrome wire gets heated up more.

Heat dissipated in a wire is given by

$$H = I^2 Rt$$

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

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

$\therefore \quad H \propto \rho$

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

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

Q.5 Why are alloys used for making standard resistance coils?

Ans. Alloys have

(i)low value of temperature coefficient and the resistance of the alloy does not vary much with rise in temperature.

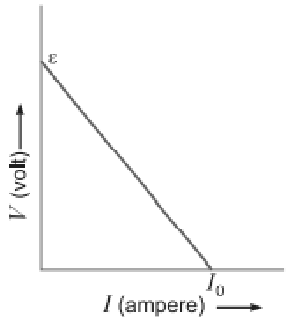
(ii) high resistivity, so even a smaller length of the material is sufficient to design high standard resistance.

Q.6 Define the terms (i) drift velocity, (ii) relaxation time.

Ans. (i) Drift Velocity: The average velocity acquired by the free electrons of a conductor in a direction opposite to the externally applied electric field is called drift velocity. The drift velocity will remain the same with lattice ions/atoms.

(ii) Relaxation Time: The average time of free travel of free electrons between two successive collisions is called the relaxation time.

Q.7 Plot a graph showing variation of voltage 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?



Ans-

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

At $I = 0, V = \varepsilon$

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

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

Q.8 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.

Ans-

In series current is same,

So, $\quad I_X = I_Y = I = neAv_d$

For same diameter, cross-sectional area is same

$$A_X = A_Y = A$$

$$\therefore \quad I_X = I_Y \quad \Rightarrow \quad n_x eAv_x = n_y eAv_y$$

$$\text{Given} \quad n_x = 2n_y \quad \Rightarrow \quad \frac{v_x}{v_y} = \frac{n_y}{n_x} = \frac{n_y}{2n_y} = \frac{\mathbf{1}}{\mathbf{2}}$$

Q.9 A conductor of length 'l' is connected to a dc source of potential 'V'. If the length of the conductor is tripled by gradually stretching it, keeping 'V' constant, how will (i) drift speed of electrons and (ii) resistance of the conductor be affected? Justify your answer.

Ans-

(*i*) We know that $v_d = -\frac{eV\tau}{ml} \propto \frac{1}{l}$

When length is tripled, the drift velocity becomes one-third.

(*ii*) $R = \rho\frac{l}{A}, \quad l' = 3l$

New resistance

$$R' = \rho\frac{l'}{A'} = \rho \times \frac{3l}{A/3} = 9R \quad \Rightarrow \quad R' = \mathbf{9R}$$

Hence, the new resistance will be 9 times the original.

Q.10 A potential difference V is applied across the ends of copper wire of length l and diameter D. What is the effect on drift velocity of electrons if (i) V is halved? (ii) l is doubled? (iii) D is halved?

Ans-

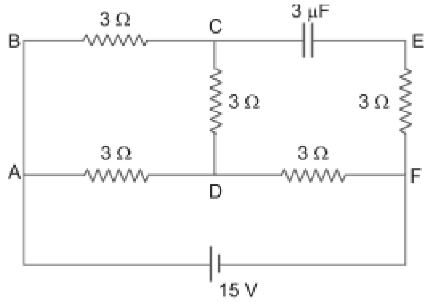
$$\text{Drift velocity, } v_d = \frac{I}{neA} = \frac{V/R}{neA} = \frac{V}{neA\left(\frac{\rho l}{A}\right)} = \frac{V}{ne\rho\, l}$$

(*i*) As $v_d \propto V$, when V is halved the drift velocity is halved.

(*ii*) As $v_d \propto \frac{1}{l}$, when l is doubled the drift velocity is halved.

(*iii*) As v_d is independent of D, when D is halved drift velocity remains unchanged.

Q.11 In the circuit shown in the figure, find the total resistance of the circuit and the current in the arm CD.



Ans-

It can be seen that resistances BC and CD are in series and their combination is in parallel with AD.

Then $\frac{1}{R_P} = \frac{1}{6} + \frac{1}{3} \Rightarrow R_P = 2\,\Omega$

Total resistance of circuit is $2 + 3 = 5\,\Omega$

(Due to capacitor, resistor $3\,\Omega$ in EF will not be counted)

Total current $= \frac{15}{5} = 3$ A.

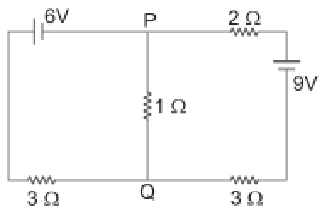
This current gets divided at junction A.

Voltage across $DF = 3\,\Omega \times 3\text{ A} = 9$ V and Voltage across $AD = 15 - 9 = 6$ V

I across $CD = \frac{6}{3+3} = 1$ A

Hence, current through arm CD = **1 A.**

Q. 12 Find the magnitude and direction of current in 1Ω resistor in the given circuit



Ans-

For the mesh $APQBA$

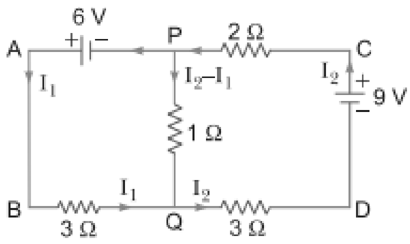
$$-6 - 1(I_2 - I_1) + 3I_1 = 0$$

or $\quad -I_2 + 4I_1 = 6 \quad \quad ...(i)$

For the mesh $PCDQP$

$$2I_2 - 9 + 3I_2 + 1(I_2 - I_1) = 0$$

or $\quad 6I_2 - I_1 = 9 \quad \quad ...(ii)$



Solving (i) and (ii), we get

$$I_1 = \frac{45}{23}\text{A} \quad \text{and} \quad I_2 = \frac{42}{23}\text{A}$$

$\therefore$ Current through the 1 Ω resistor $= (I_2 - I_1) = \mathbf{\frac{-3}{23}A}$

Q.13 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?

Ans

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

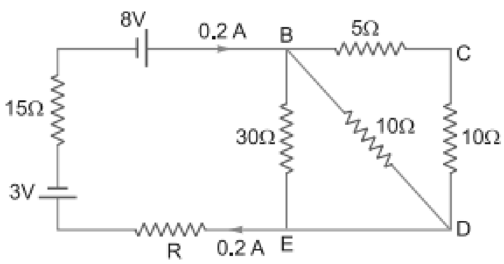
Effective resistance between B and E

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

Applying Kirchhoff's Law

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

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



Q.14 Using the concept of free electrons in a conductor, derive the expression for the conductivity of a wire in terms of number density and relaxation time. Hence obtain the relation between current density and the applied electric field E.

Ans-

The acceleration, $\vec{a} = -\frac{e}{m}\vec{E}$

The average drift velocity is given by, $v_d = -\frac{eE}{m}\tau$

(τ = average time between collisions or relaxation time)

If n is the number of free electrons per unit volume, the current I is given by

$$I = neA|v_d|$$

$$= \frac{e^2A}{m}\tau n|E|$$

But $I = |j|A$ (where j= current density)

Therefore, we get

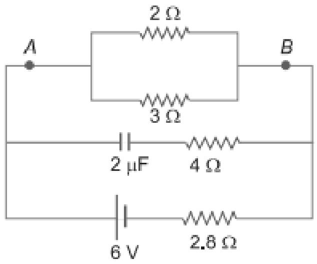
$$|j| = \frac{ne^2}{m}\tau|E|.$$

The term $\frac{ne^2}{m}\tau$ is conductivity.

$$\therefore \sigma = \frac{ne^2\tau}{m}$$

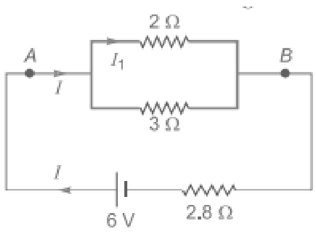
$$\Rightarrow \quad J = \sigma E$$

Q.15 Calculate the steady current through the 2 Ω resistor in the circuit shown below



Ans-

In steady state there is no current in capacitor branch, so equivalent circuit is shown in fig. Net resistance of circuit,



$$R_{eq} = \frac{2 \times 3}{2+3} + 2.8 = 1.2 + 2.8 = 4\,\Omega$$

Net emf, $E = 6$ V

Current in circuit, $I = \frac{E}{R_{eq}} = \frac{6}{4} = 1.5$ A

Potential difference across parallel combination of 2 Ω and 3 Ω resistances.

$$V' = IR' = 1.5 \times 1.2 = 1.8 \text{ V}$$

Current in 2 Ω resistance

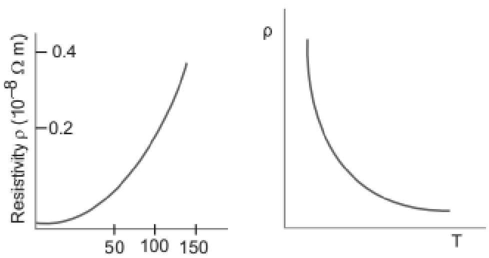
$$I_1 = \frac{V'}{R_1} = \frac{1.8}{2} = \mathbf{0.9\ A}$$

Q.16 Show, on a plot, variation of resistivity of (i) a conductor, and (ii) a typical semiconductor as a function of temperature. Using the expression for the resistivity in terms of number density and relaxation time between the collisions, explain how resistivity in the case of a conductor increases while it decreases in a semiconductor, with the rise of temperature.

Ans- We know that, $\boldsymbol{\rho = \frac{m}{ne^2\tau}}$

Where m is mass of electron t = charge density, τ = relaxation time

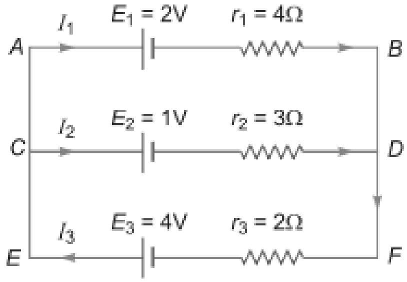
e = charge on the electron.



(i) In case of conductors with increase in temperature, relaxation time decreases, so resistivity increases.

(ii) In case of semiconductors with increase in temperature number density (n) of free electrons increases, hence resistivity decreases

Q.17 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.



Ans-

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

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

Applying Kirchhoff's second law to mesh *ABDCA*

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

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

Applying Kirchoff's second law to mesh *ABFEA*

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

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

Using (*i*) we get

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

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

Solving (*ii*) and (*iii*), we get

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

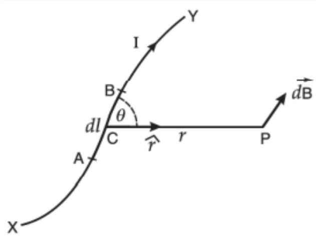
$$\text{so,} \quad I_3 = I_1 + I_2 = \mathbf{\frac{9}{13} A}$$

CHAPTER 4 MOVING CHARGES AND MAGNETISM

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

2. Source and Units of Magnetic Field Oersted’s Experiment: A Danish physicist, Hans Christian Oersted, in 1820, demonstrated that a magnetic needle is deflected by a current carrying wire. He concluded that the magnetic field is caused by current elements (or moving charges). The unit of magnetic field strength in SI system is tesla (T) or weber/metre^2 (Wb/m^2) or newton/ampere-metre (N A^{-1} m^{-1}). In CGS system, the unit of magnetic field is gauss (G). 1T=10^4 G

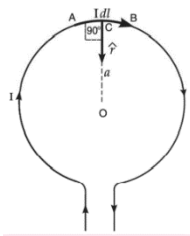
3. **Biot-Savart Law** It states that the magnetic field strength dB produced due to a current element (of current I and length dl) at a point having position vector r relative to current element is



$$dB = \frac{\mu 0}{4\pi}\frac{idl\,sin\theta}{r^2},$$

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

4, Magnetic field at the center of a circular loop is given by **B** = $\frac{\mu_o}{2}\frac{i}{r}$



5. Magnetic field due to a straight conductor of finite length carrying current I at a point at perpendicular distance a from it is given by

$$\mathbf{B} = \frac{\mu_o}{4\pi}\frac{i}{r}[\ \sin\emptyset_1 + \sin\emptyset_2\ ]$$

where $\emptyset_1$ and $\emptyset_2$are angles, which the lines joining the two ends of the conductor to the observation point make with the perpendicular from the observation point to the conductor.

6. Magnetic field due to a straight conductor of infinite length carrying current I at a point at perpendicular distance a from it is given by **B** =$\frac{\mu_o}{4\pi}\frac{2i}{r}$

7. Magnetic field due toa straight conductor of infinite length carrying current I at a point near its one end at a perpendicular distance a from it is given by patio. (by =0° and > =90°) **B** =$\frac{\mu_o}{4\pi}\frac{i}{r}$

8. The magnetic field due to a current carrying straight conductor of infinite length varies inversely as the distance of the observation points from the conductor.

9. For a given distance from the current carrying straight conductor, field is maximum, when the observation point lies along a direction perpendicular to it.

10. Ampere's Circuital Law It states that the line integral of magnetic field B " along a closed path is equal to μ_0-times the current (I) passing through the closed path.

$$\oint \vec{B}.\vec{dl} = \mu_O \mathrm{I}$$

11. **Force on a Moving Charged Particle in Magnetic Field**

The force on a charged particle moving with velocity v in a uniform magnetic field B is given by

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

This is known as Lorentz force.

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

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

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

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

12. Path of Charged Particle in a Uniform Magnetic Field

(*i*) If $\vec{v}$ is parallel to the direction of $\vec{B}$, then magnetic force = zero. So the path of particle undeflected straight line.

(*ii*) If $\vec{v}$ is perpendicular to $\vec{B}$, then magnetic field provides a force whose direction is perpend to both $\vec{v}$ and $\vec{B}$ and the particle follows a circular path. The radius r of path is given by

$$\frac{mv^2}{r} = qvB \Rightarrow r = \frac{mv}{qB}$$

If K is kinetic energy of a particle, then $P = mv = \sqrt{2mK}$

$$r = \frac{\sqrt{2mK}}{qB}$$

If V is accelerating potential in volt, $K = qV$

$$\therefore \quad r = \frac{\sqrt{2mqV}}{qB} = \frac{1}{B}\sqrt{\frac{2mV}{q}}$$

Time period of revolution is $T = \frac{2\pi\, m}{qB}$

(*iii*) If a particle's velocity $\vec{v}$ is oblique to magnetic field $\vec{B}$, then the particle follows a helical p

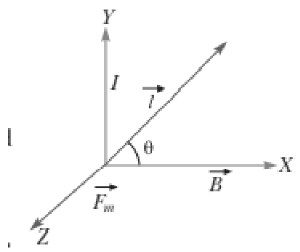
radius $r = \frac{mv\sin\theta}{qB} = \frac{mv_{\perp}}{qB}$

Time period $T = \frac{2\pi m}{qB}$

and pitch $P = v_{11}T = v\cos\theta\frac{2\pi m}{qB}$

where v_{11} is a component of velocity parallel to the direction of magnetic field.

13. Magnetic Force on a Current Carrying Conductor of Length l " is given by

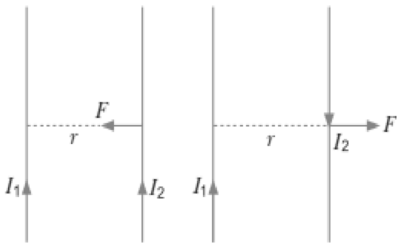


$F_m = i(\vec{l}\ X\ \vec{B})$ =ilBsinθ

Magnitude of force is F_m = IlB sin θ

Direction of force F_m " is normal to l " and B " given by Fleming's Left Hand Rule. If θ = 0 (.i e l , is parallel to B), then magnetic force is zero

14. Force between Parallel Current Carrying Conductors



Two parallel current carrying conductors attract while antiparallel current carrying conductors repel.

The magnetic force per unit length on either current carrying conductor at separation 'r' is given by

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

Its unit is newton/metre abbreviated as N/m.

15. Torque Experienced by a Current Loop (of Area A) Carrying Current I in a Uniform Magnetic Field B is given by $\vec{\tau} = Ni(\vec{A}\ X\ \vec{B}) = (\vec{M}\ X\ \vec{B})$, where M = Ni A is magnetic moment of loop. The unit of magnetic moment in SI system is ampere × metre^2 (Am^2)

16. Potential energy of a current loop in a magnetic field

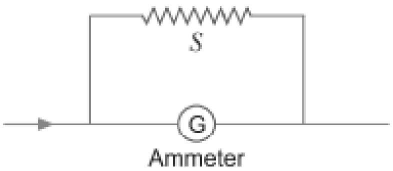
When a current loop of magnetic moment M is placed in a magnetic field, then potential energy of magnetic dipole is $U = -\vec{M}.\vec{B} = -MB\cos\theta$

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

(ii) When θ=π, U=+MB (maximum or unstable equilibrium position)

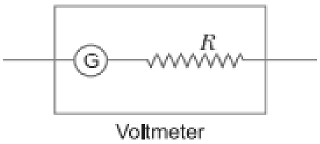
(iii) When $\theta = \frac{\pi}{2}$ potential energy is zero

17. Conversion of Galvanometer into Ammeter A galvanometer may be converted into ammeter by using very small resistance in parallel with the galvanometer coil. The small resistance connected in parallel is called a shunt. If G is resistance of galvanometer, I_g is current in galvanometer for full scale deflection, then for conversion of galvanometer into ammeter of range I ampere, the shunt is given by



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

18. Conversion of Galvanometer into Voltmeter A galvanometer may be converted into voltmeter by connecting high resistance (R) in series with the coil of galvanometer. If V volt is the range of voltmeter formed, then series resistance is given by $R = \frac{V}{I_g} - G$



QUESTIONS WITH ANSWERS

Q. 1 Is the source of magnetic field analogue to the source of electric field?

Ans. No. It is because, the source of magnetic field is not a magnetic charge. In case of electric field, the source of electric field is electric charge.

Q. 2 Does a current carrying circular coil produce uniform magnetic field?

Ans. No, magnetic field produced due to a current carrying circular coil is not uniform. However, it may be considered as uniform at the centre of the circular coil.

Q. 3 What is the effect of increasing the number of turns on magnetic field produced due to a circular coil?

Ans. The magnetic field produced by a coil of m turns is n times the magnetic field produced by a coil of single turn. $B = \frac{\mu_O Ni}{2r}$

Q. 4 Looking at a circular coil, the current is found to be flowing in anticlockwise direction. Predict the direction of magnetic field produced at a point on the axis of the coil on the same side as the observer.

Ans. The direction of magnetic field is perpendicular to the plane of the coil and directed towards the observer.

Q. 5 What kind of magnetic field is produced by an infinitely long current carrying conductor?

Ans. Magnetic field lines are concentric circular loops in a plane perpendicular to the straight conductor. The centres of the circular magnetic field lines lie on the conductor.

Q. 6. In what respect does a wire carrying a current differ from a wire, which carries no current?

Ans. A current carrying wire produces magnetic field. It is because, when current flows through a wire, electrons move inside it along a definite direction. On the other hand, in a wire which carries no current, electrons are in motion in random direction. Such a wire does not produce anymagnetic field.

Q.7 An electric charge enters in electric field at right angles to the direction of electric field. What is the nature of the path followed?

Ans. The electric charge will move along a parabolic path.

Q.8 What is the magnitude of transverse acceleration produced in the motion of the electric charge, when it passes through the electric field?

Ans. If a charge q having mass m passes transversely through an electric field E, then acceleration,

$$a = \frac{qE}{m}$$

Q. 8 Under what condition is the force acting on a charge moving through a uniform magnetic field minimum?

Ans. A charge moving through a magnetic field, experiences no force (minimum), when it moves along the direction of magnetic field.

Q. 9 An electron is projected in the direction of magnetic field. How will its motion be affected by the action of magnetic field?

Ans. No force acts on the electron due to the magnetic field, when it is projected in the direction of magnetic field. Hence, its motion will not be affected.

Q. 10. What will be the path of a charged particle moving perpendicular to the direction of a uniform magnetic field?

Ans. When the charged particle moves perpendicular to the direction of a uniform magnetic field, it experiences a force perpendicular to its direction of motion. As such, it moves alone a circular path.

Q. 11. Does a stationary charge experience a force in an electric field?

Ans. The force due to electric field does not depend, whether the charge is at rest or is in motion. A stationary charge experiences force in an electric field, which is given by $F = qE$

Q. 12 When is the force on a moving charge due to a magnetic field maximum and when is it minimum?

Ans. We know, $F_m = Bqv\sin\theta$

For force to be maximum, $\sin\theta = 1$ ie. $\theta = 90°$ ie. when the charged particle moves perpendicular to the direction of magnetic field.

For force to be minimum, $\sin\theta = 0$ i.e. $\theta = 0°$ 1.e. when the charged particle moves along the direction of magnetic field.

Q. 13 Why does a charged particle moving at right angle to the direction of a magnetic field follow a circular path?

Ans. When a charged particle moves at right angle to the direction of a magnetic field, it experiences force which always acts perpendicular to the velocity. Hence, the magnitude of its velocity remains constant and only the direction of the velocity of the charged particle changes. In other words, the force on the charged particle acts as centripetal force and it follows a circular path.

Q.14. Why does not a charged particle moving at right angle to the direction of a magnetic field undergo any change in kinetic energy?

Or

The energy of a charged particle moving in a uniform magnetic field does not change. Why? Explain.

Ans. The force on a charged particle moving in a uniform magnetic field always acts in a direction perpendicular to the direction of motion of the charge. As work done by the magnetic field on the charge is zero, the energy of the charged particle does not change.

Q. 15 What is the nature of force, when the two parallel conductors carry currents in the (i) same direction (ii) opposite direction?

Ans. (i) Force is attractive. (ii) Force is repulsive.

Q.16. Does the torque on a planar current loop 1n magnetic field change, when its shape is changed without changing its geometrical area?

Ans. The torque on a planar current loop in a magnetic field does not change, when its shape is changed without changing the area of the loop.

Q.17 A current carrying loop free to turn is placed in a uniform magnetic field B. What will be its orientation relative to B in the equilibrium state?

Ans. In equilibrium state, the current carrying loop will orient itself, such that B is perpendicular to the plane of the coil. It is because of the fact that in this orientation, the torque on the current loop becomes zero.

Q. 18. Under what circumstances, will a current carrying loop not rotate in the magnetic field?

Ans. If the current carrying loop is placed in a magnetic field, with its plane perpendicular to the field, then it will not rotate.

Q. 19 Is the resistance of an ammeter greater than or less than that of the galvanometer of which it is formed?

Ans. The resistance of an ammeter is always less than that of the galvanometer, of which it is formed.

Q. 20 Why should an ammeter have a low resistance?

Ans. For measuring current in a circuit, an ammeter is connected in series. So that the current in the circuit remains practically unchanged on connecting the ammeter, the resistance of the ammeter should be low.

Q. 21 How is an ammeter connected in an electric circuit?

Ans. An ammeter is connected in series in an electric circuit.

Q.22. How can a galvanometer be converted into voltmeter?

Ans. A galvanometer can be converted into a voltmeter by connecting a suitable high resistance in series to its coil.

Q. 23 Is the resistance of a voltmeter greater than or less than that of the galvanometer of which it is formed?

Ans. The resistance of a voltmeter is always greater than that of the galvanometer, of which it is formed.

Q. 24 What is the resistance of an ideal voltmeter and an ammeter?

Ans. The resistance of an ideal voltmeter is infinite and that of an ammeter is zero.

Q.25 How is a voltmeter connected in an electric circuit?

Ans. A voltmeter is connected in parallel in an electric circuit.

Q.26 Give two differences between a voltmeter and an ammeter.

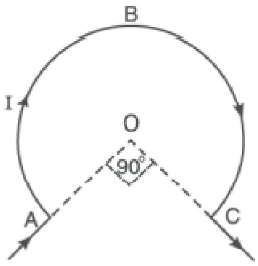
Ans. (i) An ammeter is a low resistance instrument and is used to measure current in an electrical circuit.

(ii) A voltmeter is a high resistance instrument and is used to measure potential difference in an electrical circuit.

Q.27 The wire shown in the diagram carries a current of 10 A. Determine the magnitude of magnetic field induction at the centre O. Given that radius of the bent coil is 3 cm.

Ans- The magnetic field induction at the centre of a current carrying circular wire of radius a is given by

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi I}{a}$$



A circular wire subtends an angle of 2π radians at its centre. Suppose that the given circular part ABC of the wire subtends an angle θ at its centre. Then, magnetic field at the point O due to the circular part ABC is given by

$$B' = B \times \frac{\theta}{2\pi} = \frac{\mu_0}{4\pi} \cdot \frac{2\pi I}{a} \times \frac{\theta}{2\pi}$$

or $$B' = \frac{\mu_0}{4\pi} \cdot \frac{I}{a}\theta$$

Here, $I = 10\ A\ ;\ a = 3\ cm = 0{\cdot}03\ m$

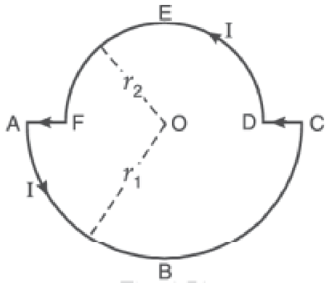
and $\theta = 360° - 90° = 270° = \frac{3\pi}{2}$ rad

$\therefore$ $$B' = \frac{10^{-7} \times 10 \times 3\pi}{0{\cdot}03 \times 2} = \mathbf{1{\cdot}57 \times 10^{-4}\ T}$$

Q.28 A wire loop is formed by joining two semi-circular wires of radii r, and r, as shown in diagram. If the loop carries a current I, find the magnetic field at the centre O.

Ans. The magnetic field at the point O due to the semi-circular part ABC,

$$B_1 = \frac{\mu_0}{4\pi} \cdot \frac{\pi I}{r_1} \qquad \text{(outwards)}$$



The magnetic field at the point O due to the semi-circular part DEF,

$$B_2 = \frac{\mu_0}{4\pi} \cdot \frac{\pi I}{r_2} \qquad \text{(outwards)}$$

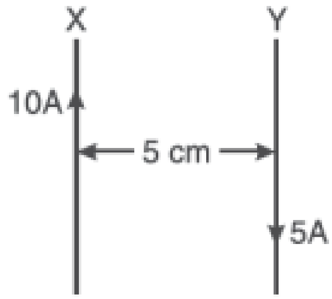
Since the point O lies on the straight parts AF and CD of the loop, the magnetic field at point O due to these parts is zero.

Therefore, net magnetic field at point O due to wire loop,

$$B = B_1 + B_2 = \frac{\mu_0}{4\pi} \cdot \frac{\pi I}{r_1} + \frac{\mu_0}{4\pi} \cdot \frac{\pi I}{r_2}$$

or $$B = \frac{\mu_0}{4\pi} \cdot \pi I \left(\frac{1}{r_1} - \frac{1}{r_2}\right) \textbf{ (in outward direction)}$$

Q. 29 Two parallel straight wires X and Y separated by a distance 5 cm in air carry current of 10 A and 5 A respectively in opposite direction as shown in diagram. Calculate the magnitude and direction of the force on a 20 cm length of the wire Y.



Ans- Force on a unit length of the wire Y due to the wire X,

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

Here, $I_1 = 10$ A ; $I_2 = 5$ A ; $r = 5$ cm $= 0{\cdot}05$ m

Also, $\frac{\mu_0}{4\pi} = 10^{-7}$ T A m^{-1}

$\therefore \quad F = \frac{10^{-7} \times 2 \times 10 \times 5}{0{\cdot}05} = 2 \times 10^{-4}$ N m^{-1}

Force on 20 cm *i.e.* 0·2 m length of the wire Y ,

$F' = F \times 0{\cdot}2 = 2 \times 10^{-4} \times 0{\cdot}2$

$= \mathbf{4 \times 10^{-5}}$ **N**

Q.30 A galvanometer has a resistance of 60 Ω and a full-scale deflection is produced by 1.0 mA. How will you convert it in to

(a) an ammeter to read 1A (full scale) and

(b) voltmeter to read 3 V (full scale)?

Ans- Here G = 60 Ω , I= 1A , V= 3V, I_g 1.0mA

(a) To enable galvanometer to read 1 A :

Here, I = 1 A. The required resistance,

$$S = \frac{I_g \times G}{I - I_g} = \frac{10^{-3} \times 60}{1 - 10^{-3}} = 0{\cdot}06\ \Omega$$

= 0·06 Ω (in parallel)

(b) To enable galvanometer to read 3 V :

Here, V =1·5 V

The required resistance,

$$R = \frac{V}{I_g} - G = \frac{3}{10^{-3}} - 60$$

= 2,940 Ω (in series)

CHAPTER 5 MAGNETISM AND MATTER

Magnetic dipole. An arrangement of two unlike poles of equal strength and separated by a small distance ts called magnetic dipole.

In SI, the unit of magnetic pole strength is ampere metre (A m).

The distance between the two magnetic poles is called the magnetic length of the magnetic dipole. It is denoted by 2 | , a vector from south to north pole of the magnetic dipole.

Magnetic dipole moment. The product of the pole strength of the either magnetic pole and the magnetic length of the magnetic dipole is called its magnetic dipole moment. It is denoted by $\vec{M}$

Mathematically - $\vec{M}$ =m ($\overrightarrow{2l}$)

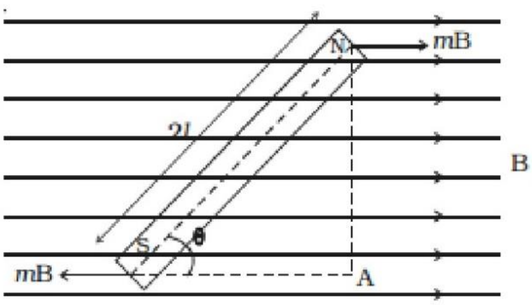
Here, m is pole strength of the magnetic dipole. The SI unit of magnetic dipole moment is ampere/metre^2 (A m^2).

Current loop and magnetic dipole. A current loop of area A carrying current I behave as a magnetic dipole having magnetic dipole moment,

M=IA

Torque on a magnetic dipole in a magnetic field. When a magnetic dipole of magnetic dipole moment M is placed in a uniform magnetic field of strength B_- making an angle 4 with the direction of magnetic field, it experiences a torque, which is given by

$$|\vec{\tau}| = |\vec{M} \times \vec{B}| = MB \sin\theta$$



Potential energy stored in a magnetic dipole on rotating inside a magnetic field.

The work done in rotating a magnetic dipole against the torque acting on it, when placed in magnetic field is stored inside the magnetic dipole in the form of its potential energy.

When the magnetic dipole is rotated from its initial position θ_1, to the final position θ_2, then the potential energy stored is given by

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

Magnetic intensity. It is defined as the ratio of magnetic induction in vacuum to the absolute magnetic permeability of free space. It is given by

$$H = \frac{B_O}{\mu_O}$$

where μ_O = 4π x 10^{-7} tesla metre/ampere is absolute permeability of vacuum.

Magnetic intensity is also known as H-field or magnetising field strength. The unit of magnetic intensity i.e. A/ m is also equivalent to N /m^2 T or N/Wb or J/m^{-3} T

Intensity of magnetisation. It is defined as the magnetic dipole moment developed per unit volume or the pole strength developed per unit area of cross-section of the specimen. It is given by

$$I = \frac{M}{V} = \frac{m}{a}$$

Here, V is volume and A is area of cross-section of the specimen.

In SI, the unit of intensity of magnetisation is ampere/metre (A/m}).

Magnetic induction. It is defined as the number of magnetic lines of induction (magnetic field lines inside the material) crossing per unit area normally through the magnetic material.

If H is the strength of the magnetising field, then magnetic induction is given by

$$B = \mu_O (H + I)$$

In SI, the unit of the strength of magnetising field is ampere/ metre (A/ m) and that of magnetic induction is tesla (T) or weber /metre^2 (Wb/ m^2)

Magnetic susceptibility. The magnetic susceptibility of a material is defined as the ratio of the intensity of magnetisation (1) and the strength of magnetising field (H). It is given by

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

The magnetic susceptibility has no units.

Magnetic permeability. The magnetic permeability of a material is defined as the ratio of the magnetic induction (B) of the material to the strength of magnetising field (H). It is given by

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

In SI, the unit of magnetic permeability is tesla metre/ ampere (T m/ A).

Diamagnetic substances. Those substances, which when placed in a magnetic field are feebly magnetised in a direction opposite to that of the magnetising field.

Paramagnetic substances. Those substances, which when placed in a magnetic field are feebly magnetised in the direction of the magnetising field.

Ferromagnetic substances. Those substances, which when placed in a magnetic field are strongly magnetised in the direction of the magnetising field.

QUESTIONS WITH ANSWERS

Q.1 What do you mean by directive property of a magnetic dipole?

Ans. A freely suspended magnet always aligns itself along the N-S line.

Q.2 A bar magnet is cut into two equal pieces trans-verse to its length. What happens to its dipole moment?

Ans. Let m and 2l be the pole strength and the length of the given bar magnet. When the magnet is cut into two equal pieces transverse to its length, each piece will be a magnet having pole strength m (unchanged) and length l. Therefore, the magnetic moment of each piece will be ml i.e. one half of that of the original magnet.

Q.3 Why ordinarily a piece of iron does not behave as a magnet?

Ans. In an ordinary piece of iron, the molecular magnets are randomly oriented and form closed chains. Since the molecular magnets cancel the effect of each other, the ordinary iron piece does not behave as a magnet.

Q.4 What is the source of magnetic field (magnetism)?

Ans. Magnetism is of electrical origin. The electrons revolving in an atom behave as tiny current loops and these current loops give rise to magnetism.

Q.5 Does an isolate magnetic pole exists like an isolate electric charge?

Ans. No, an isolate magnetic pole does not exist.

Q.6 What is the unit of magnetic pole strength?

Ans. Unit of magnetic pole strength, ampere metre (A m).

Q.7 What is the unit and direction of magnetic dipole moment?

Ans. The unit of magnetic dipole moment is A m2 and its direction is from S-pole to N-pole of the magnetic dipole.

Q.8 Can a current loop be treated as magnetic dipole?

Ans. A current loop can be treated as a magnetic dipole. If the current loop has an area A and carries a current I, then its magnetic dipole moment is given by M=IA

Q.9 Define Bohr magneton and write its value.

Ans. Bohr magneton ts defined as the magnetic dipole moment associated with an atom due to orbital motion of an electron in the first orbit of hydrogen atom.

Bohr magneton, μ_B = 9.27 x 10^{-24} A/m^2

Q.10 Does a bar magnet exert a torque on itself due to its own field? Does one element of a current-carrying wire exert a force on another element of the same wire?

Ans. No, a bar magnet does not exert a force or torque on itself due to its own field. But an element of a current carrying conductor experiences force due to another element of the conductor.

Q.11 When does a magnetic dipole possess maximum potential energy inside a magnetic field?

Ans. A magnetic dipole possesses maximum potential energy, when its magnetic moment M and the magnetic field B are antiparallel.

Q.12 When does a magnetic dipole possess minimum potential energy inside a magnetic field?

Ans. A magnetic dipole possesses maximum potential energy, when its magnetic moment M and the magnetic field B are parallel.

Q.13 Compare the magnetic fields due to a straight solenoid and a bar magnet.

Ans. The magnetic field of a bar magnet and a straight solenoid are identical. The two ends of the straight solenoid behave as the north and south poles as in case of a bar magnet.

Q.14 What is the basic difference between magnetic lines of force and electric lines of force?

Ans. The electric lines of force originate from positive charge and end at negative charge and are thus discontinuous curves. But as the isolated magnetic poles do not exist, the magnetic field lines are closed loops.

Q.15 Why two magnetic lines of force do not cross each other?

Ans. Two magnetic field lines cannot intersect each other. It is because, if they do so, then at the point of intersection, the magnetic field will have two directions along the tangents to the two field lines.

Q.16 An iron bar is magnetised with the help of another magnet or by subjecting it toa magnetising field. The magnetism acquired by the magnet is assumed due to the alignment of molecular magnets. Does the length of the iron bar undergo a change during the magnetisation process?

Ans. Yes, the length of the iron bar increases in the direction of magnetisation. This effect is called magneto-striction and is used for producing ultrasonic waves.

Q.17 The poles of a magnet cannot be separated. How does this statement derive support from the magnetic dipole behaviour of a current loop?

Ans. A current loop behaves as a magnetic dipole. It’s one face behaves as -pole, while the other as s-pole. As the two faces of the current loop cannot be separated from each other, it follows that the magnetic poles developed on the two faces also cannot be separated from each other.

Q.18 A magnetised needle in a uniform magnetic field experiences a torque but no net force. An iron nails near a bar magnet, however, experiences a force of attraction in addition to a torque, why?

Ans. The force and torque act on the nail due to the induced magnetic moment acquired by it. The iron needles will also not experience any force, if magnetic field is uniform. The magnetic field due to a bar magnet is not uniform. Therefore, an iron nail experiences both a force and torque, when placed near a bar magnet.

It may be pointed that the nail experiences a net attractive force. It is because the attractive force on the nearer end (unlike induced pole) of the nail is greater than the repulsive force on its farther end (like induced pole).

Q.19 Why does a magnetic dipole possess potential energy, when placed at some inclination with the direction of the field?

Ans. In equilibrium, a magnetic dipole always aligns itself along the direction of the magnetic field. When the magnetic dipole is displaced from the equilibrium position, a restoring torque acts on the dipole to bring it back. Therefore, to place the dipole at some inclination with the field, work has to be done against the restoring torque. This work done is stored in the dipole as its potential energy.

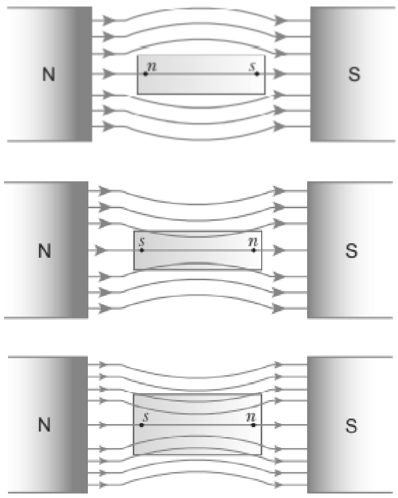
Q.20 What do you mean by magnetic lines of force? Why two such lines do not cross each other/?

Ans. The magnetic field line is the path along which an isolated north pole will tend to move, if it is free to do so. Two magnetic field lines cannot intersect each other. It is because, if they do so, then at the point of intersection, the magnetic field will have two directions along the tangents to the two field lines.

Q.21 Magnetic field arises due to charges in motion. Can a system have magnetic moment, even though its net charge is zero?

Ans. A system can have a magnetic moment even though its net charge is zero. It is because, the average charge of a system may be zero, but it is not necessary that magnetic-moments due to various current loops will also be zero. For example, a neutron has zero charge, but possesses non zero magnetic moment.

Q.22 Draw the magnetic field lines for a current carrying solenoid when a rod made of (a) copper, (b) aluminium and (c) iron are inserted within the solenoid as shown.

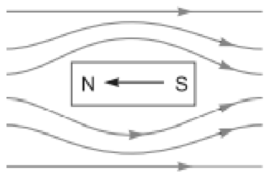


Ans- (a) When a bar of diamagnetic material (copper) is placed in an external magnetic field, the field lines are repelled or expelled and the field inside the material is reduced.

(b) When a bar of paramagnetic material (Aluminium) is placed in an external field, the field lines gets concentrated inside the material and the field inside is enhanced.

(c) When a ferromagnetic material (Iron) is placed in an internal magnetic field, the field lines are highly concentrated inside the material

Q.23 Explain the following:



(i) Why do magnetic field lines form continuous closed loops?

(ii) Why are the field lines repelled (expelled) when a diamagnetic material is placed in an external uniform magnetic field?

Ans. (i) Magnetic lines of force form continuous closed loops because a magnet is always a dipole and as a result, the net magnetic flux of a magnet is always zero.

(ii) When a diamagnetic substance is placed in an external magnetic field, a feeble magnetism is induced in opposite direction. So, magnetic lines of force are repelled

Q.24 Write three points of differences between para-, dia- and ferro- magnetic materials, giving one example for each.

Ans-

	Diamagnetic	Paramagnetic	Ferromagnetic
1	$-1 \leq \chi < 0$	$0 < \chi < \varepsilon$	$x \gg 1$
2	$0 \leq \mu_r < 1$	$1 \leq \mu_r < (1 + \varepsilon)$	$\mu_r \gg 1$
3	$\mu < \mu_0$	$\mu > \mu_0$	$\mu \gg \mu_0$

Examples:

Diamagnetic materials: Bi, Cu, Pb, Si, water, NaCl, Nitrogen (at STP)

Paramagnetic materials: Al, Na, Ca, Oxygen (at STP), Copper chloride

Ferromagnetic materials: Fe, Ni, Co, Alnico

Q.25 A bar magnet of magnetic moment 1.5 JT^{-1} lies aligned with the direction of a uniform magnetic field of 0.22 T.

(a) What is the amount of work required by an external torque to turn the magnet so as to align its magnetic moment

(i) normal to the field direction? and

(ii) opposite to the field direction?

(b) What is the torque on the magnet in cases (i) and (ii)?

Ans-

(*a*) Work done in aligning a magnet from orientation θ_1 to θ_2 is given by

$$W = U_2 - U_1 = -mB\cos\theta_2 - (-mB\cos\theta_1)$$
$$= -mB(\cos\theta_2 - \cos\theta_1)$$

(*i*) Here $\theta_1 = 0°, \theta_2 = 90°$

$$\therefore \quad W = mB(\cos 0° - \cos 90°) = mB(1 - 0) = mB$$
$$= 1.5 \times 0.22 = \mathbf{0.33\ J}$$

(*ii*) Here $\theta_1 = 0°, \theta_2 = 180°$

$$\therefore \quad W = mB(\cos 0° - \cos 180°) = 2mB$$
$$= 2 \times 1.5 \times 0.22 = \mathbf{0.66\ J}$$

(*b*) Torque $\tau = mB\sin\theta$

In (*i*) $\theta = 90°, \tau = mB\sin 90° = mB = 1.5 \times 0.22 =$ **0.33 N-m**

This torque tends to align the magnet along the direction of field direction.

In (*ii*) $\theta = 180°, \tau = mB\sin 180° = \mathbf{0}$

CHAPTER 6 ELECTROMAGNETIC INDUCTION

1. **Magnetic Flux**. The number of magnetic field lines crossing a surface normally is called magnetic flux ($\emptyset_B$) linked with the surface.

Mathematically- $\varphi = \vec{B}.\vec{A} = BA\cos\theta$

where B is the magnetic field, A is the area of the surface and θ is the angle, which the direction of the magnetic field makes with normal to the surface.

Unit. In SI, unit of magnetic flux is weber (Wb) **1 weber = 10^8 maxwell**

2. **Electromagnetic induction**. It is the phenomenon of production of e.m.f. in a coil, when the magnetic flux linked with the coil is changed. The e.m.f. so produced is called induced e.m.f. and the resulting current is called induced current.

3. Faraday's laws of electromagnetic induction-

1. Whenever magnetic flux linked with a circuit (a loop of wire or a coil or an electric circuit in general) changes, induced e.m.f. is produced.
2. The induced e.m.f. lasts as long as the change in the magnetic flux continues.
3. The magnitude of the induced e.m.f. is directly proportional to the rate of change of the magnetic flux.

Mathematically: Induced e.m.f., $e = -\frac{d\emptyset}{dt} = -\frac{\emptyset_2 - \emptyset_1}{t}$

4. **Lenz's law**. It states that the induced current produced in a circuit always flows in such a direction that it opposes the change or the cause that produces it. Lenz's law can be used to find the direction of the induced current.
5. **Motional E.M.F**. When a conductor of length / moves with a velocity v in a magnetic field B, so that magnetic field is perpendicular to both the length of the conductor and its direction of motion, the magnetic Lorentz force on the conductor gives rise to e.m.f. across the two ends of the conductor.

Mathematically: **e=Blv**

6. **Eddy currents**. The currents induced in the body of a conductor, when the magnetic flux linked with the conductor changes, are called eddy currents (or Foucault's currents). The direction of the eddy currents set up in the conductor can be found by applying Lenz's law or Fleming's right hand rule.
7. **Self-induction**. The phenomenon according to which an opposing induced e.m.f. is produced in a coil as a result of change in current or magnetic flux linked with it, is called self-induction.
8. **Coefficient of self-induction**. The coefficient of self-induction or simply self-inductance (L) of a coil is numerically equal to the magnetic flux () linked with the coil, when a unit current flows through it.

Mathematically**:** $\emptyset = LI$

9. **The self-inductance** of a coil ts also numerically equal to the induced e.m.f. produced in the coil, when the rate of change of current in the coil is unity.

Mathematically $e = -L\frac{dI}{dt}$**,** Unit: In SI, the unit of self-inductance is henry (H).

The self-inductance of a coil is said to be one henry, if a rate of change of current of 1 ampere per second induces an e.m.f. of 1 volt in it.

10. **Energy stored in an inductor**. When a current! flows through an inductor of self-inductance L, the energy stored in the inductor is given by

$$U = \frac{1}{2} L I^2$$

The energy resides in the inductor in the form of magnetic field.

11. **Self-inductance of a long solenoid**. The self-inductance of a long solenoid of length /, area of cross-section A and number of turns per unit length 1 is given by

$$L = \mu_0 n^2 l A$$

12. **Energy stored in a solenoid.** When a current is passed through a solenoid, the energy is stored inside it in the form of magnetic field. If the current builds up a magnetic field of induction B, then the energy stored in the solenoid is given by

$$U = \frac{1}{2\mu_o} B^2 A l$$

where l is length and A, the area of cross-section of the solenoid.

13. **Mutual induction**. The phenomenon according to which an opposing induced e.m.f. is produced in a coil as a result of change in current or magnetic flux linked with a neighbouring coil is called mutual induction.

14. **Coefficient of mutual induction**. The coefficient of mutual induction or simply mutual inductance (M) of the two coils is numerically equal to the magnetic flux (p) linked with one coil, when a unit current flows through the neighbouring coil.

Mathematically- $\emptyset = MI$

15. **The mutual inductance** of two coils is also numerically equal to the induced e.m.f. produced in one coil, when the rate of change of current is unity in the other coil.

Mathematically - $e = -M\frac{dI}{dt}$

Unit. In SI, the unit of mutual inductance is henry (H).

16. **The mutual inductance** of two coils is said to be one henry, if a rate of change of current of 1 ampere per second in one coil induces an e.m.f. of 1 volt in the neighbouring coil.

17. **Mutual inductance of two long solenoids**. When over a solenoid S, of length /, area of cross-section A and number of turns per unit length 1, another solenoid S, of same length and number of turns per unit length 11, is wound, then mutual inductance between the two solenoids is given by

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

18. **Fleming's right-hand rule**. It is used to find the direction of flow of the induced current.

It states that if the thumb, fore finger and the central finger of the right hand are kept perpendicular to each other, so that the fore finger points in the direction of the field and the thumb in the direction of motion of the conductor, then the induced current flows in the direction of the central finger.

19. **Induction coil**. It is a device used to obtain high potential difference from a low d.c. potential difference.

It is based upon the phenomenon of mutual induction.

20. **Alternating current generator**. It is a device used to obtain a supply of alternating e.m.f. by converting rotational mechanical energy into electrical energy. It is based on the phenomenon of electromagnetic induction.

The instantaneous value of e.m.f. produced is given by

$$e = nBA\omega \sin\omega t$$

where n is number of turns of the coil, A is the area of coil and ω is angular frequency of rotation of the coil inside a magnetic field strength B.

QUESTIONS WITH ANSWERS

Q.1 Two spherical bobs, one metallic and the other of glass, of the same size are allowed to fall freely from the same height above the ground. Which of the two would reach earlier and why?

Ans. Glass would reach earlier. This is because there is no effect of electromagnetic induction in glass, due to presence of earth's magnetic field, unlike in the case of metallic ball.

Q.2 When current in a coil change with time, how is the back emf induced in the coil related to it?

Ans. The back emf induced in the coil opposes the change in current.

Q.3 State the law that gives the polarity of the induced emf.

Ans. Lenz's Law: The polarity of induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produces it.

Q.4 A light metal disc on the top of an electromagnet is thrown up as the current is switched on. Why? Give reason.

Ans. A metal disc is placed on the top of a magnet, as the electric current flows through the coil, an induced current in the form of Eddies flows through the metal plate, the lower face attains the same polarity, and hence the metal disc is thrown up.

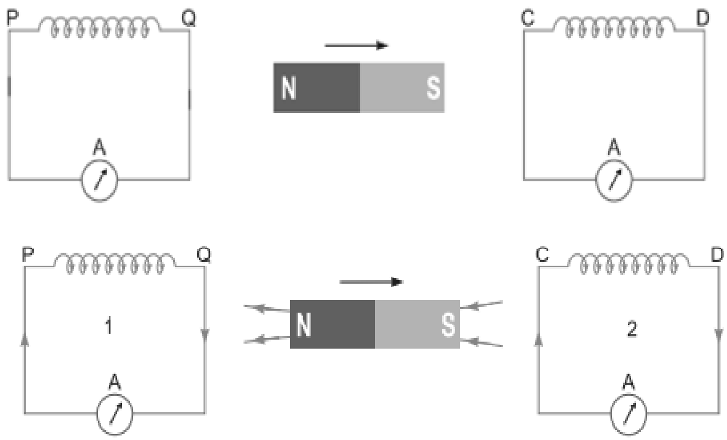
Q.5 Give one example of use of eddy currents.

Ans. (i) Electromagnetic damping in certain galvanometers.

(ii) Magnetic braking in trains.

(iii) Induction furnace to produce high temperature. (Any one)

Q.6 A bar magnet is moved in the direction indicated by the arrow between two coils PQ and CD. Predict the directions of induced current in each coil.



Ans. In figure, N-pole is receding away coil (PQ), so in coil (PQ), the nearer faces will act as S-pole and in coil (CD) the nearer face will also act as S-pole to oppose the approach of magnet towards coil (CD), so currents in coils will flow clockwise as seen from the side of magnet. The direction of current will be from P to Q in coil (PQ) and from C to D in coil (CD).

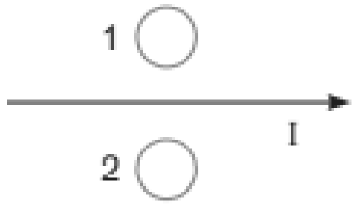
Q.7 A planar loop of rectangular shape is moved within the region of a uniform magnetic field acting perpendicular to its plane. What is the direction and magnitude of the current induced in it?

Ans. If planar loop moves within the region of uniform magnetic field, there is no magnetic flux changes by loop so, no current will be induced in the loop. Hence no direction.

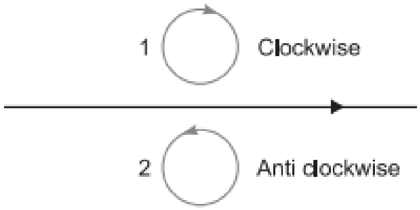
Q.8 The motion of copper plate is damped when it is allowed to oscillate between the two poles of a magnet. What is the cause of this damping?

Ans. As the plate oscillate, the changing magnetic flux through the plate produces a strong eddy current in the direction, which opposes the cause. Also, copper being diamagnetic substance, it gets magnetised in the opposite direction, so the plate motion gets damped.

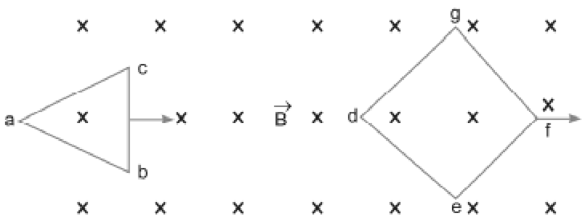
Q.9 Predict the directions of induced currents in metal rings 1 and 2 lying in the same plane where current I in the wire is increasing steadily.



Ans-



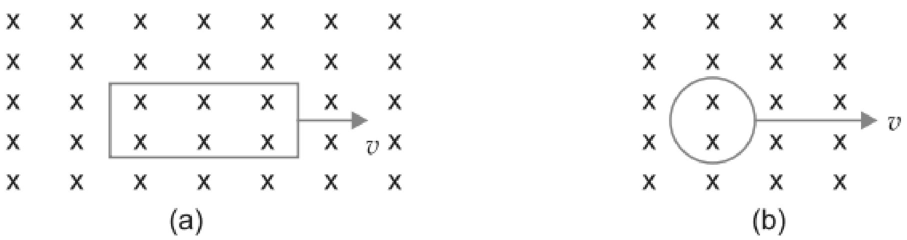
Q.10 Two loops of different shapes are moved in the region of a uniform magnetic field pointing downward. The loops are moved in the directions shown by arrows. What is the direction of induced current in each loop?



Ans- Loop abc is entering the magnetic field, so magnetic flux linked with it begins to increase. According to Lenz's law, the current induced opposes the increases in magnetic flux, so current induced will be anticlockwise which tends to decrease the magnetic field.

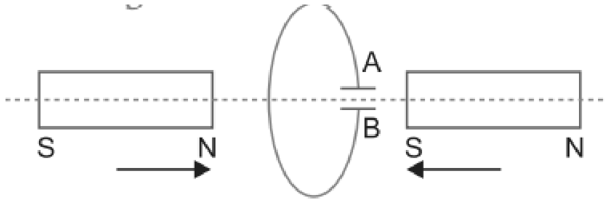
Loop defg is leaving the magnetic field; so flux linked with it tends to decrease, the induced current will be clockwise to produce magnetic field downward to oppose the decrease in magnetic flux.

Q.11 A rectangular loop and a circular loop are moving out of a uniform magnetic field region to a field free region with a constant velocity. In which loop do you expect the induced emf to be a constant during the passage out of the field region? The field is normal to the loop.



Ans- In rectangular coil the induced emf will remain constant because in this the case rate of change of area in the magnetic field region remains constant, while in circular coil the rate of change of area in the magnetic field region is not constant.

Q.12 Predict the polarity of the capacitor C connected to coil, which is situated between two bar magnets moving as shown in figure.



Ans- Current induced in coil will oppose the approach of magnet; therefore, left face of coil will act as N-pole and right face as S-pole. For this the current in coil will be anticlockwise as seen from left, therefore, the plate A of capacitor will be positive and plate B will be negative.

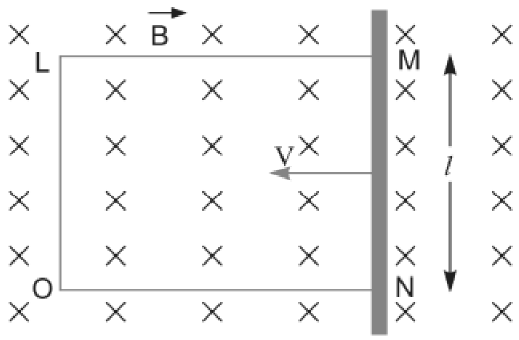
Q.13 A wire in the form of a tightly wound solenoid is connected to a DC source, and carries a current. If the coil is stretched so that there are gaps between successive elements of the spiral coil, will the current increase or decrease? Explain.

Ans. The current will increase. As the wires are pulled apart the flux will leak through the gaps. Lenz's law demands that induced emf resist this decrease, which can be done by an increase in current.

Q. 14 A solenoid is connected to a battery so that a steady current flows through it. If an iron core is inserted into the solenoid, will the current increase or decrease? Explain.

Ans. The current will decrease. As the iron core is inserted in the solenoid, the magnetic field increases and the flux increases. Lenz's law implies that induced emf should resist this increase, which can be achieved by a decrease in current. However, this change will be momentarily.

Q.15 Consider a metallic pipe with an inner radius of 1 cm. If a cylindrical bar magnet of radius 0.8 cm is dropped through the pipe, it takes more time to come down than it takes for a similar unmagnetized cylindrical iron bar dropped through the metallic pipe. Explain.



Ans. For the magnet, eddy currents are produced in the metallic pipe. These currents will oppose the motion of the magnet. Therefore, magnet's downward acceleration will be less than the acceleration due to gravity g. On the other hand, an unmagnetized iron bar will not produce eddy currents and will fall an acceleration g. Thus, the magnet will take more time.

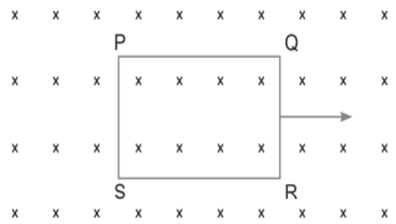
Q.16 A rectangular conductor LMNO is placed in a uniform magnetic field of 0.5 T. The field is directed perpendicular to the plane of the conductor. When the arm MN of length of 20 cm is moved towards left with a velocity of 10 m/s. Calculate the emf induced in the arm. Given the resistance of the arm to be 5 Ω (assuming that other arms are of negligible resistance), find the value of the current in the arm.

Ans- Induced emf in a moving rod in a magnetic field is given by e = Blv

Since the rod is moving to the left so e = Blv = 0.5 × 0.2 × 10 = 1 V

Current in the rod I = $\frac{e}{R} = \frac{1}{5}$ = 0.2 V

Q.17 The closed loop (PQRS) of wire is moved out of a uniform magnetic field at right angles to the plane of the paper as shown in the figure. Predict the direction of the induced current in the loop.



Ans. So far the loop remains in the magnetic field, there is no change in magnetic flux linked with the loop and so no current will be induced in it, but when the loop comes out of the magnetic field, the flux linked with it will decrease and so the current will be induced so as to oppose the decrease in magnetic flux, i.e., it will cause magnetic field downwards; so the direction of current will be clockwise.

Q.18 A 0.5 m long solenoid of 10 turns/cm has area of cross-section 1 cm^2. Calculate the voltage induced across its ends if the current in the solenoid is changed from 1A to 2A in 0.1s.

Ans-

Here $l = 0.5$ m

$n = 10$ tuns/cm $= 1000$/m

$A = 1\ cm^2 = 1\times10^{-4}$ m

Change in current $dI = (2 - 1) = 1$ A, $dt = 0.1$s

The induced voltage

$$|V| = L\frac{dI}{dt}$$

$$= \mu_0 n^2 Al\frac{dI}{dt}$$

$$= 4\pi\times10^{-7}\times(1000)^2\times10^{-4}\times0.5\times\frac{1\text{ A}}{0.1\text{ s}}$$

$$= 4\pi\times5\times10^{-5}$$

$$= 20\pi\times10^{-5} = \mathbf{0.628\ mV}$$

Q.19 How does the mutual inductance of a pair of coils change when

(i) distance between the coils is increased and

(ii) number of turns in the coils is increased?

Ans- (i) Mutual inductance decreases.

(ii) Mutual inductance increases.

Q.20 Two identical loops, one of copper and the other of aluminium, are rotated with the same angular speed in the same magnetic field. Compare

(i) the induced emf and

(ii) the current produced in the two coils. Justify your answer.

Ans- (i) Induced emf, $e = -\frac{d\phi}{dt} = -\frac{d}{dt}(BA\cos\omega t)$

$= BA\,\omega\sin\omega t$,

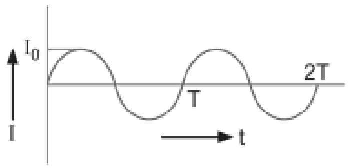
As B, A, ω are same for both loops, so induced emf is same in both loops.

(ii) Current induced, $I = \frac{e}{R} = \frac{e}{\rho l/A} = \frac{eA}{\rho l}$

As area A, length l and emf e are same for both loops but resistivity ρ is less for copper, therefore current I induced is larger in copper loop.

CHAPTER 7 ALTERNATING CURRENT

1. **Alternating Current**

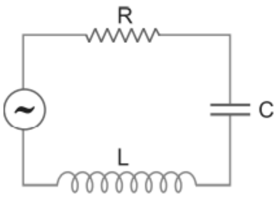


   Alternating current is the one which changes in magnitude continuously and in direction periodically.
   The maximum value of current is called current-amplitude or peak value of current.
   It is expressed as $I = I_O \sin \omega t$
   Similarly alternating voltage (or emf) is $V = V_O \sin \omega t$
2. Mean and RMS Value of Alternating Currents
   The mean value of alternating current over complete cycle is **zero**
   $$(I_{mean})_{full\ cycle} = 0$$
   While for half cycle it is
   $$(I_{mean})_{half\ cycle} = \frac{2I_0}{\pi} = 0.636 I_0$$
   $$V_{av} = \frac{2V_0}{\pi} = 0.636\, V_0$$
   An electrical device reads root mean square value as
   $$I_{rms} = \sqrt{(I^2)_{mean}} = \frac{I_0}{\sqrt{2}} = 0.707 I_0 \,;\, V_{rms} = \frac{V_0}{\sqrt{2}} = 0.707\, V_0$$
3. Phase Difference between Voltage and Current
   In a circuit having a reactive component, there is always a phase difference between applied voltage and the alternating current.
   If $E = E_o \sin \omega t$
   Current is $I = I_o \sin (\omega t + \varphi)$
   where φ is the phase difference between voltage and current.
4. Impedance and Reactance Impedance:
   The opposition offered by an electric circuit to an alternating current is called impedance.
   It is denoted as Z. Its unit is ohm. $Z = \frac{V}{I} = \frac{V_O}{I_O} = \frac{V_{rms}}{I_{rms}}$
   Reactance: The opposition offered by inductance and capacitance or both in ac circuit is called reactance.
   It is denoted by X_C or X_L.
   The opposition due to inductor alone is called the inductive reactance while that due to capacitance alone is called the capacitive reactance.
   Inductive reactance, $X_L = \omega L$
   Capacitive reactance, $X_C = \frac{1}{\omega C}$
5. LC Oscillations
   A circuit containing inductance L and capacitance C is called an LC circuit.
   If capacitor is charged initially and ac source is removed, then electrostatic energy of capacitor $(\frac{q^2}{2C})$ is converted into magnetic energy of inductor $(\frac{1}{2}LI^2)$ and vice versa periodically; such oscillations of energy are called LC oscillations. The frequency is given by $\omega = \frac{1}{\sqrt{LC}}$
6. AC Generator It is a device used to convert mechanical energy into electrical energy and is based on the phenomenon of electromagnetic induction.
   If a coil of N turns, area A is rotated at frequency ν in uniform magnetic field of induction B, then motional emf in coil (if initially it is perpendicular to field) is $e = NBA\,\omega \sin \omega t$
   with $\omega = 2\pi\nu$ Peak emf, $e_O = NBA\omega$

QUESTIONS WITH ANSWERS

Q.1 Define capacitor reactance. Write its SI units?
Ans. The imaginary/virtual resistance offered by a capacitor to the flow of an alternating current is called capacitor reactance, $X_C = \frac{1}{\omega C}$,Its SI unit is ohm.
Q.2 Explain why current flows through an ideal capacitor when it is connected to an ac source but not when it is connected to a dc source in a steady state.
Ans. For ac source, circuit is complete due to the presence of displacement current in the capacitor. For steady dc, there is no displacement current, therefore, circuit is not complete.
Mathematically, Capacitive reactance $X_C = \frac{1}{\omega C} = \frac{1}{2\pi n C}$ So, capacitor allows easy path for ac source.
For dc, n = 0, so Xc = infinity, So capacitor blocks dc
Q.3 What is wattless current?
Ans. When pure inductor and/or pure capacitor is connected to ac source, the current flows in the circuit, but with no power loss; the phase difference between voltage and current is $\frac{\pi}{2}$.
Such a current is called the wattless current.
Q.4 Mention the two characteristic properties of the material suitable for making core of a transformer.
Ans. Two characteristic properties:
(i) Low hysteresis loss
(ii) Low coercivity
Q.5 Why is the use of ac voltage preferred over dc voltage? Give two reasons.
Ans.
(i)The generation of ac is more economical than dc.
(ii) Alternating voltage can be stepped up or stepped down as per requirement during transmission from power generating station to the consumer.
(iii) Alternating current in a circuit can be controlled by using wattless devices like the choke coil.
(iv) Alternating voltages can be transmitted from one place to another, with much lower energy loss in the transmission line.
Q.6 When an ac source is connected to an ideal inductor show that the average power supplied by the source over a complete cycle is zero.
Ans. For an ideal inductor phase difference between current and applied voltage = π/2
∴ Power, $P = V_{rms} I_{rms} \cos \varphi = V_{rms} I_{rms} \cos \pi/2 = 0$
Thus, the power consumed in a pure inductor is zero.
Q.7 Both alternating current and direct current are measured in amperes. But how is the ampere defined for an alternating current?
Ans. An ac current changes direction with the source frequency and the attractive force would average to zero. Thus, the ac ampere must be defined in terms of some property that is independent of the direction of current. Joule's heating effect is such property and hence it is used to define rms value of ac.
Q.8 State the underlying principle of a transformer. How is the large-scale transmission of electric energy over long distances done with the use of transformers?
Ans. The principle of transformer is based upon the principle of mutual induction which states that due to continuous change in the current in the primary coil an emf gets induced across the secondary coil. At the power generating station, the step-up transformers step up the output voltage which reduces the current through the cables and hence reduce resistive power loss. Then, at the consumer end, a step-down transformer steps down the voltage. Hence, the large-scale transmission of electric energy over long distances is done by stepping up the voltage at the generating station to minimise the power loss in the transmission cables.

Q.9 The figure shows a series LCR circuit with L = 5.0 H, C = 80 μF, R = 40 Ω 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.

Ans-

(*i*) We know

$$\omega_r = \text{Angular frequency at resonance} = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{5\times 80\times 10^{-6}}} = \mathbf{50\ rad/s}$$

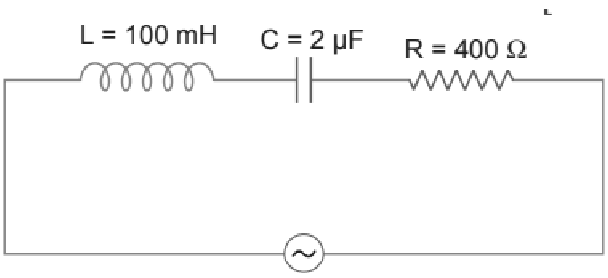
(*ii*) Current at resonance, $I_{rms} = \frac{V_{rms}}{R} = \frac{240}{40} = \mathbf{6\ A}$

(*iii*) V_{rms} across capacitor

$$V_{rms} = I_{rms}X_C = 6\times\frac{1}{50\times 80\times 10^{-6}} = \frac{6\times 10^6}{4\times 10^3} = \mathbf{1500\ V}$$

Q.10 (i) Find the value of the phase difference between the current and the voltage in the series LCR circuit shown below. Which one leads in phase: current or voltage?

(ii) Without making any other change, find the value of the additional capacitor, C_1, to be connected in parallel with the capacitor C, in order to make the power factor of the circuit unity.



V = V_0 sin (1000t + f)

Ans-

(*i*) Inductive reactance,

$$X_L = \omega L = (1000\times 100\times 10^{-3})\ \Omega = 100\ \Omega$$

Capacitive reactance,

$$X_C = \frac{1}{\omega C} = \left(\frac{1}{1000\times 2\times 10^{-6}}\right)\Omega = 500\ \Omega$$

Phase angle,

$$\tan\phi = \frac{X_L - X_C}{R}$$

$$\tan\phi = \frac{100-500}{400} = -1$$

$$\phi = -\frac{\pi}{4}$$

As $X_C > X_L$, (phase angle is negative), hence current leads voltage.

(*ii*) To make power factor unity

$X_{C'} = X_L$ (where C' = net capacitance of parallel combination)

$$\frac{1}{\omega C'} = 100$$

$$C' = 10\times 10^{-6}\ \text{F}$$

$\therefore$ $C' = 10\ \mu F$

$\because$ $C' = C + C_1$

$\Rightarrow$ $10 = 2 + C_1$ $\Rightarrow C_1 = \mathbf{8\ \mu F}$

Q.11 The primary coil of an ideal step-up transformer has 100 turns and transformation ratio is also 100. The input voltage and power are 220 V and 1100 W respectively.

Calculate

(a) the number of turns in the secondary coil.

(b) the current in the primary coil.

(c) the voltage across the secondary coil.
(d) the current in the secondary coil.
(e) the power in the secondary coil.

Ans-

(a) Transformation ratio $r = \dfrac{\text{Number of turns in secondary coil } (N_S)}{\text{Number of turns in primary coil } (N_P)}$

Given $N_P = 100$, $r = 100$

$\therefore$ Number of turns in secondary coil, $N_S = rN_P = 100 \times 100 = \mathbf{10{,}000}$

(b) Input voltage $V_P = 220$ V, Input power $P_{in} = 1100$ W

Current in primary coil $I_p = \dfrac{P_{in}}{V_P} = \dfrac{1100}{220} = \mathbf{5\ A}$

(c) Voltage across secondary coil (V_S) is given by

$$r = \frac{V_S}{V_P}$$

$\Rightarrow$ $V_S = rV_P = 100 \times 220 = 22{,}000\ \text{V} = \mathbf{22\ kV}$

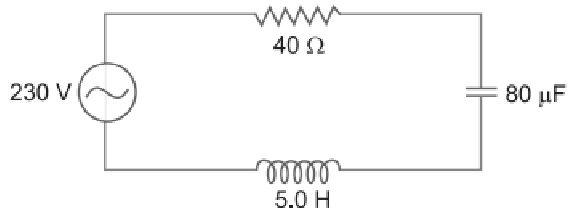
(d) Current in secondary coil is given by

$$r = \frac{I_P}{I_S} \Rightarrow I_S = \frac{I_P}{r} = \frac{5}{100} = \mathbf{0.05\ A}$$

(e) Power in secondary coil, $P_{out} = V_S I_S = 22 \times 10^3 \times 0.05 = \mathbf{1100\ W}$

Obviously power in secondary coil is same as power in primary. This means that the transformer is ideal, *i.e.*, there are no energy losses.

Q.12 The figure shows a series LCR circuit connected to a variable frequency 230 V source.



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

(a) $\omega = \dfrac{1}{\sqrt{LC}} = \dfrac{1}{\sqrt{5 \times 80 \times 10^{-6}}} = \dfrac{1}{\sqrt{400 \times 10^{-6}}}$

$\omega = \dfrac{1000}{20} = 50\ \text{rad/s} \Rightarrow f = \dfrac{\omega}{2\pi} = \dfrac{50}{2\pi} = \mathbf{\dfrac{25}{\pi}\ Hz}$

(b) At resonance, $Z = R = \mathbf{40\ \Omega}$

$$I_{max} = \frac{230\sqrt{2}}{R} = \frac{230\sqrt{2}}{40} = \mathbf{8.1\ A}$$

(c) $V_C = I_{max} X_C = \dfrac{230\sqrt{2}}{40} \times \dfrac{1}{50 \times 80 \times 10^{-6}} = 2025\ \text{V}$ $\quad [\because X_C = \dfrac{1}{\omega C}]$

$V_L = I_{max} X_L = \dfrac{230\sqrt{2}}{40} \times 50 \times 5 = 2025\ \text{V}$ $\quad [\because X_L = \omega L]$

$V_C - V_L = 0$

CHAPTER 8 ELECTROMAGNETIC WAVES

1. Conduction current is the current, which arises due to flow of electrons through the connecting wires in an electric circuit.

2. Displacement current is the current, which arises due to time rate of change of electric flux (p,) in some part of the electric circuit.

Mathematically- $$I_D = \in_o \frac{d\phi_B}{dt}$$

3. When a capacitor is charged or a charged capacitor is allowed to discharge, the electric flux between the plates of the capacitor changes with time and it gives rise to displacement current between the plates.

4. The conduction and displacement currents are entirely different from each other. However, displacement current produces magnetic field in the same manner, as the conduction current does.

5. The displacement current is always equal to the conduction current.

6. Modified Ampere circuital law states that the line integral of magnetic field B over a closed path is equal to μ_o, times the sum of the conduction current (I) and the displacement current (I,) threading the closed path.

Mathematically- $$\oint \vec{B}.\vec{dl} = \mu_o \left(I_C + \epsilon_o \frac{d\phi_B}{dt}\right)$$

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

7. Following four equations, which describe the laws of electromagnetism, are called Maxwell's equations

(i) $\oint \vec{E}.\vec{dS} = \frac{q}{\in_o}$ (Gauss's law in electrostatics)

(ii) $\oint \vec{B}.\vec{dS} = 0$ (Gauss's law in magnetism)

(iii) $\oint \vec{E}.\vec{dl} = - \frac{d\phi_B}{dt}$ (Faraday's law of electromagnetic induction)

(iv) $\oint \vec{E}.\vec{dl} = \mu_o I$ (Ampere-Maxwell's circuital law)

8. Maxwell's equations are mathematical formulation of Gauss' law in electrostatics, Gauss' law in magnetism, Faraday's law of electromagnetic induction and Ampere's circuital law.

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

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

11. The electromagnetic waves are transverse in nature.

12. The velocity of electromagnetic waves in free space is given by $c = \frac{1}{\sqrt{\mu_o \in_o}} = 3 \times 10^8$ m/s

In a material medium, velocity of electromagnetic waves is given by $\mathbf{v} = \frac{1}{\sqrt{\mu \ \in}}$

13. The ratio of the amplitudes of electric and magnetic fields is constant and it is equal to velocity of the electromagnetic waves in free space.

Mathematically- $\frac{E_O}{B_O} = \mathbf{c}$

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

15. The electric vector of an electromagnetic wave is responsible for its optical effect. For this reason, the electric vector is also called light vector.

16. The energy transported by electromagnetic waves is given by $\mathbf{U} = \mathbf{h\nu} = \frac{hc}{\lambda}$

where U is energy transported by electromagnetic waves in a given time and c is speed of electromagnetic waves in free space.

17. The momentum transported by electromagnetic waves is given by $\mathbf{p} = \frac{U}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$

18. The intensity of electromagnetic waves i.e. energy crossing per second per unit area of a surface normally is given by $\mathbf{I} = \frac{1}{2} \epsilon_o E_o^2$

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

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

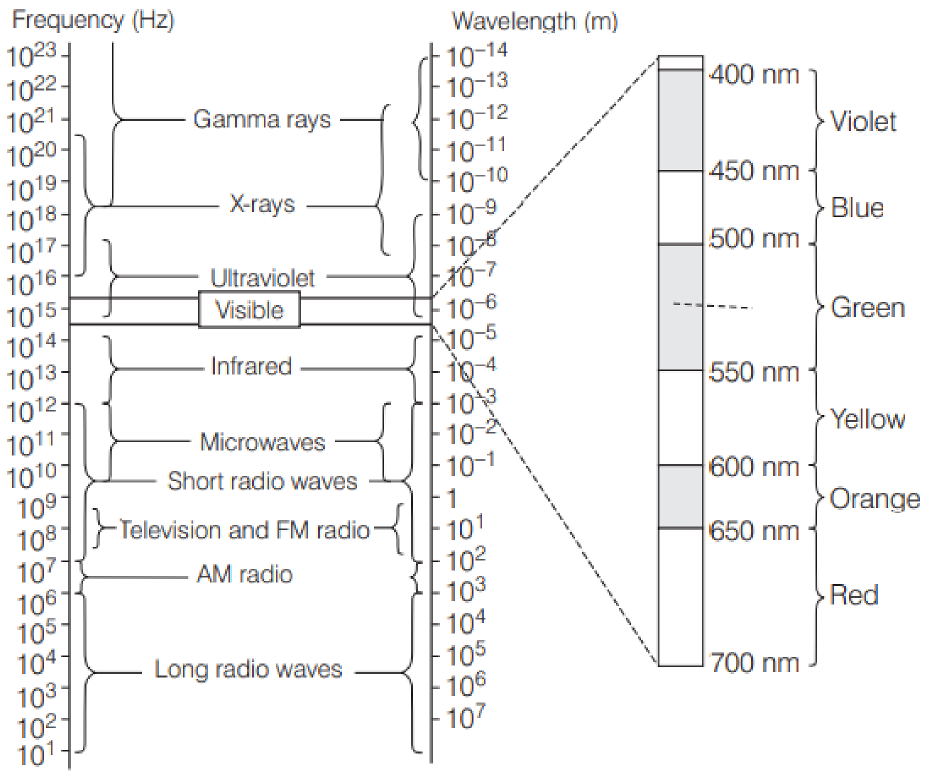
The main parts of electromagnetic spectrum are namely- γ-rays, X-rays, ultra-violet rays, visible light, infra-red rays, microwaves and radio waves.

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

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

23. The orderly arrangement of EM waves in increasing or decreasing order of wavelength l and frequency n is called electromagnetic spectrum. The range varies from 10 -12 m to 10^4 m, i.e. from γ-rays to radio waves.

Electromagnetic wave spectrum is shown below



Uses of Electromagnetic Spectrum

(i) **γ-rays** are highly penetrating; they can penetrate thick iron blocks. Due to high energy, they are used to initiate some nuclear reactions. γ-rays are produced in nuclear reactions. In medicine, they are used to destroy cancer cells.

(ii) **X-rays** are used in medical diagnostics to detect fractures in bones, tuberculosis of lungs, presence of stone in gallbladder and kidney. They are used in engineering to check flaws in bridges. In physics X-rays are used to study crystal structure.

(iii) **Ultraviolet rays** provide vitamin D. These are harmful for skin and eyes. They are used to sterilise drinking water and surgical instruments. They are used to detect invisible writing, forged documents, finger prints in forensic lab and to preserve food items.

(iv) **Infrared rays** are produced by hot bodies and molecules. These waves are used for long distance photography and for therapeutic purposes.

(v) **Radio waves** are used for broadcasting programmes to distant places. According to frequency range, they are divided into following groups

(1) Medium frequency band or medium waves 0·3 to 3 MHz

(2) Short waves or short frequency band 3 MHz — 30 MHz

(3) Very high frequency (VHF) band 30 MHz to 300 MHz

(4) Ultrahigh frequency (UHF) band 300 MHz to 3000 MHz

(vi) **Microwaves** are produced by special vacuum tubes, namely; klystrons, magnetrons and gunn diodes. Their frequency range is 3 GHz to 300 GHz. They are used in RADAR systems for aircraft navigation and microwave used in homes

QUESTIONS WITH ANSWERS

Q.1 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?

Ans- As we know that, the direction of electromagnetic wave is perpendicular to both electric and magnetic fields. Here, electromagnetic wave is travelling in z-direction, then electric and magnetic fields are in xy-direction and are perpendicular to each other.

Frequency of waves, n = 30 MHz = 30 X 10^6 Hz Speed, c = 3X10^8 m/s

Using the formula, c = nType equation here.λ Wavelength of electromagnetic waves,

$$\lambda = \frac{c}{n} = \frac{3 \times 10^8}{30 \times 10^6} = 10 \text{ m}$$

Thus, the wavelength of electromagnetic waves is 10 m.

Q.2 The electric field of an electromagnetic wave is given by **$E= 50 \sin\omega(t- \frac{x}{c})$ N/C**. Find the energy contained in a cylinder of cross-section 10cm^2 and length 50 cm along the X-axis.

Ans-The average value of energy density (energy / volume) is given by $U_{av} = \frac{1}{2} \in_o E_o^2$

Total volume of the cylinder **V = A l**

Total energy contained in the cylinder, U = (U_{av}) V= $(\frac{1}{2} \in_o E_o^2)$ **Al**

$$= \frac{1}{2} (8.86 X 10^{-12})(50)^2(10 \text{ X } 10^{-4})(50 \text{ X } 10^{-2})$$

$$= 5.5 \text{ X } 10^{-12} \text{ J}$$

Q.3 (i) Arrange the following electromagnetic waves in the descending order of their wavelengths.

(a) Microwaves (b) Infrared rays (c) Ultraviolet radiation (d) g-rays

(ii) Write one use each of any two of them

Ans-(i) The decreasing order of wavelengths of electromagnetic waves is

Microwaves > **Infrared** > **Ultraviolet radiation** > **γ -rays**

(ii) Microwaves -They are used in RADAR devices.

γ -rays- It is used in radio therapy.

Q.4 Name the parts of the electromagnetic spectrum which is

(i) suitable for RADAR systems in aircraft navigations.

(ii) used to treat muscular strain.

(iii) used as a diagnostic tool in medicine.

Write in brief, how these waves can be produced?

Ans- (i) Microwaves are suitable for RADAR systems that are used in aircraft navigation. These rays are produced by special vacuum tubes, namely klystrons and magnetrons diodes.

(ii) Infrared rays are used to treat muscular strain. These rays are produced by hot bodies and molecules. (iii) X-rays are used as a diagnostic tool in medicine. These rays are produced, when high energy electrons are stopped suddenly on a metal of high atomic number.

Q.5 Answer the following questions-

(i) Name the EM waves which are used for the treatment of certain forms of cancer. Write their frequency range.

(ii) Thin ozone layer on top of stratosphere is crucial for human survival. Why?

(iii) Why is the amount of the momentum transferred by the EM waves incident on the surface so small?

Ans- (i) γ-rays are used for the treatment of certain forms of cancer. Its frequency range is **3×10^{19} Hz to 5×10^{22} Hz.**

(ii) The thin ozone layer on top of stratosphere absorbs most of the harmful ultraviolet rays coming from the sun towards the earth. They include UVA, UVB and UVC radiations, which can destroy the life system on the earth. Hence, this layer is crucial for human survival.

(iii) An electromagnetic wave transports linear momentum as it travels through space. If an electromagnetic wave transfers a total energy U to a totally absorbing surface in time t, then total linear momentum delivered to the at surface.

This means, the momentum range of EM waves is **10^{-19} to 10^{-41}**. Thus, the amount of momentum transferred by the EM waves incident on the surface is very small

Q.6 Answer the following questions.

(i) Show, by giving a simple example, how EM waves carry energy and momentum.

(ii) How are microwaves produced? Why is it necessary in microwaves ovens to select the frequency of microwaves to match the resonant frequency of water molecules?

(iii) Write two important uses of infrared waves

Ans- (i) Consider a plane perpendicular to the direction of propagation of the wave. An electric charge, on the plane will be set in motion by the electric and magnetic fields of EM wave, incident on this plane. This is only possible, if EM wave constitutes momentum and energy. Thus, this illustrates that EM waves carry energy and momentum.

(ii) Microwaves are produced by special vacuum tube like the klystron, magnetron and Gunn diode. The frequency of microwaves is selected to match the resonant frequency of water molecules, so that energy is transformed efficiently to increase the kinetic energy of the molecules. Thus, facilitating the food to cook properly.

(iii) Uses of infrared rays

(a) In knowing the molecular structure and therapy to heal muscular pain.

(b) In remote control of TV, VCR, etc.

7. The magnetic field in a plane electromagnetic wave is given by

$B_y = 2 \times 10^{-7} \sin [0.5 \times 10^3 x + 1.5 \times 10^{11} t]$ (in T)

(a) What is the wavelength and frequency of the wave?

(b) Write an expression for the electric field.

Ans-Here, **$B_y = 2 \times 10^{-7} \sin [0.5 \times 10^3 x + 1.5 \times 10^{11} t]$**

(a) The Y-component of the magnetic field is given

by **$B_y = B_O \sin 2\pi \left(\frac{x}{\lambda} + \frac{t}{T}\right)$**

Comparing the given equation with the above equation:

$$\frac{2\pi}{\lambda} = \frac{1}{0.5 \, x \, 10^3}$$

$$\lambda = 1.257 \, x \, 10^{-2} \text{ m}$$

Also $\frac{2\pi}{T} = 1.5 \times 10^{11}$

Or $\nu = 2.387 \times 10^{10}$ Hz

(b) Since the argument of sine in the expression for the magnetic field is of the type (kx + ωt), the direction of propagation of the e. m. wave is along negative X-axis and the magnetic field is along negative Y-axis. Hence, the electric field is along negative Z-axis and expression for it is given by

$E_y = E_O \sin 2\pi \left(\frac{x}{\lambda} + \frac{t}{T}\right)$

Here, **$E_O = B_O c = 2 \times 10^{-7} \times 3 \times 10^8 = 60$ V/m**

$E_z = 60 \sin [0.5 \times 10^3 x + 1.5 \times 10^{11} t]$ (in V/m)

Q.8 Suggest reasons, why

(a) food in metal containers cannot be cooked in a microwave oven.

(b) an empty glass container does not get hot in a microwave oven.

Ans. In a microwave oven, the frequency of microwaves is selected to match the resonance frequency of water molecules, so that the energy from the waves is transferred efficiently to the kinetic energy of the molecules. This raises the temperature of any food containing water.

(a) The atoms of the metallic container are set into forced vibrations by the microwaves. Due to this, energy of the microwaves is not efficiently transferred to the metallic container. Owing to this, food in metallic containers cannot be cooked in a microwave oven.

(b) The molecules of the glass container do not respond to the frequency of microwaves. Due to this, energy from the microwaves is not transferred to the glass container and hence it does not get hot in a microwave oven.

CHAPTER 9 RAY OPTICS AND OPTICAL INSTRUMENTS

1. Reflection of Light

Reflection. When light travelling in a medium strikes a reflecting surface, it goes back into the same medium obeying certain
laws. This phenomenon is known as reflection of light.

Laws of reflection. 1. The incident ray, the normal to the reflecting surface at the point of incidence and the reflected ray all lie in the same plane.

2. The angle of incidence (i) is always equal to the angle of reflection (r).

Spherical mirror. The portion of a reflecting surface, which forms part of a sphere, is called a spherical mirror.

Concave spherical mirror. A spherical mirror, whose reflecting surface is towards the centre of the sphere, of which the mirror forms a part is called concave spherical mirror.

Convex spherical mirror. A spherical mirror, whose reflecting surface is away from the centre of the sphere of which the mirror forms a part is called convex spherical mirror.

Relation between f and R: f =R/2

According to new cartesian sign conventions, both f and R, are taken as negative for a concave mirror and positive for a convex mirror.

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

where u and v denote the object and image distances from the pole of the mirror.

According to new cartesian sign conventions, the distances of the real objects and real images (both lie in front of the mirror) are taken as negative, while those of virtual objects and virtual images (both lie behind the mirror) are taken as positive.

Linear magnification. The ratio of the size of the image (formed by the mirror) to the size of the object is called linear magnification produced by the mirror.

Mathematically- $\mathbf{m} = \frac{I}{O} = -\frac{v}{u} = \frac{f}{f-u} = \frac{f-v}{f}$

According to new cartesian sign conventions, when the image formed is real (inverted), the magnification produced by the mirror is negative and when the image formed is virtual (erect), the magnification produced by the mirror is positive.

Spherical aberration. The inability of a spherical mirror of large aperture to bring all the rays in a wide beam of light falling on it to focus at a single point is called spherical aberration.

2. Refraction of Light

Refraction. The phenomenon of change in the path of light as it goes from one medium to another is called refraction.

Laws of refraction.

1. The incident ray, the normal to the refracting surface at the point of incidence and the refracted ray all lie in the same plane.

2. The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for any two- given media. It is called Snell's law.

Mathematically- $\frac{\sin i}{\sin r} = \mu_b^a$

Absolute retractive index (μ). 1 he absolute refractive index of a medium is defined as the ratio of the velocity of light in vacuum (c) to the velocity of light in that medium (v).

Real and apparent depth. When an object is placed in an optically denser medium, the apparent depth of the

object is always less than its real depth.

Mathematically-: 1. $\frac{Real\ depth}{Apparent\ depth} = \mu_b^a$

2. **Normal shift d= t** $\left(1 - \frac{1}{\mu_b^a}\right)$

Total internal reflection. The phenomenon of reflection of light that takes place when a ray of light travelling in a denser medium gets incident at the interface of the two media at an angle greater than the critical angle for that pair of media.

Mathematically $\mu_b^a = \frac{1}{\sin C}$

μ_b^a is refractive index of the denser medium £ w.r.t. the rarer medium a and C is the critical angle.

Spherical refracting surface. The portion of a refracting medium, whose curved surface forms the part of a sphere, is called spherical refracting surface.

When object is situated in the rarer medium, the relation is as follows

$$-\frac{\mu_1}{u} + \frac{\pi_2}{v} = \frac{\mu_2 - \mu_1}{R}$$

When the object is situated in denser medium, the relation is as follows

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

Power of spherical refracting surface: P= $\frac{\mu_2 - \mu_1}{R}$

Here, R is measured in metre.

Lens maker's formula. The relation connecting the focal length of the lens with the radii of curvature of its two surfaces and the refractive index of the material of the lens is called lens maker's formula.

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

The focal length of a convex lens is taken as positive, while that of concave lens is taken as negative.

Lens formula/equation. The relation between the focal length, the object and image distances is called lens equation.

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

Linear magnification. The ratio of the size of the image (formed by the lens) to the size of the object is called linear magnification produced by the lens.

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

Power of a lens. It is defined as the reciprocal of the focal length of the lens in metre.

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

Two thin lenses placed in contact. When two lenses of focal lengths f_1 and $f_2$are placed in contact, the focal

length of the combination is given by $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$

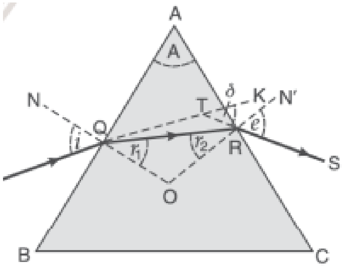
Power of the equivalent lens: $P = P_1 + P_2$

Magnification produced by equivalent lens: $m = m_1 \, x \, m_2$

Spherical aberration. The inability of a lens of large aperture to bring all the rays in a wide beam of light falling on it to focus at a single point is called spherical aberration.

DISPERSION OF LIGHT

Refraction through a prism. A prism is the portion of a transparent refracting medium bound by two plane surfaces meeting each other along a straight edge.



When a ray of light is incident on one face of a prism having angle of prism equal to A at an angle of incidence i, it suffers successive refractions at the two surfaces (angles of refraction at the two surfaces are r, and ry respectively) and then emerges out of it making an angle of emergence equal to e. Due to refraction at the two surfaces, the incident ray deviates from its path through an angle 6, called angle of deviation.

Mathematically-

1. $A = r_1 + r_2$

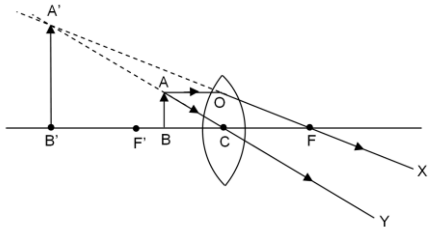
2. $A + \delta = I + e$

3. $\mu = \frac{\sin(A + \frac{\delta_m}{2})}{\sin\frac{A}{2}}$ (when the prism is placed in minimum deviation position)

4, $\delta = A(\mu - 1)$ (when angle of prism is small)

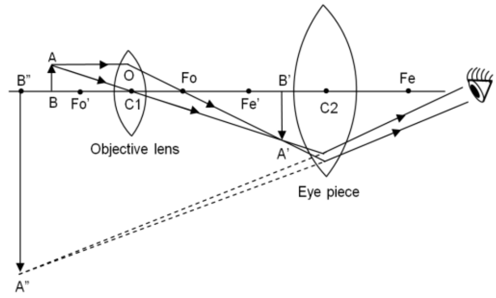
Dispersion. The phenomenon of splitting up of white light into its constituent colours is called dispersion.

Spectrum. The band of seven colours obtained on the screen is called spectrum.



Pure spectrum. A spectrum, in which the constituent colours have sharp boundaries and are distinctly visible, is called the pure spectrum.

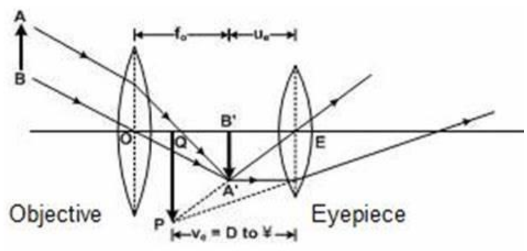
Chromatic aberration. The inability of a lens to bring the light of different colours to focus at a single point is called chromatic aberration.



Rayleigh's law of scattering. It states that the intensity of the light of wavelength A in the scattered light varies inversely as the fourth power of its wavelength. $\mathbf{I} = \frac{1}{\lambda^4}$

Simple microscope. A convex lens of small focal length is called a simple microscope or a magnifying glass. The magnifying power of a microscope is defined as the ratio of the angle subtended by the image at the eye to the angle subtended by the object seen directly, when both lie at the least distance of distinct vision.

$$\mathbf{M = 1 + \frac{D}{f}}$$



Compound microscope. A compound microscope is a two-lens system (object lens and eye lens of focal lengths f, and f,). Its magnifying power is very large, as compared to the simple microscope.

Mathematically- $\mathbf{M} = \frac{v_o}{u_o}\left(1 + \frac{D}{f_e}\right) = -\frac{L_o}{f_o}\left(1 + \frac{D}{f_e}\right)$

Astronomical telescope. It is a two-lens system and is used to observe distant heavenly objects. It is called refracting type astronomical telescope.

Normal adjustment. When the final image is formed at infinity, the telescope is said to be in normal adjustment. $\mathbf{M} = -\frac{f_o}{f_e}$

When the final image is formed at the least distance of distinct vision, magnifying power of the telescope,

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

QUESTIONS WITH ANSWERS

Q. 1 How can you distinguish between a plane mirror, a concave mirror and convex mirror just by looking at them?

Or

Is it possible to find whether a mirror is plane, concave or convex, from the nature of the image of an object formed by the mirrors?

Or

How can one ascertain without touching, whether a given mirror is plane, concave or convex?

Ans. Yes, it is possible to distinguish between the three types of the mirrors from the nature of the image of

an object formed by them as explained ahead Hold the mirrors one by one close to the face. If the image of the face is virtual (erect) and diminished, the mirror is convex; if the image is virtual and magnified, the mirror is concave and if the image is virtual and of the same size, the mirror is a plane one.

Q. 2 Why convex mirror 1S used as drivers mirror? What is its drawback?

Or

Why convex mirror is used as driver's mirror? Is it a perfect driver's mirror?

Or

Why convex mirror is used as a rear-view mirror?

Ans. The convex mirror is used as a driver's mirror as it gives a wide field of view of the traffic. However, it does not give the correct idea of the speed of the vehicles coming behind. As the convex mirror gives an erroneous idea of the traffic, it is not a perfect driver's mirror.

Q.3 Why are mirrors used in search lights parabolic and not concave spherical?

Ans. A search light is used to provide an intense parallel beam of light. If a concave mirror of large aperture is used for this purpose by placing a light source at its focus, then it does not reflect all the rays falling on it in the form of a parallel beam due to spherical aberration. A concave mirror can reflect only those rays in the form of a parallel beam, which travel near its principal axis. However, a parabolic mirror is free from spherical aberration and it is made use of in search lights.

Q. 4. A concave mirror of small aperture forms a sharper image. Why?

Ans. The rays of light travelling parallel to the principal axis after reflection from a concave mirror meet at a single point only, if the beam of light is narrow or if the mirror is of small aperture. In case, a wide beam of light falls on a concave mirror of large aperture, the rays after reflection from the mirror do not come to focus at a single point. Therefore, it follows that if the aperture of the concave mirror is small, the image formed will be sharper.

Q.5 The image of an object formed by a lens on the screen is not in sharp focus. Suggest a method to get a clear focussing of the image on the screen without disturbing the position of the object, the lens or the screen.

Ans. The focal length of a lens depends upon the refractive index of the material of the lens, which in turn depends upon the wavelength of light. Therefore, clear image of the object can be obtained by using light of suitable wavelength.

Q. 6 When monochromatic light travels from one medium to another, its wavelength changes, but frequency remains the same. Explain.

Ans. When monochromatic light travels from one medium lo another, its speed changes. The change in speed occurs due to change in wavelength. The frequency of light remains the same, as it is an inherent characteristic.

Q.7 A convex lens is placed in contact with a plane mirror. A point object at a distance of 20 cm on the axis of this combination has its image coinciding with itself. What is the focal length of the lens?

Ans. We know that the rays of light from a point on the focus of the convex lens are rendered into a beam of light parallel to its principal axis. These parallel rays of light, after normal incidence on the plane mirror, will retrace their path and will again converge at the focus of the lens. Thus, image will coincide with the object, if the object is situated at the focus of the lens.

Here, the object has been placed at a distance of 20cm from the convex lens-plane mirror combination and the image is coinciding with the object. Therefore, focal length of the lens, f=20cm

Q. 8 Why is the lens maker's formula called so?

Or

What is lens maker's formula?

Ans. The values of the radii of curvature of the two spherical surfaces, which a lens of required focal length should have, can be calculated from the lens maker's formula. Then, by grinding the two surfaces of a piece of glass, its two surfaces can be given the radii of curvature of the calculated values. Then, the lens so produced will possess the required focal length. For this reason, it is called lens maker's formula.

Q. 9 Can a convergent lens in one medium behave as a divergent lens in some other medium?

Ans. Yes. A convex lens made of glass behaves as a convergent lens when placed in air or water. However, when the same lens is immersed in carbon disulphide **($\mu = 1.63$)**, it behaves as a divergent lens. In other words, when a convergent lens is placed inside a transparent medium of refractive index greater than that of the material of the lens, it behaves as a divergent lens.

Q. 10 A concave mirror and a convex lens are held in water. What change, if any, do you expect in their respective focal lengths as compared to their values in air?

Ans. The focal length of a concave mirror has nothing to do with the medium in which it is placed. Hence, it will remain unchanged. However, the focal length of a convex lens would change, when held in water. It increases due to the fact that the relative refractive index of the material of lens w.r.t. water is less than its refractive index w.r.t. air.

Q.11 A biconvex lens made of a transparent material of refractive index 1:25 is immersed in water of refractive index 1°33. Will the lens behave as a converging or a diverging lens? Give reason.

Ans. When a convex lens is placed inside a liquid of refractive index greater than that of the material of the lens, it behaves like a diverging lens.

Q.12 A biconvex lens made of a transparent material of refractive index 1.5 is immersed in water of refractive index 1°33. Will the lens behave as a converging or a diverging lens? Give reason.

Ans. When a convex lens is placed inside a liquid of refractive index less than that of the material of the lens, it still behaves as a converging lens.

Q. 13 A biconcave lens made of a transparent material of refractive index 1.25 is immersed in water of refractive index 1°33. Will the lens behave as a converging or a diverging lens? Give reason.

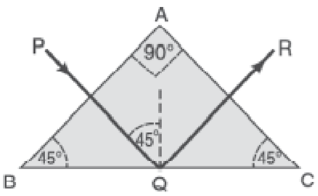
Ans. When a biconcave lens is placed inside a liquid of refractive index greater than that of the material of the lens, it behaves like a converging lens.

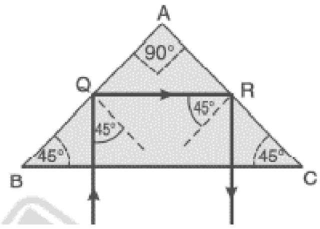
Q. 14 What type of lens is an air bubble inside water?

Ans. An air bubble inside water may be treated as a convex lens made of air and placed in water. As such, it behaves as a diverging lens.

Q.15 A right angled isosceles glass prism is made from glass of refractive index 1.5. Show that a ray of light incident normally on (i) one of the equal sides of this prism is deviated through 90° (ii) the hypotenuse of this prism is deviated through 180°.

Ans-





Q.16 How does the angle of minimum deviation of a glass prism vary, if the incident violet light is replaced by red light?

Ans. The refractive index of glass for red light is less than that for violet light. It follows that the angle of minimum deviation of a glass prism will decrease, if the incident violet light is replaced by red light.

Q.17 What is meant by dispersion of light?

Ans. The splitting of white light into its constituent colours on passing through a prism is called dispersion of light.

Q. 18 (a) Name the factors on which the deviation produced in the path of a ray of light by a prism depends.

(b) What are the features, when a prism is placed in minimum deviation position.

Ans.(a) It depends on angle of prism, material of prism and the angle of incidence.

(b) (i) The prism lies symmetrically w.r.t. incident ray and the emergent ray i.e. the angle of incidence is equal to the angle of emergence. Asa result, the angle of refraction at the first face is equal to that at the second face.

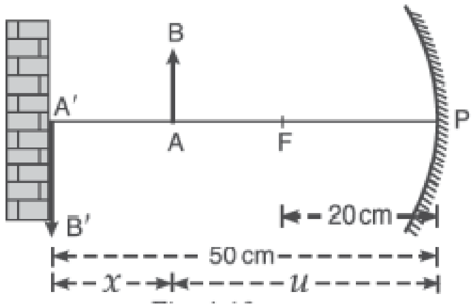
(ii) The refracted ray passes parallel to the base of prism.

Q.19 Explain, why white light is dispersed when passing through a prism.

Ans. The velocity of light in a material medium depends upon its colour (wavelength) i.e. the refractive index of a material is different for different colours. If we incident a ray of white light on a prism; on emerging, the different colours are deviated through different angles. Due to this, white light splits into its constituent colours and the phenomenon is called dispersion.

Q. 20 Astronomers prefer to use telescopes with large objective diameters lo observe astronomical objects.

Ans. When the objective of a telescope has large diameter, both its resolving power and light gathering power are large. As such, it helps to resolve two nearby stars and enables the astronomers to see even the faint stars.



Q. 21 Write two merits of a reflecting type telescope over refracting type telescope.

Ans. 1. As the objective is a spherical mirror, the reflecting type telescope is free from chromatic aberration.

2. The defect of spherical aberration is reduced by using parabolic mirror as objective.

Q. 22 Which two main considerations are kept in mind while designing the objective of an astronomical telescope?

Ans. While designing the objective of an astronomical telescope, following are the two main considerations -

1. It should have large aperture.

2. Its focal Length should be large.

Q. 23 A concave mirror of focal length 20 cm is placed 50 cm from a wall. How far from the wall an object be placed to form its real image on the wall?

Ans-. Fig. shows a concave mirror placed at a distance of 50 cm from the wall. Suppose that the object AB is placed at a distance x from the wall, to form its image A’ B’ on the wall.

Since the image is formed on the same side of the

object,

v = -50cm

Also, f=-20cm (concave mirror)

From the mirror formula, we have $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

$\frac{1}{u} = \frac{1}{f} - \frac{1}{v} = \frac{1}{-20} - \frac{1}{-50} = -\frac{3}{100}$

or u = —33-3cm

Therefore, the distance of the object from the wall,

x = 50—$|u|$ =50—$||-33.3|$

= 16.7 cm

Q.24 An object is placed at a distance of 36cm from a convex mirror. A plane mirror is placed in between, so that the two virtual images so formed coincide. If the plane mirror is at a distance of 24 cm from the object, find the radius of curvature of the convex mirror.

Ans- Fig. shows an object AB placed at a distance

PA = 36 cm from the convex mirror.

The distance of the plane mirror from the object is MA = 24 cm. The image A'B' of the object in the plane mirror will be formed at a distance of 24 cm behind it i.e. MA' = 24 cm.

Since the image formed in the plane mirror coincides with that formed by the convex mirror,

v = PA'=(MA+MA')—-PA

= 2MA - PA

= 2x24-36=12cm

Also, u=—-36cm

Now $\frac{2}{R} = \frac{1}{u} + \frac{1}{v} = \frac{1}{-36} + \frac{1}{12} = \frac{1}{18}$ or R = 36 cm

Q.25 An object is placed in front of a concave mirror of radius of curvature 40 cm at a distance of 10 cm. Find the position, nature and magnification of the image.

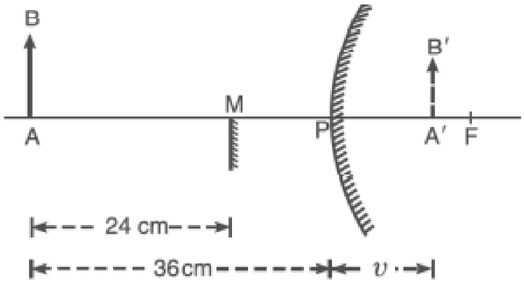
Ans- Here, u =-10cm; R=-40cm (concave mirror)

∴ f=R/2=-40 /2= -20cm

From the mirror formula, we have $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-20} - \frac{1}{-10} = \frac{1}{20}$ **or v= +20**

As v is positive, a virtual and erect image will be formed on the other side of the object i.e. behind the mirror.



m = $-\frac{v}{u} = -\frac{+20}{-10} = 2$

Q.26 A tank is filled with water to a height of 12.5 m. The apparent depth of the needle lying at the bottom of the tank as measured by a microscope is 9.4 cm. What is the refractive index of water? If water is replaced by a liquid of refractive index 1.63 up-to the same height, by what distance would the microscope be moved to focus on the needle again?

Ans.

Refractive index, (μ) = $\frac{\text{Real depth}}{\text{Apparent depth}}$

Given H = 12.5 cm, h = 9.4 cm

∴ Refractive index of water $\mu_w = \frac{12.5}{9.4} = 1.33$

Refractive index of liquid, $\mu_l = 1.63$

∴ Apparent height with liquid in tank,.h = $\frac{\text{Real depth}}{\textit{refractive index}} = \frac{12.5}{1.63} = 7.7$ cm

∴ Displacement of microscope, x = 9.4 – 7.7 = 1.7 cm

Q.27 A double convex lens is made of a glass of refractive index 1.55, with both faces of the same radius of curvature. Find the radius of curvature required, if the focal length is 20 cm.

Ans. Given, f = 20 cm and n = 1.55

Let the radius of the curvature of each of two surfaces of the lens be R.

If $R_1 = R$, then $R_2 = -R$

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

$\frac{1}{20} = (1.55 - 1)\left(\frac{1}{R} - \frac{1}{-R}\right)$

$\frac{1}{20} = \frac{0.55}{2R}$, **R = 22cm**

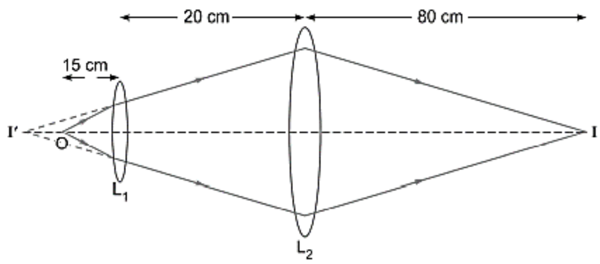
Q.28 What is the focal length of a combination of a convex lens of focal length 30 cm and a concave lens of focal length 20 cm in contact? Is the system a converging or a diverging lens? Ignore thickness of lenses.
Ans. Given f_1 = + 30 cm, f_2 = – 20 cm

The focal length (F) of combination of given by $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$

$$F = \frac{f_1 f_2}{f_1 + f_2} = \frac{30\, x - 20}{30 + (-20)} = \mathbf{-60cm}$$

That is, the focal length of combination is 60 cm and it acts like a diverging lens.
Q.29 A small telescope has an objective lens of focal length 144 cm and an eye piece of focal length 6.0 cm. What is the magnifying power of the telescope? What is the separation between the objective and the eye-piece?
Ans. Given f_O = 144 cm, f_e = 6.0 cm
Magnifying power of telescope, M = $-\frac{f_O}{f_e} = -\frac{144}{6}$ = **-24**
Negative sign shows that the final image is real and inverted.
Separation between objective and eye-piece L = $f_O + f_e$ = 144 + 6 = 150 cm

Q.30 In the following diagram, an object 'O' is placed 15 cm in front of a convex lens L_1 of focal length 20 cm and the final image is formed at 'I' at a distance of 80 cm from the second lens L_2. Find the focal length of the L_2.



Ans- Let focal length of lens L2 be x cm
Now, for lens, L_1
u = – 15 cm; f = +20 cm; v =?
Using lens formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

$\frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{20} + \frac{1}{-15} = -\frac{1}{60}$

⇒ v = –60 cm i.e., 60 cm from lens in the direction of object.
Now, for lens, L_2
The image formed by lens L_1, will act as object for lens L_2
u = –60 + (–20) = –80 cm v = +80 cm (given) and f = x cm
Applying lens formula for lens L_2

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

$\frac{1}{80} - \frac{1}{-80} = \frac{1}{x}$

$\frac{1}{x} = \frac{2}{80}$ **, x = 40 cm,** Hence, focal length of lens L_2 is 40 cm

CHAPTER 10 WAVE OPTICS

Huygens' Principle

Wavefront. The locus of the points in the medium, which at any instant are vibrating in the same phase, is called wavefront.

Ray of light is the line drawn perpendicular to the wavefront.

Huygens' principle.

1. Each point on a given (or primary) wavefront acts as a source of secondary wavelets, sending out disturbance in all directions in a similar manner as the original source of light does.

2. The new position of the wavefront at any instant (called secondary wavefront) is the envelope of the secondary wavelets at that instant.

It is also called Huygens' construction and it is used to find the new position of the wavefront at a later time.

Interference of Light

Interference. The phenomenon of non-uniform distribution of energy in the medium due to superposition of two light waves is called interference of light.

Coherent sources. Two sources are said to be coherent, if they emit light waves of same wavelength (or frequency) and of a stable phase difference.

Young's double slit experiment. consider that two coherent sources are separated by a distance d so as to produce interference fringes on a screen held at a distance D from the plane of the slits. When the slits are illuminated with a monochromatic light of wavelength4, then alternate dark and bright fringes are formed on the two sides of the central bright fringe. Let be the phase difference and x, the path difference between the two light waves reaching a point P on the screen.

1. **Condition for maximum intensity at point P-**

Phase difference, $\Delta\emptyset = 2n\pi$

or path difference, x = nλ, where n = 0,1, 2.........

2. **Condition for minimum intensity at point P-**

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

or path difference, x = (2n+1)λ/2, where n = 0, 1,2 ....

3. **Ratio of the maximum and minimum intensity-**

$$\frac{I_{max}}{I_{min}} = \frac{(a_1+a_2)^2}{(a_1-a_1)^2}$$

Here, a_1, and a_2, are amplitudes of the two light waves.

Also, ratio of intensity of light due to the two slits of widths w, and w, is given by

$$\frac{I_1}{I_2} = \frac{w_1}{w_2} \quad \frac{(a_1)^2}{(a_2)^2}$$

4. (a) Distance of nth bright fringe from the centre of the screen- $y_n = \frac{nD\lambda}{d}$

(b) Angular position of the nth bright fringe- $\theta_n = \frac{y_n}{D} = \frac{n\lambda}{d}$

5. (a) Distance of nth dark fringe from the centre of the screen- $y_n = \frac{(2n+1)D\lambda}{2d}$

(b) Angular position of the nth dark fringe- $\theta_n = \frac{y_n}{D} = \frac{(2n+1)\lambda}{2d}$

6. Fringe width- $\beta = \frac{D\lambda}{d}$

Interference due to a thin film. Consider a thin transparent film of thickness t and refractive index 4. When the monochromatic light of wavelength 4 is incident on the upper surface of the film, it is partly reflected and partly refracted into the material of the film. At the lower surface, the ray of light is partly reflected and partly transmitted out of the film. After the successive reflections and refractions take place at the two surfaces of the film, the rays of light interfere in reflected system and the transmitted system. If r is angle of refraction, then the path difference between the rays is given by **x=2µtcosr**

1. **Condition for film to appear bright or dark reflected system-**
   Due to reflection of the ray of light at the surface of denser medium (thin liquid film), an additional phase difference of a or a path difference of λ/2 is introduced.

As a result, the film will **appear dark**, when path difference x is an integral multiple of A i.e. when

2µtcosr = nλ **,**where n = 1, 2, 3, ...000

The film will **appear bright**, when

2µtcosr =(2n +1) λ/2 ,where n = 0, 1, 2, wee

In case the film is of negligible thickness i.e. t << A, then the net path will be just **λ**/2 (the path difference introduced due to the reflection from denser medium) and hence the film will appear dark.

2. **Condition for film to appear bright or dark transmitted system**
   The film will **appear bright**, when

   2µtcosr = nλ **,**where n = 1, 2, 3, ...000

   and the film will **appear dark**, when

   2µtcosr =(2n +1) λ/2 ,where n = 0, 1, 2, ………………

In case the film is of negligible thickness, then there will be no path difference between the two transmitted rays and hence the film will appear bright.

Diffraction The phenomenon of bending of light round the sharp corners and spreading into the regions of the geometrical shadow is called diffraction.

Diffraction from a slit. A narrow slit of width a is placed at a distance D from the screen. When the slit is illuminated with a monochromatic light of wavelength, then alternate bright and dark bands of light are formed on both the sides of the central maximum.

1. (a) Angular position of the nth secondary minimum- $\theta_n = \frac{n\lambda}{a}$

(b) Distance of the nth secondary maximum from the centre of the screen- $y_n = \frac{nD\lambda}{a}$

2. (a) Angular position of the nth secondary maximum- $\theta_n = \frac{(2n+1)\lambda}{2a}$

(b) Distance of the nth secondary maximum from the centre of the screen- $y_n = \frac{(2n+1)D\lambda}{2a}$

3. (a) Width of a secondary maximum or minimum- $\beta = \frac{D\lambda}{a}$

(b) Width of the central maximum- $\beta_o = \frac{2D\lambda}{a}$

4. Half angular width of central maximum. The angular position of first secondary minimum is known as half angular width of the central maximum. Thus, half angular width of central maximum $\frac{\lambda}{a}$

5. Fresnel distance. It is defined as the distance of the screen from the slit, beyond which the spreading of light due to diffraction becomes quite large as compared to the size of the slit. Itis denoted by Z_F

Mathematically- $Z_F = \frac{a^2}{\lambda}$

QUESTIONS WITH ANSWERS

Q. 1 What do you understand by a wavefront?

Ans. A source of light sends out disturbance in all directions. In a homogeneous medium, the disturbance reaches all those particles of the medium in phase, which are located at the same distance from the source of light. The locus of all the particles of the medium, which at any instant are vibrating in the same phase, is called the wavefront.

Q. 2 What are the drawbacks of wave theory of light?

Ans. The wave theory of light is based on the existence of all pervading ether medium. However, Michelson and Morley's experiment proved that the ether medium did not exist at all. It led to the failure of the wave theory of light.

Q.3 When monochromatic light travels from one medium to another, its wavelength changes but frequency remains the same. Explain.

Ans. Frequency is the fundamental characteristic of the source emitting waves and does not depend upon the medium. Light reflects and refracts due to the interaction of incident light with the atoms of the medium. These atoms always take up the frequency of the incident light which forces them to vibrate and emit light of same frequency. Hence, frequency remains same.

Q.4 Why are coherent sources required to create interference of light?

Ans. Coherent sources are required for sustained interference. If sources are incoherent, the intensity at a point will go on changing with time.

Q.5 Differentiate between a ray and a wavefront.

Ans. A wavefront is a surface of constant phase. A ray is a perpendicular line drawn at any point on wavefront and represents the direction of propagation of the wave.

Q.6 What type of wavefront will emerge from a (i) point source and (ii) distant light source?

Ans. (i) Spherical wavefront

(ii) Plane wavefront.

Q.7 What will be the effect on interference fringes if red light is replaced by blue light?

Ans. $\beta = \frac{D\lambda}{d}$,the wavelength of blue light is less than that of red light; hence if red light is replaced by blue light, the fringe width decreases, i.e., fringes come closer

Q.8 In a single-slit diffraction experiment, the width of the slit is made double the original width. How does this affect the size and intensity of the central diffraction band?

Ans. In single slit diffraction experiment fringe width is $\beta = \frac{2D\lambda}{d}$ If d is doubled, the width of central maxima is halved. Thus, size of central maxima is reduced to half. Intensity of diffraction pattern varies with square of slit width. So, when the slit gets double, it makes the intensity four times.

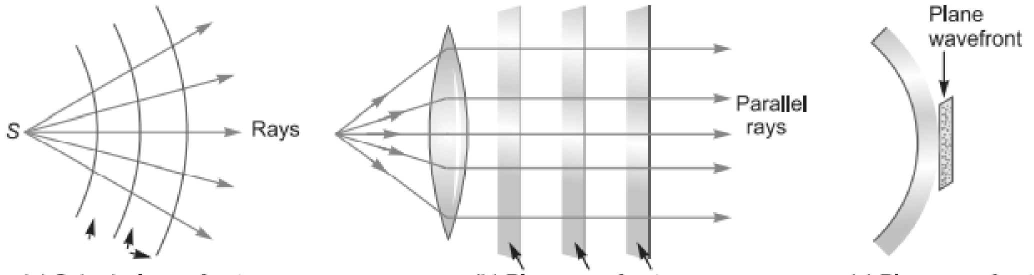
Q.9 What is the shape of the wavefront in each of the following cases:

(a) light diverging from a point source.

(b) light emerging out of a convex lens when a point source is placed at its focus.

(c) the portion of a wavefront of light from a distant star intercepted by the earth.

Ans-
a) The wavefront will be spherical of increasing radius, fig. (a). (
b) The rays coming out of the convex lens, when point source is at focus, are parallel, so wavefront is plane, fig. (b).
(c) The wavefront starting from star is spherical. As star is very far from the earth, so the wavefront intercepted by earth is a very small portion of a sphere of large radius; which is plane (i.e., wavefront intercepted by earth is plane), fig. (c)



(a) Spherical wavefront (b) Plane wavefront (c) Plane wavefront

Q.10 Explain the following, giving reasons:
(i) When monochromatic light is incident on a surface separating two media, the reflected and refracted light both have the same frequency as the incident frequency.
(ii) When light travels from a rarer to a denser medium, the speed decreases. Does this decrease in speed imply a reduction in the energy carried by the wave?
(iii) In the wave picture of light, intensity of light is determined by the square of the amplitude of the wave. What determines the intensity in the photon picture of light?
Ans. (i) Reflection and refraction arise through interaction of incident light with atomic constituents of matter which vibrate with the same frequency as that of the incident light. Hence frequency remains unchanged.
(ii) No; when light travels from a rarer to a denser media, its frequency remains unchanged. According to quantum theory of light, the energy of light photon depends on frequency and not on speed.
(iii) For a given frequency, intensity of light in the photon picture is determined by the number of photon incident normally on a crossing an unit area per unit time.
Q.11 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°. Find the spacing between the two slits.
Ans-

Angular fringe width $\beta_\theta = \frac{\beta}{D} = \frac{\lambda}{d}$

$\therefore$ Spacing between slits, $d = \frac{\lambda}{\beta_\theta}$

Here $\lambda = (600\text{ nm} = 600\times10^{-9}\text{m}) = 6\times10^{-7}\text{m}$, $\beta_\theta = 0.1° = \frac{0.1\times\pi}{180}$ radians

$$\therefore \quad d = \frac{6\times10^{-7}}{(0.1\pi/180)} = \frac{6\times10^{-7}\times180}{0.1\times3.14} = \mathbf{3.44\times10^{-4}\ m}$$

CHAPTER 11 DUAL NATURE OF RADIATION AND MATTER

Photon. It is a packet of energy. A photon of frequency v possesses energy $\mathbf{h\nu}$. The rest mass of a photon is zero.

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

Photoelectric effect. The phenomenon of ejection of electrons from a metal surface, when light of sufficiently high frequency falls on it, is known as photoelectric effect.

The electrons so emitted are called photoelectrons.

Threshold frequency. The minimum frequency ($\boldsymbol{\nu_O}$)), which the incident light must possess so as to eject photoelectrons from a metal surface, is called threshold frequency of the metal.

Mathematically- $\mathbf{W = h\nu_O}$

Laws of photoelectric effect.

1. Photoelectric emission takes place from a metal surface, when the frequency of incident light is above its threshold frequency.
2. The photoelectric emission starts as soon as the light is incident on the metal surface.
3. The maximum kinetic energy with which an electron is emitted from a metal surface is independent of the intensity of light and depends upon its frequency.
4. The number of photoelectrons emitted is independent of the frequency of the incident light and depends only upon its intensity.

Cut off potential. It is that minimum value of the negative potential (V_O), which should be applied to the anode in a photo cell so that the photoelectric current becomes zero.

Mathematically- $\mathbf{eV_o = \frac{1}{2}\, mv_{max}{}^2}$

where $\boldsymbol{v_{max}}$ is the maximum velocity with which the photoelectrons are emitted

Einstein's photoelectric equation. When light of frequency ν is incident on a metal surface, whose work function is W (i.e. $\mathbf{h\nu_O}$), then the maximum kinetic energy ($\mathbf{\frac{1}{2}\, mv_{max}{}^2}$) of the emitted photoelectrons is given by $\mathbf{h\nu = h\nu_O + \frac{1}{2}\, mv_{max}{}^2}$

$$\mathbf{eV_O = hc\,(\frac{1}{\lambda} - \frac{1}{\lambda_o})}$$

It is called Einstein's photoelectric equation. It can explain the laws of photoelectric emission.

Photoelectric cell. A photocell is an arrangement, which produces electric current, when light falls on its cathode.

de-Broglie hypothesis. Both radiation and matter have dual nature.

A particle of momentum p is associated with de-Broglie wave of wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$

The above relation is called de-Broglie relation and the wavelength of the wave associated is called de-Broglie wavelength of the particle.

de-Broglie wavelength of electron. An electron of kinetic energy E possesses de-Broglie wavelength,

$$\lambda = \frac{h}{\sqrt{2mE}}$$

If electron is accelerated through a potential difference V, so as to acquire kinetic energy E (=e V), then

$$\lambda = \frac{h}{\sqrt{2meV}} = \frac{12.27}{\sqrt{V}}\ A^o$$

QUESTIONS WITH ANSWERS

Q.1 How does the intensity affect the photoelectric current?

Ans. As intensity increases the photoelectric effect. Since each incident photon ejects one photoelectron from a metal surface, therefore, the number of photoelectrons emitted depends on the number of photons falling on the metal surface, which in turn depends on the intensity of the incident light. Hence, as the intensity increases, the number of photoelectrons ejected increases and hence photoelectric current increases.

Q.2 Write the basic features of photon picture of electromagnetic radiation on which Einstein's photoelectric equation is based.

Ans. Features of the photons:

(i)Photons are particles of light having energy E = hν and momentum p = h/λ

(ii) Photons travel with the speed of light in vacuum, independent of the frame of reference.

(iii) Intensity of light depends on the number of photons crossing unit area in a unit time.

Q.3 Define the term 'stopping potential' in relation to photoelectric effect.

Ans. The minimum retarding (negative) potential of anode of a photoelectric tube for which photoelectric current stops or becomes zero is called the stopping potential.

Q.4 Define the term 'threshold frequency' in relations to photoelectric effects.

Ans. Threshold frequency is defined as the minimum frequency of incident radiation which can cause photoelectric emission. It is different for different metal.

Q.5 In photoelectric effect, why should the photoelectric current increase as the intensity of monochromatic radiation incident on a photosensitive surface is increased? Explain.

Ans. The photoelectric current increases proportionally with the increase in intensity of incident radiation. Larger the intensity of incident radiation, larger is the number of incident photons and hence larger is the number of electrons ejected from the photosensitive surface.

Q.6 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?

Ans. In the first case, energy given out is less than the energy supplied. In the second case, the material has to supply the energy as the emitted photon has more energy. This cannot happen for stable substances.

Q.7 Do all the electrons that absorb a photon come out as photoelectrons?

Ans. No, most electrons get scattered into the metal. Only a few come out of the surface of the metal.

Q.8 Light of wavelength 3500 Å is incident on two metals A and B. Which metal will yield more photoelectrons if their work functions are 5 eV and 2 eV respectively?

Ans. Metal B will yield more photo electrons. work function of Metal B is lower than that of A for the same wavelength of light. Hence metal B will give more electrons.

Q.9 The momentum of photon of electromagnetic radiation is 3.3 10^{-29} kg-m/s. Find out the frequency and wavelength of the wave associated with it.

Ans- (i) Given, h = 6.63 10^{-34} J/s, c= 3 x10^{8} m/s and p = 3.3 x 10 $^{-29}$- kg m/s

Momentum, $p=\frac{h\nu}{c}$ or $\nu = \frac{pc}{h} = \frac{3.3 \, x \, 10^{-29} \, x \, 3 \, x \, 10^{8}}{6.63 \, x \, 10^{-34}}$ = 1.5 x 10^{13} Hz

$\lambda = \frac{c}{\nu} = \frac{3 \, x \, 10^{8}}{1.5 \, x \, 10^{13}}$ = 2 x 10^{-5} m

Q.10 Monochromatic light of frequency 6.0 × 10^{14} Hz is produced by a laser. The power emitted is 2.0 × 10^{-3} W Calculate the

(i) energy of a photon in the light beam and

(ii) number of photons emitted on an average by the source.

Ans. **Calculating**

(i) Energy of a photon = hν= 6.63 × 10^{-34} × 6.0 × 10^{14} J = 3.978 × 10^{-19} J

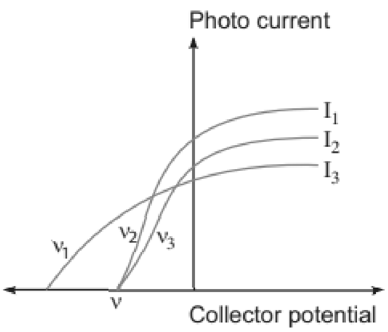
(ii) Number of photons emitted per second = $\frac{\text{Power}}{\text{Energy of photon}} = \frac{2 \, x 10^{-3}}{3.978 \, x \, 10^{-19}}$

= 5.03 × 10^{15} photons/second

Q.11 (a) Define the term 'intensity of radiation' in photon picture.

(b) Plot a graph showing the variation of photo current vs collector potential for three different intensities $I_1 > I_2 > I_3$, two of which (I_1 and I_2) have the same frequency ν and the third has frequency $\nu_1 > \nu$.

(c) Explain the nature of the curves on the basis of Einstein's equation.



Ans-(a) The amount of light energy or photon energy incident per metre square per second is called intensity of radiation.

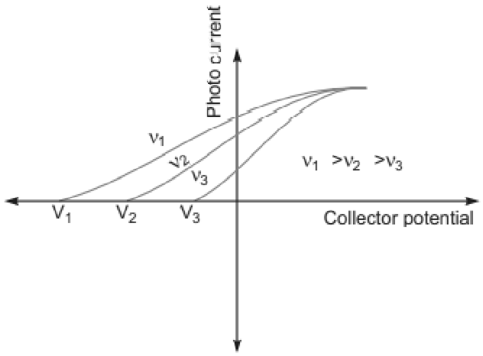
(b) $\nu_2 = \nu_3 = \nu$

(c) As per Einstein's equation,

(i) The stopping potential is same for I_1 and I_2 as they have the same frequency.

(ii) The saturation currents are as shown in figure because $I_1 > I_2 > I_3$.

Q.12 Show the variation of photocurrent with collector plate potential for different frequencies but same intensity of incident radiation.



Q.13 Write Einstein's photoelectric equation and point out any two characteristic properties of photons on which this equation is based.

Ans. If radiation of frequency (ν) greater than threshold frequency (ν0) irradiate the metal surface, electrons are emitted out from the metal. So Einstein's photoelectric equation can be given as

$$K_{\text{max=}} = \frac{1}{2} m v^2 = h\nu - h\nu_O$$

Characteristic properties of photons:

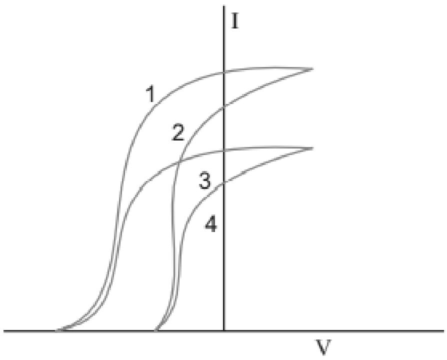
(i) Energy of photon is directly proportional to the frequency (or inversely proportional to the wavelength.

(ii) In photon-electron collision, total energy and momentum of the system of two constituents remains constant.

Q.14 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?

Ans. Work Function: The minimum energy required to free an electron from metallic surface is called the work function.

Smaller the work function, larger the kinetic energy of emitted electron.



Q.15 The given graph shows the variation of photo-electric current (I) with the applied voltage (V) for two different materials and for two different intensities of the incident radiations. Identify and explain using Einstein's photo electric equation for the pair of curves that correspond to

(i) different materials but same intensity of incident radiation,

(ii) different intensities but same materials.

Ans-

(a) 1 and 2 correspond to same intensity but different material.

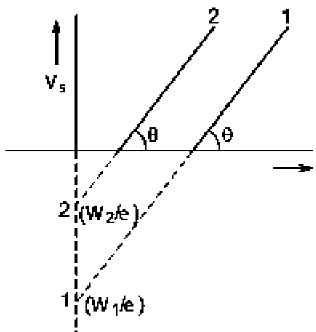
(b) 3 and 4 correspond to same intensity but different material.

This is because the saturation currents are same and stopping potentials are different. Intensity of light Photoelectric current

(a) 1 and 3 correspond to different intensity but same material.

(b) 2 and 4 correspond to different intensity but same material.

This is because the stopping potentials are same but saturation currents are different



Q.16 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?

Ans- The graph of stopping potential V_s and frequency (ν) for two photosensitive materials 1 and 2 is shown in fig.

(i)Slope of graph tan θ $=\frac{h}{c}$ universal constant.

(ii) Intercept of lines depend on the work function

Q.17 A proton and an alpha particle are accelerated through the same potential. Which one of the two has (i) greater value of de Broglie wavelength associated with it and (ii) less kinetic energy? Give reasons to justify your answer.

Ans-

(i) de Broglie wavelength

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

For same V, $\lambda \propto \frac{1}{\sqrt{mq}}$

$$\frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_\alpha q_\alpha}{m_p q_p}} = \sqrt{\frac{4m_p}{m_p} \cdot \frac{2e}{e}}$$

$$= \sqrt{8} = 2\sqrt{2}$$

Clearly, $\lambda_p > \lambda_\alpha$.

Hence, proton has a greater de-Broglie wavelength.

(ii) Kinetic energy, $K = qV$

For same V, $K \propto q$

$$\frac{K_p}{K_\alpha} = \frac{q_p}{q_\alpha} = \frac{e}{2e} = \frac{1}{2}$$

Clearly, $K_p < K_\alpha$.

Hence, proton has less kinetic energy.

Q.18 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 reasons to justify your answer

Ans-

(i) de Broglie wavelength, $\lambda = \frac{h}{\sqrt{2mqV}}$

Here V is same for proton and deutron.

As mass of proton < mass of deutron and $q_p = q_d$

Therefore, $\lambda_p > \lambda_d$ for same accelerating potential.

(ii) We know that momentum $= \frac{h}{\lambda}$

Therefore, $\lambda_p > \lambda_d$

So, momentum of proton will be less than that of deutron.

Q.19 An α-particle and a proton are accelerated from rest by the same potential. Find the ratio of their de- Broglie wavelengths.

de-Broglie wavelength $\lambda = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}}$

For -particle, $\lambda_\alpha = \frac{h}{\sqrt{2m_\alpha q_\alpha V}}$

For proton, $\lambda_p = \frac{h}{\sqrt{2m_p q_p V}}$

$\therefore$ $\frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p q_p}{m_\alpha q_\alpha}}$

But $\frac{m_\alpha}{m_p} = 4, \frac{q_\alpha}{q_p} = 2$

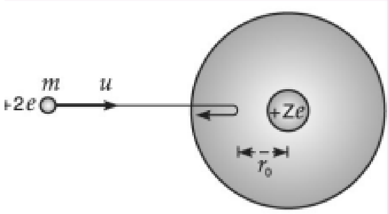
$\therefore$ $\frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{1}{4} \cdot \frac{1}{2}} = \frac{1}{\sqrt{8}} = \frac{\mathbf{1}}{\mathbf{2\sqrt{2}}}$.

CHAPTER 12 ATOMS

Thomson's atom model. In a sphere, the positive charge is uniformly distributed over its whole volume and the electrons are embedded in it. The oscillations of electrons about their equilibrium positions give rise to radiation of definite frequency.

Rutherford's atom model. Practically, entire macs of the atom and all its positive charge are concentrated in a small central core, while the electrons revolve around it. The central positive and massive core is called nucleus.

Distance of closest approach. The minimum distance from the nucleus, when an energetic a-particle travels directly towards the center of the nucleus is called the distance of closest approach. It gives an estimate of the size of the nucleus.



Mathematically- $r_o = \frac{1}{4\pi\epsilon_o}\frac{2Ze^2}{\frac{1}{2}mv^2}$

where the letters have their usual meanings.

Bohr's atom model. It was introduced, as Rutherford atom model could not account for stability of the atom and the line spectra of the hydrogen atom. Bohr's atom model is based on following postulates-

1. Electrons revolve round the nucleus in certain fixed orbits, called stationery orbits.
2. The stationary orbits are those, in which angular momentum of electron is integral multiple of h/2 2.

Mathematically- **mvr = nh/2π** (Bohr's quantisation condition)

3. While revolving in stationery orbits, electrons do not radiate energy. The energy is emitted (or absorbed) when electrons jump from higher to lower energy orbits (or lower to higher energy orbits). The frequency of the emitted radiation is given by

$$h\nu = E_i - E_f \quad \text{(Bohr's frequency condition)}$$

Bohr's theory of hydrogen atom.

An electron having charge -e revolves with speed v in a circular orbit of radius r round the nucleus having charge + e.

1. Radius of nth orbit $r_n = 4\pi \in_o \frac{n^2h^2}{4\pi^2me^2}$

2. Speed of electron in nth orbit $v_n = \frac{1}{4\pi\in_o}.\frac{2\pi e^2}{nh}$

3. Energy of electron in nth orbit $E_n = -\left(\frac{1}{4\pi\in_o}\right)^2.\frac{2\pi^2me^4}{n^2h^2} = -\frac{R_H}{n^2}hc$

Here $R_{H=}\left(\frac{1}{4\pi\in_o}\right)^2.\frac{2\pi^2me^4}{ch^3}$ **called Rydberg's constant for hydrogen atom.**

4. Energy of radiation emitted $E = \left(\frac{1}{4\pi\in_o}\right)^2.\frac{2\pi^2me^4}{h^2}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$

5. Frequency of radiation emitted $\nu = \left(\frac{1}{4\pi\in_o}\right)^2.\frac{2\pi^2me^4}{h^3}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$

6. Wavelength of radiation emitted $\frac{1}{\lambda} = \left(\frac{1}{4\pi\in_o}\right)^2.\frac{2\pi^2me^4}{ch^3}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$

Excitation energy. The energy required to raise the electron from its ground state to some higher energy level is called excitation energy.

Excitation potential. The potential difference through which the electron in an atom has to be accelerated, so as to just raise it from its ground state to the excited state, is called excitation potential.

Ionisation energy. The energy required to knock an electron completely out of an atom is called ionisation energy.

Ionisation potential. The potential difference through which the electron in an atom has to be accelerated so as to just ionise it, is called ionisation potential.

The ionisation potential is numerically equal to the ionisation energy.

X-rays. When fast moving electrons strike a target of high atomic weight, X-rays are produced.

When electrons are accelerated through a potential difference V, the kinetic energy acquired by the electron is given by $eV = \frac{1}{2}mv^2$

When the whole of the kinetic energy of the electron is converted into the energy of X-rays produced, then X-ray of maximum frequency is produced. The maximum frequency is given by $\nu_{max} = \frac{eV}{h}$

where h is Planck's constant.

The minimum possible wavelength of the X-rays produced is given by $\lambda_{min} = \frac{hc}{eV}$

QUESTIONS WITH ANSWERS

Q.1 Write two important limitations of Rutherford nuclear model of the atom.

Ans. Two important limitations of Rutherford Model are:

(i)According to Rutherford model, electron orbiting around the nucleus, continuously radiates energy due to the acceleration; hence the atom will not remain stable.

(ii)As electron spirals inwards; its angular velocity and frequency change continuously, therefore it should emit a continuous spectrum. But an atom like hydrogen always emits a discrete line spectrum.

Q.2 Which is easier to remove: orbital electron from an atom or a nucleon from a nucleus?

Ans. It is easier to remove an orbital electron from an atom. The reason is the binding energy of orbital electron is a few electron-volts while that of nucleon in a nucleus is quite large (nearly 8 MeV). This means that the removal of an orbital electron requires few eV energy while the removal of a nucleon from a nucleus requires nearly 8 MeV energy

Q.3 Show that the radius of the orbit in hydrogen atom varies as n^2, where n is the principal quantum number of the atom.

Ans-

Let r be the radius of the orbit of a hydrogen atom. Forces acting on electron are centrifugal force (F_c) and electrostatic attraction (F_e)

At equilibrium, $F_c = F_e$

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} \qquad \text{[for H-atom, } Z = 1\text{]}$$

According to Bohr's postulate

$$mvr = \frac{nh}{2\pi} \quad \Rightarrow \quad v = \frac{nh}{2\pi mr}$$

$$m\left(\frac{nh}{2\pi mr}\right)^2 \cdot \frac{1}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} \quad \Rightarrow \quad \frac{mn^2h^2}{4\pi^2m^2r^2.r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

$$r = \frac{n^2h^2\varepsilon_0}{\pi me^2} \quad \Rightarrow \quad \therefore \quad r \propto n^2$$

Q.4 Find out the wavelength of the electron orbiting in the ground state of hydrogen atom.

Ans-

Radius of ground state of hydrogen atom, $r = 0.53\ \text{Å} = 0.53 \times 10^{-10}\ \text{m}$

According to de Broglie relation, $2\pi r = n\lambda$

For ground state, $n = 1$

$$2 \times 3.14 \times 0.53 \times 10^{-10} = 1 \times \lambda$$

$$\therefore \quad \lambda = 3.32 \times 10^{-10}\ \text{m}$$

$$= \mathbf{3.32\ Å}$$

Q.5 When is H_α line in the emission spectrum of hydrogen atom obtained? Calculate the frequency of the photon emitted during this transition.

Ans-

The line with the longest wavelength of the Balmer se

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

where λ = wavelength

$R = 1.097 \times 10^7\ \text{m}^{-1}$ (Rydberg constan

When the electron jumps from the orbit with $n = 3$ to

we have

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right) \Rightarrow \frac{1}{\lambda} = \frac{5}{36}R$$

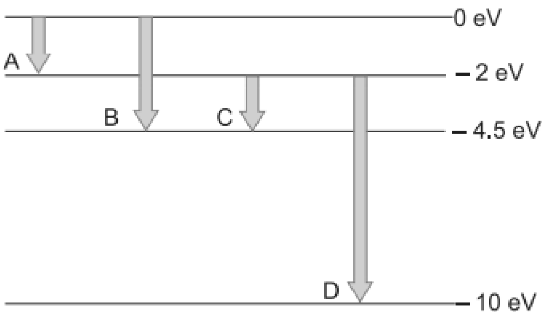
The frequency of photon emitted is given by

$$\nu = \frac{c}{\lambda} = c \times \frac{5}{36}R$$

$$= 3 \times 10^8 \times \frac{5}{36} \times 1.097 \times 10^7\ \text{Hz}$$

$$= \mathbf{4.57 \times 10^{14}\ Hz}$$

Q.6 The energy levels of a hypothetical atom are shown alongside. Which of the shown transitions will result in the emission of a photon of wavelength 275 nm? Which of these transitions correspond to emission of radiation of (i) maximum and (ii) minimum wavelength?



Ans-

Energy of photon wavelength 275 nm

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{275 \times 10^{-9} \times 1.6 \times 10^{-19}}\ \text{eV} = 4.5\ \text{eV}.$$

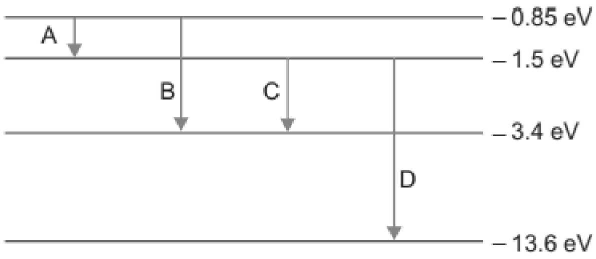
This corresponds to transition '*B*'.

(*i*) $\Delta E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{\Delta E}$

For maximum wavelength ΔE should be minimum. This corresponds to transition *A*.

(*ii*) For minimum wavelength ΔE should be maximum. This corresponds to transition *D*.

Q.7 The energy level diagram of an element is given. Identify, by doing necessary calculations, which transition corresponds to the emission of a spectral line of wavelength 102.7 nm.



Ans-

$$\Delta E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{102.7 \times 10^{-9}} \text{J}$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{102.7 \times 10^{-9} \times 1.6 \times 10^{-19}} \text{eV}$$

$$= \frac{66 \times 3000}{1027 \times 16} = 12.04 \text{ eV}$$

Now, $\Delta E = |-13.6 - (-1.50)|$

$= \mathbf{12.1\ eV}$

Hence, transition shown by arrow D corresponds t

Q.8 Determine the distance of closest approach when an alpha particle of kinetic energy 4.5 MeV strikes a nucleus of Z = 80, stops and reverses its direction.

Ans-

Let r be the centre to centre distance between the alpha particle and the nucleus (Z = 80). When the alpha particle is at the stopping point, then

$$K = \frac{1}{4\pi\varepsilon_0} \frac{(Ze)(2e)}{r}$$

or $$r = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2Ze^2}{K}$$

$$= \frac{9 \times 10^{9} \times 2 \times 80\, e^2}{4.5 \text{ MeV}} = \frac{9 \times 10^{9} \times 2 \times 80 \times (1.6 \times 10^{-19})^2}{4.5 \times 10^{6} \times 1.6 \times 10^{-19}}$$

$$= \frac{9 \times 160 \times 1.6}{4.5} \times 10^{-16} = 512 \times 10^{-16} \text{m}$$

$$= \mathbf{5.12 \times 10^{-14}\ m}$$

Q.9 The ground state energy of hydrogen atom is – 13.6 eV. If an electron makes a transition from an energy level – 1.51 eV to – 3.4 eV, calculate the wavelength of the spectral line emitted and name the series of hydrogen spectrum to which it belongs.

Ans-

Energy difference = Energy of emitted photon

$$= E_1 - E_2$$

$$= -1.51 - (-3.4) = 1.89 \text{ cV} = 1.89 \times 1.6 \times 10^{-19} \text{ J}$$

$$\lambda = \frac{hc}{E_1 - E_2}$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{1.89 \times 1.6 \times 10^{-19}} = \frac{19.8}{3.024} \times 10^{-7}$$

$$= 6.548 \times 10^{-7} \text{ m} = \mathbf{6548\ Å}$$

This wavelength belongs to Balmer series of hydrogen spectrum.

CHAPTER 13 NUCLEI

1. The nucleus of an element, whose chemical symbol is X, is represented as $_{Z}X^{A}$, where Z and A are respectively the atomic number and mass number of the element.
2. Mass number is the integer closest to the nuclear mass.
3. The number of protons in the nucleus of an atom is equal to its atomic number (Z).
4. The number of neutrons in the nucleus of an atom is equal to the difference between its mass number and atomic number (A — Z).
5. Neutrons and protons are collectively called **nucleons**.
6. Neutron is unstable particle outside the nucleus.
7. The atoms of an element (same atomic number) having different mass number are called **isotopes.**
8. The atoms of different elements (different atomic number) having the same mass number are called **isobars**.
9. The atoms, whose nuclei have same number of neutrons are called **isotones.**
10. The atoms, whose nuclei have same difference in the number of neutrons and protons are called **isodiaspheres.**
11. The volume of a nucleus is always directly proportional to its mass number. It leads to the expression for nuclear radius as $\mathbf{R = R_o\, A^{1/3}}$

Where R_o = 1.1 x 10^{-15} m is known as nuclear unit radius.

12. The order of the size of the nucleus is **10^{-15} m.**
13. The order of the size of the atom is **10^{-10} m**.
14. The density of nuclear matter is same for all nuclei i.e. independent of the mass number of the nucleus. It is found to be of the order of 10^{17} kg/m^3
15. The extremely large magnitude of electrostatic force of repulsion between protons is the basic cause of nuclear instability.
16. Inside the nucleus, Coulomb's electrostatic repulsion between two protons is about **10^{36}** times the gravitational attraction between them.
17. The forces holding the nucleons together inside the nucleus are called nuclear forces.

(i) Nuclear forces are exchange type of forces. These forces arise between the nucleons due to the exchange of **π-mesons**.

(ii) These forces are short range, basically very strong attractive, charge independent, charge symmetric, spin dependent and non- central forces.

18. The relative strengths of the gravitational, Coulomb's and nuclear forces are $F_g : F_e : F_n$**: :1:10^{36}: 10^{38}**
19. Atomic mass unit (a.m.u.) is defined as 1/12 th of the mass of one $_{6}C^{12}$ atom.

Mathematically: **1 amu = 1:660565 x 10^{-27} kg ≈ 931.5 MeV**

20. Mass of a proton, **m_p = 1.007275 a.m.u. = 1.67265 x 10^{-27} kg**
21. Mass of a neutron**, m_n = 1.008665 a.m.u. = 1.67495 x 10^{-27} kg**

22. The difference between the sum of the masses of nucleons constituting a nucleus and the rest mass of the nucleus is called mass defect.

Mathematically- **$\Delta m = [Z\, m_p + (A-Z)\, m_n] - m_N({}_ZX^A)$**

23. The energy equivalent to mass defect of the nucleus is called its binding energy.

Mathematically- **B.E.=(Δm)c^2**

24. Nucleons are bound together by the strong nuclear force. The binding energy of the nucleus may be termed as the work done against the binding force to pull the nucleons apart.

25. The average energy required to extract one nucleon from the nucleus is called its binding energy per nucleon.

Mathematically- **B.E. per nucleon = $\frac{B.E.}{A}$**

26. Packing fraction is defined as the mass defect per nucleon of the nucleus.

Mathematically- **Packing fraction = $\frac{\Delta m}{A}$**

27. The stability of a nucleus depends upon a number of factors. A nucleus is found to be more stable, if

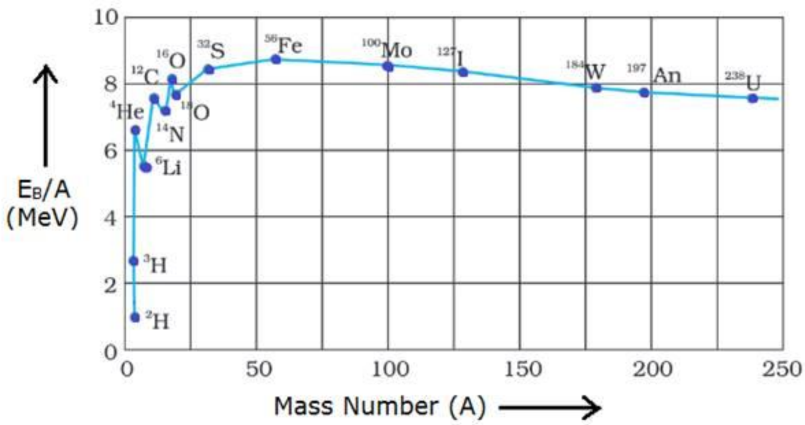
(i) its binding energy per nucleon (rather than the total binding energy of the nucleus) is high.

(ii) its neutron to proton ratio is high.

(iii) it is even-even nucleus (even no. of protons and even no. of neutrons). The even-odd and odd-even nuclei are less stable, while odd-odd nuclei are least stable.

28. Refer to following Fig.

Following conclusions can be drawn from the graph between B.E./A and A:



(i) The binding energy per nucleon has a low value for both very light and very heavy nuclei.

(ii) In the region A < 20, the B.E./A of the nuclei is quite low except for the nuclei He, cl and O. In an attempt to have greater value of B.E./A, the nuclei in the region A < 20 unite to form a heavier nucleus and therefore, the nuclei in this region are prone to nuclear fusion.

(iii) In the region A > 210, the B.E./A of the nuclei is again quite low. The nuclei in this region have a tendency to split so as to improve the value of their B.E./A. Hence, in region A > 210, the nuclei are prone to nuclear fission.

(iv) In the region 40 < A < 120, the nuclei are most stable. It is indicated by the flat shape of the graph. The value of the B.E./A in this region is maximum (= 8:8 MeV per nucleon).

29. This low value of binding energy per nucleon in case of heavy nuclei is unable to have control over the Coulomb's repulsion between the large number of protons. Such nuclei are unstable and are found to undergo α-decay.

30. The neutron to proton ratio increases during β-decay.

31. The B-decay leads to increase in Coulomb's repulsive force, but it increases binding energy per nucleon.

32. The neutron to proton ratio decreases during β-decay

33. $_{26}\boldsymbol{Fe}^{56}$ has highest value of binding energy per nucleon.

QUESTIONS WITH ANSWERS

Q.1 Write two characteristic features of nuclear force which distinguish it from Coulomb's force.

Ans. Characteristic Features of Nuclear Force

(i) Nuclear forces are short range attractive forces (range 2 to 3 fm) while Coulomb's forces have range up to infinity and may be attractive or repulsive.

(ii) Nuclear forces are charge independent forces; while Coulomb's force acts only between charged particles

Q.2 Why do stable nuclei never have more protons than neutrons?

Ans. Protons are positively charged and repel one another electrically. This repulsion becomes so great in nuclei with more than 10 protons or so, that an excess of neutrons which produce only attractive forces, is required for stability.

Q.3 (i) A radioactive nucleus 'A' undergoes a series of decays as given below:

$$A \xrightarrow{\alpha} A_1 \xrightarrow{\beta} A_2 \xrightarrow{\alpha} A_3 \xrightarrow{\gamma} A_4$$

The mass number and atomic number of A_2 are 176 and 71 respectively. Determine the mass and atomic numbers of A_4 and A.

(iii) Write the basic nuclear processes underlying β^+ and β^- decays.

(*i*) If we consider β^- decay, the decay scheme may be represented as

$$^{180}_{72}A \xrightarrow{\alpha} {}^{176}_{70}A_1 \xrightarrow{\beta^-} {}^{176}_{71}A_2 \xrightarrow{\alpha} {}^{172}_{69}A_3 \xrightarrow{\gamma} {}^{172}_{69}A_4$$

A_4 : Mass Number = 172

Atomic Number = 69

A : Mass Number = 180

Atomic Number = 72

If we consider β^+ decay, then

$$^{180}_{74}A \xrightarrow{\alpha} {}^{176}_{72}A_1 \xrightarrow{\beta^+} {}^{176}_{71}A_2 \xrightarrow{\alpha} {}^{172}_{69}A_3 \xrightarrow{\gamma} {}^{172}_{69}A_4$$

A_4 : Mass Number = 172

Atomic Number = 69

A : Mass Number = 180

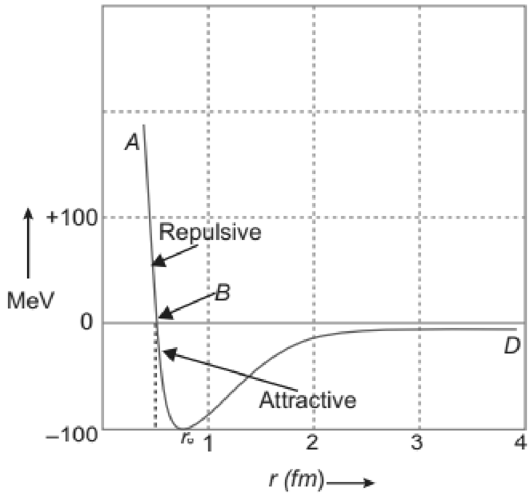
Atomic Number = 74

ii) Basic nuclear process for β^+ decay, $p \rightarrow n + {}^{0}_{1}e + \nu$

For β^- decay, $n \rightarrow p + {}^{0}_{-1}e + \bar{\nu}$

Q.4 Draw a graph showing the variation of potential energy between a pair of nucleons as a function of their separation. Indicate the regions in which the nuclear force is (i) attractive, (ii) repulsive. Write two important conclusions which you can draw regarding the nature of the nuclear forces.

Ans-



Conclusions:

(i) The potential energy is minimum at a distance r0 of about 0.8 fm.

(ii) Nuclear force is attractive for distance larger than r_O.

(iii) Nuclear force is repulsive if two are separated by distance less than r_O.

(iv) Nuclear force decreases very rapidly at r0/equilibrium position.

Q.5 The neutron separation energy is defined as the energy required to remove a neutron from the nucleus. Obtain the neutron separation energies of the nuclei ${}^{41}_{20}Ca\ and\ {}^{27}_{13}Al$ from the following data

$m({}^{40}_{20}\text{Ca}) = 39.962591$ u $\quad m({}^{26}_{13}\text{Al}) = 25.986895$ u

$m({}^{41}_{20}\text{Ca}) = 40.962278$ u $\quad m({}^{27}_{13}\text{Al}) = 26.981541$ u

Ans-

When a neutron is separated from ${}^{41}_{20}$Ca, we are left with ${}^{40}_{20}$Ca and the reaction becomes

$${}^{41}_{20}\text{Ca} \longrightarrow {}^{40}_{20}\text{Ca} + {}_0n^1$$

Mass defect,

$$\Delta m = m\,({}^{40}_{20}\text{Ca}) + m({}_0n^1) - m({}^{41}_{20}\text{Ca})$$

$$= 39.962591 + 1.008665 - 40.962278$$

$$= 0.008978 \text{ u}$$

Energy for separation of neutron $= \Delta m \times 931$

$$= 0.008978 \times 931$$

$$= 8.358 \text{ MeV}$$

When a neutron is separated from ${}^{27}_{13}$Al, we are left with ${}^{26}_{13}$Al. Thus, the reaction becomes

$${}^{27}_{13}\text{Al} \longrightarrow {}^{26}_{13}\text{Al} + {}^{1}_{0}n$$

Mass defect,

$$\Delta m = m\,({}^{26}_{13}\text{Al}) + m({}_0n^1) - m({}^{27}_{13}\text{Al})$$

$$= 25.986895 + 1.00865 - 26.981541$$

$$= 0.014019$$

$\therefore$ Energy for separation of neutron

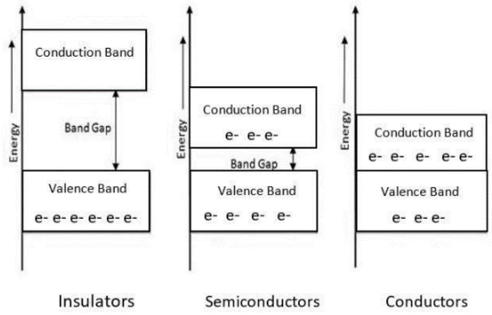
$$= \Delta m \times 931 = 0.014019 \times 931$$

$$= 13.06 \text{ MeV}$$

CHAPTER 14

SEMICONDUCTOR ELECTRONICS: MATERIAL DEVICES

Energy bands in solids. Due to interaction between closed packed atoms in solids, the splitting of energy levels take place and it gives rise to formation of energy bands. The energy band formed by a series of levels containing valence electrons is called valence band and the lowest unfilled energy band formed just above the valence band is called conduction band.



The energy gap is called forbidden energy gap.

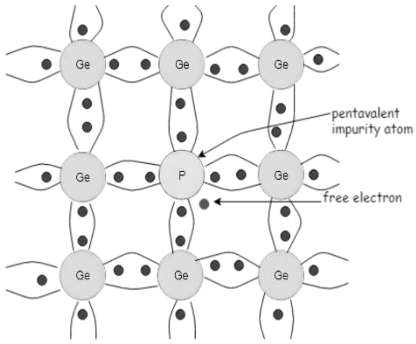
Conductors. The conduction and valence bands partly overlap each other in case of conductors. In other words, there is no forbidden energy gap in conductors.

Semiconductors. The conduction and valence bands are separated by the small width (= 1 eV) of forbidden energy gap. The valence band is completely filled, while the conduction band is empty. The electrons cross from valence band to conduction band even when a small amount of energy is supplied.

Insulators. The width of forbidden energy gap between the valence and conduction bands is quite large (= 10 eV). Ordinarily, electrons cannot jump from valence to conduction band even on applying, a strong electric field.

Intrinsic semiconductors. A semiconductor free from all types of impurities is called intrinsic semiconductor. At 0 K, a semiconductor is an insulator i.e. it possesses zero conductivity. When temperature is increased, a few covalent bonds break up and release the electrons. These electrons move to conduction band leaving behind equal number of holes in valence band. The conductivity of an intrinsic semiconductor is due to both electrons and holes.

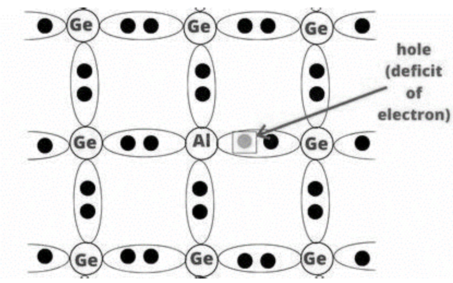
Doping. The process of adding impurity atoms (pentavalent or trivalent) to a pure semiconductor, so as to increase its conductivity in a controlled manner is called doping. The impurity atoms added are very small (= 1 in 10° semiconductor atoms). The pentavalent impurity atoms are called donor atoms, while the trivalent impurity atoms are called acceptor atoms.



Extrinsic semiconductor. A semiconductor doped with a suitable impurity, so as to possess conductivity much higher than the semiconductor in pure form is called an extrinsic semiconductor.

n-type semiconductor. When a pentavalent impurity, such as arsenic or antimony or phosphorus is added to a pure semiconductor, the number of free electrons become more than the holes in the semiconductor and such an extrinsic semiconductor is called n-type semiconductor. In other words, in a n-type semiconductor, electrons are majority carriers and holes are minority carriers.

p-type semiconductor. When a trivalent impurity, such as indium or gallium or boron is added to a pure semiconductor, the semiconductor becomes deficient in electrons i.e. number of holes become more than the



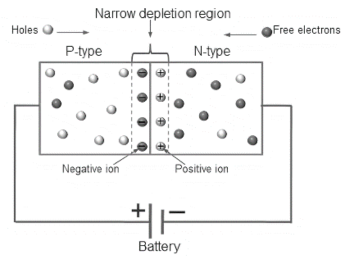
number of electrons. Such a semiconductor is called p-type semiconductor. It has holes as majority carriers and electrons as minority carriers.

Electrical conductivity of a semiconductor. The conductivity of a semiconductor is determined by the mobility (μ) of both electrons and holes and their concentration.

Mathematically- $\boldsymbol{\sigma = e\,(n_e\mu_e + n_h\mu_h)}$

Here, n_e and n_h represent number density, while μ_e and μ_h represent mobility of electrons and holes respectively.

p-n junction. The device obtained by growing a p-type semiconductor over a n-type semiconductor or vice-versa is called a p-n junction. It conducts in one direction only. It is also called a junction diode.

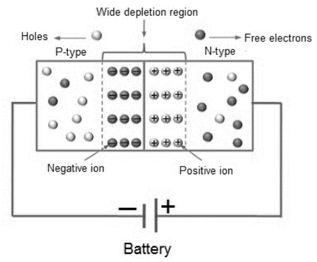


Forward bias

Depletion layer. It is a thin layer formed between the p and n-sections and devoid of holes and electrons. Its width is about 10^{-8} m. A potential difference of about 0.7 V is produced across the junction, which gives rise to a very high electric field (= 10^6 V m^{-1}).

Forward biasing. The p-n junction is said to be forward biased, when the positive terminal of the external battery in the circuit is connected to p-section and the negative terminal to n-section of the junction diode.

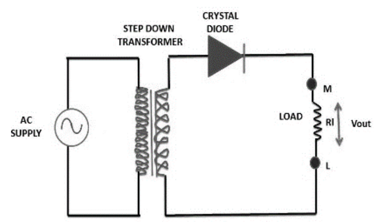
The flow of majority carriers across the junction from both the sections of the junction diode is responsible for the forward current.



Reverse bias

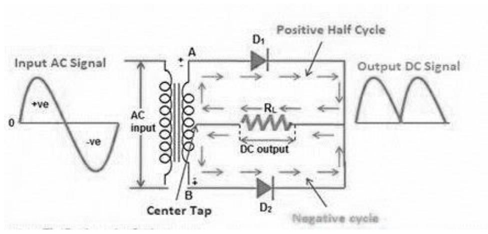
Reverse biasing. The p-m junction is said to be reverse biased, when the positive terminal of the external battery in the circuit is connected to n-section and the negative terminal to p-section of the junction diode.

The flow of minority carriers across the junction from both the sections of the junction diode is responsible for the reverse current.



Junction diode as rectifier. Because of its unidirectional conduction property, the p-n junction is used to convert an a,c. voltage into d. c, voltage, It is, then, said to be acting as a rectifier.

1. **Half wave rectifier**. A rectifier, which rectifies only one half of each a.c. input supply cycle, is called a half wave rectifier. A half wave rectifier gives discontinuous and pulsating d.c. output. As alternative half cycles of the a.c. input supply go waste, its efficiency is very low.



2. **Full wave rectifier**. A rectifier which rectifies both halves of each a.c. input cycle is called a full wave rectifier. The output of a full wave rectifier is continuous but pulsating in nature. However, it can be made smooth by using a filter circuit.

QUESTIONS WITH ANSWERS

Q. 1 What is valence band?

Ans. The energy band formed by a series of energy levels containing the valence electrons is known as valence band.

Q. 2 What is conduction band?

Ans. The lowest unfilled energy band lying just above the valence band is called conduction band.

Q. 3 What is forbidden energy gap?

Ans. The energy gap between the valence band and the conduction band is called the forbidden energy gap.

Q. 4. What is the value of forbidden gap energy of germanium?

Ans. 0:7 eV.

Q. 5 Why germanium is preferred over silicon for making semiconductor devices?

Ans. For germanium (Ge) and silicon (Si), the values of forbidden energy gap are 0.7 eV and 1.1 eV respectively. Owing to the smaller value of forbidden energy gap, germanium is preferred over silicon.

Q. 6. What is Fermi energy level?

Ans. The highest energy level, which an electron can occupy in the valence band at 0 K is called Fermi energy level.

Q. 7. What is an intrinsic semiconductor?

Ans. A semiconductor free from all types of impurities is called an intrinsic semiconductor.

Q 8. What is the ratio of number of holes and the number of conduction electrons in an n-type intrinsic semiconductor?

Ans. It is less than 1.

Q. 9. What is doping?

Ans. The process of adding trivalent or pentavalent atoms to a pure semiconductor in a very small ratio is called doping.

Q. 10. Why semiconductors are doped?

Ans. The conductivity of intrinsic semiconductors is so small that it is practically of no use. The semiconductors are dopped so as to increase their conductivity.

Q. 11. What type of impurity is added to obtain n-type semiconductor?

Ans. Pentavalent atoms, such as arsenic and phosphorous.

Q. 12 Which type of semiconductor is formed, when

(a) germanium is doped with indium?

(Lb) germanium is duped with arsenic?

Ans. (a) p-type (b) n-type

Q. 13. What is a p-type semiconductor?

Ans. When a semiconductor is doped with a trivalent impurity, the holes are created in the covalent bonds. As a result, the semiconductor possesses a large number of holes (majority carriers) and a small number of electrons (minority carriers). Such a semiconductor is called p-type semiconductor.

Q. 14. What is a hole?

Ans. A vacancy created in the covalent bond of a semiconductor is called hole.

Q. 15. Which type of doping creates a hole?

Ans. The doping of semiconductor with impurity atoms having 3 electrons in valence shell creates holes.

Q. 16. Distinguish between intrinsic and extrinsic semi-conductors?

Ans. A semiconductor free from all types of impurities is called an intrinsic semiconductor. At room temperature, a few covalent bonds break up and the electrons come out. In the bonds, from which electrons come out, vacancies are created. These vacancies in covalent bonds are called holes. In an intrinsic semiconductor, holes and electrons are equal in number and they are free to move about in the semiconductor. On the other hand, a semiconductor doped with a suitable impurity (donor or acceptor), so that it possesses conductivity much higher than that of pure semiconductor, is called an extrinsic semiconductor. The extrinsic semiconductor may be of n-type or p-type.

Q. 17 An n-type semiconductor has a large number of electrons but still it is electrically neutral. Explain.

Ans. An n-type semiconductor is obtained by doping pure Si or Ge-crystal with a pentavalent impurity. As the impurity atoms enter into the configuration of the Si-crystal, its four electrons take part in covalent bonding, while the fifth electron is left free. Since each atom of the semiconductor as a whole is electrically neutral; the n-type Ge-crystal, though having large number of free electrons, is electrically neutral.

Q.18. What is the difference between hole-current and electron current?

Ans. In a p-type semiconductor, there are vacancies called holes. When such a material conducts, an electron from a nearby covalent bond jumps into the vacant place in order to fill it and thereby the hole shifts to the covalent bond from which the electron has jumped. The movement of holes constitutes the hole-current. In an n-type semiconductor, the free electrons constitute the electron-current.

Q. 19 Why is a semiconductor damaged by a strong current?

Ans. A strong current, when passed through a semiconductor, heats up the semiconductor and the covalent bonds break up. It results in a large number of free electrons. The material, then, behaves just as a conductor. As now the semiconductor no longer possesses the property of low conduction, it is said to be damaged.

Q.20 Explain the terms depletion layer and potential barrier for a junction diode.

Or

What do you mean by depletion region and potential barrier in a junction diode?

Ans. **Depletion region**. A layer, created around the junction between p and n-sections of a junction diode devoid of holes and electrons, is called depletion region.

Potential barrier. The potential difference developed across the junction due to migration of majority carriers is called potential barrier.

Q. 22. How does the width of the depletion region of a p-n junction vary, if the reverse bias applied to it increases? Or

Why does the thickness of the depletion layer in a p-n diode vary with increase in reverse bias?

Ans. When a p-n junction is formed, a small potential difference (fictitious battery) is set up across the depletion layer. When the junction diode is reverse biased, the polarity of the applied d.c. source aids the fictitious battery. Due to this, potential drop across the junction increases and diffusion of holes and electrons across the junction decreases. It makes the width of the depletion layer larger.

Q. 23 The resistance of a p-n junction is low, when forward biased and is high, when reverse biased. Explain.

Ans. When a p-n junction is forward biased, the junction width decreases and as a result its resistance also decreases. On the other hand, when a p-n junction is reverse biased, the junction width increases. It brings about an increase in its resistance.

Q. 24 How is forward biasing different from reverse biasing in a p-n junction diode?

Ans. To forward bias a p-n junction, positive pole of the battery is connected to its p-section and negative pole of the battery is connected to its n-section. During forward bias, the width of the depletion layer small and as a result, the resistance of a p-n junction Is low. The above facts in case of reverse bias of a p-n junction, are exactly opposite.

Q, 25 Current in the forward bias is known to be more (= mA) than the current in the reverse bias (= μA). What is the reason, then, to operate the photodiode in reverse bias?

Ans. It is because, saturation current during reverse bias increases linearly with the increase of the intensity of light. As such, the change in reverse current is directly proportional to the change in the intensity of light and it can be easily measured,

REFERENCES-- NCERT
CBSE ACADEMIC